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

Annual Report
for
April 2004 - March 2005

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

March 2005

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. Motoyoshi Ikeda	Head, Dr. Arie Budiman
Cooperative Universities	Kyoto University Kagosima University Tottori University Kanazawa University University of Shiga Prefecture Kansai University Tokyo University of Agriculture and Technology Hokkaido University of Education Hokkaido Institute of Technology	Research Center for Geotechnology, Indonesian Institute of Sciences Research Center for Limnology, Indonesian Institute of Sciences 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	131	113
Graduate students	14	0

2. Activity in 2004 fiscal year

2-1. Cooperative study

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

	Japan	*Indonesia*
Leader	Seigo Higashi	Herwint Simbolon
Number of scientists	24	25
Sent or invited scientists	8	3

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

	Japan	*Indonesia*
Leader	Mitsuru Osaki	Hanny Wijaya
Number of scientists	36	29
Sent or invited scientists	12	4

Group 3. Hydrology and peatland technology in Central Kalimantan

	Japan	*Indonesia*
Leader	Harukuni Tachibana	Nyoman Sumawijaya
Number of scientists	27	10
Sent or invited scientists	18	3

Group 4. Function of Aquatic Ecosystem in Kalimantan

	Japan	*Indonesia*
Leader	Toshio Iwakuma	Gadis Sri Haryani
Number of scientists	16	33
Sent or invited scientists	10	3

2-2. Seminars

Seminar-1 **:** Core-University-Program Workshop

Date: 18 June, 2004

Place: Lecture room, Graduate School of Environmental Earth Science, Hokkaido University, Sapporo, Japan

Title: Land management and biodiversity in Southeast Asia, 2004

Presentations: 23 oral presentations

Number of participants: 57 scientists

Seminar-2 **:** International workshop

Date: 7-8 December, 2004

Place: Conference hall, Bogor Agricultural University, Bogor, Indonesia

Title: Human dimension of tropical peatland under global environmental changes

Presentations: 35 oral presentations and 20 poster presentations

Number of participants: 83 scientists

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
Shiro Tsuyuzaki
Ryuichi Masuda
Masatugu Suzuki
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Toshiki Aoi
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Kuniyasu Momose
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Hiroaki Satoh
Kiyoto Maekawa
Tomonori Kikuchi
Midori Kidokoro
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Dwi Astuti
Tomofumi Shimada
Kazuki Matsuda
Taiki Horikawa
Elizabeth A. Widjaja
Rugayah
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Tukirin Partomihardjo
Beth Paul Naiola
Dedy Darnaedi
Joeni Setijo Rahajoe
Siti Nuramaliati Prijono
Agustinus Suyanto
Ibnu Maryanto
Sri Sulandari
Maharadatunkamsi
Syamsul Arifin Zein
Hari Sutrisno
Erniwati
Sih Kahono
Dewi Malia Prawiradilaga
Patricia Erosa Putir Cakrabirawa
Dessy Natalia
Ronny Ratchman Noor
Toto Tohamat

Ecosystem function and genetic diversity in wetland forests of Kalimantan

In 2004, we continued surveys of forest structure in wetlands of central Kalimantan as well as the Halimun National Park, West Java, studies of genetic diversity of parrot birds, rats, insects, etc using DNA samples collected from many islands of Indonesia, and observations of behaviors of mammals such as sun bear and proboscis monkey.

The analysis of the forest structure revealed that growth rates of trees often exhibit wide variation and positive skewness of the frequency distribution and also that the temporal autocorrelation is common in the growth rates of forest trees, suggesting that the temporal autocorrelation causes the positive skew in growth rate distributions. We proposed the "passage" distribution of growth rates, defined by the density of trees passing a particular size over a given inter-census interval, as a superior description of growth performance of trees with temporally autocorrelated growth, and the passage distribution is associated with the conventional resident distribution of growth rates defined by the growth rates of trees within a particular size range at a given census. The passage distribution is approximated by the resident distribution weighted by the absolute growth rate. For common rain forest tree populations, the average of the passage distribution is nearly twice that of the resident distribution. Simulation models which use growth rates estimated from resident distributions and assume a Markov process are valid only to reconstruct the dynamics of the overall size structure of a stand. When examining the influence of life history strategy on forest dynamics, models must incorporate the effect of temporal autocorrelation on growth rates.

As a part of comprehensive studies on genetic diversity of Indonesian animals, we developed 13 pairs of microsatellite primers from random amplified polymorphic DNA (RAPD) fragments for analyzing the molecular phylogeography of weaver ant which shows a wide-range distribution and can be one of key insects to assess the values of biogeographical boundaries lying across Indonesia. Moreover, we analyzed phylogenetic relationships of Murinae genera distributed in South-East Asia including Indonesia, by using the nucleotide sequences for mitochondrial cytochrome *b* (Cyt*b*) as well as the nuclear recombination activating gene 1 (*RAG1*) and interphotoreceptor retinoid-binding protein (*IRBP*). These genes were also used for analyzing the phylogenetic relationships of 17 *Mus* species which were consequently divided into three distinct groups. The radiation of the species groups were estimated to have occurred at ca. 2-3 mya.

The observations of sun bear and proboscis monkey was conducted in northern Borneo. Bears were studied by using a radiotelemetry and we found that a male bear tended to spend more time in the oil palm plantation than a female especially in the rainy season, suggesting the population control of this bear species should be performed in the rainy season. Proboscis monkeys were studied with special reference to social behaviors of an all-male group and we found that a few females joined this all-male group with occasional occurrence of copulation between subadult females and subadult or large juvenile males. The size of this all-male group was largest of all-male groups so far reported, which is probably attributed to the habitat fragmentation because of the expansion of oil palm plantations.

Ecological Research

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Original Article

Effect of temporal autocorrelation on apparent growth rate variation in forest tree census data and an alternative distribution function of tree growth rate

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Abstract Distributions of forest tree growth rates often display wide variation and positive skewness even within a narrow range of tree sizes. Temporal autocorrelation of growth rates is also commonly observed in forest trees. We suggest that temporal autocorrelation causes the positive skew in growth rate distributions. We propose the 'passage' distribution of growth rates, defined by the density of trees passing a particular size over a given inter-census interval, as a superior description of growth performance of trees with temporally autocorrelated growth. We relate the passage distribution to the conventional 'resident' distribution of growth rates, defined by the growth rates of trees within a particular size range at a given census. The passage distribution is approximated by the resident distribution weighted by the absolute growth rate. For common rain forest tree populations, the average of the passage distribution is nearly twice that of the resident distribution. Simulation models which use growth rates estimated from resident distributions and assume a Markov process are valid only to reconstruct the dynamics of the overall size structure of a stand. When examining the influence of life history strategy on forest dynamics, models must incorporate the effect of temporal autocorrelation on growth rates.

Keywords Growth rate · Recruitment rate · Resident distribution · Passage distribution · Simulation

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Introduction

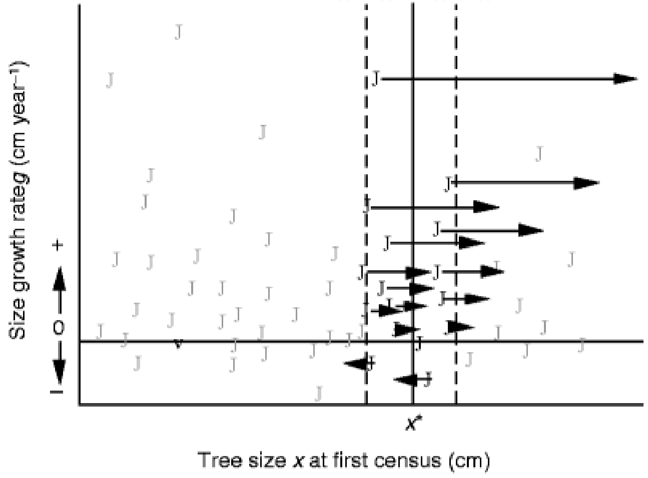
Individual growth rates are highly varied within tree populations, even among trees within a narrow size range (Lieberman et al. 1985; Swaine et al. 1987; Clark and Clark 1992; Picard and Bar-Hen 2000). A positively skewed distribution of growth rates is commonly observed, with a majority of slow-growing trees and only a few fast-growing trees (Kohyama and Hara 1989). The positive skewness of tree growth rate distributions is generally attributed to microenvironmental heterogeneity (Kohyama and Hara 1989). The distribution of light environments under the forest canopy, for instance, is often similarly skewed—only a small proportion of trees experience light conditions favorable for rapid growth (Yoda 1974). While micro-environmental heterogeneity may serve as a proximal cause of skewed growth rate distributions, we suggest that the fundamental cause is temporal autocorrelation of growth rates, which may or may not derive from temporally autocorrelated micro-environmental heterogeneity.

Temporally autocorrelated growth, i.e., the observation that faster growing trees at one census tend to remain faster growing over subsequent censuses, is common in rain forests (Swaine et al. 1987; Kohyama and Hara 1989; Clark and Clark 1992; Manokaran and Swaine 1994). Temporal autocorrelation in growth rates may result from (a) persistent heterogeneity in microenvironmental conditions that affect tree growth, (b) inherent variation among trees (e.g., due to genetics or disease), or (c) a combination of the two. In mixed-size stands, such autocorrelation causes a bias toward observing more slow-growing individuals and fewer fast-growing individuals within any size class. Consistently fast-growing trees move through a size class more quickly than slow-growing trees—or conversely, the residence time of fast-growing trees within a size class is shorter than the residence time of slow-growing trees. Because residence time is inversely related to growth rate, the distribution of growth rates observed within a size class is skewed toward greater frequency of slow-growing trees when growth rates are positively correlated over time.

Resident growth rate versus passage growth rate

The distribution of individual growth rates is generally estimated from the distribution of growth rates of trees within a given size class. We refer to this standard, cross-sectional estimate as the resident growth rate distribution because it is based on the resident population within a size class at the time of any particular census (Fig. 1a). However, the resident distribution may be a poor estimate of the individual growth rate distribution. Here we propose an alternative estimate—the passage growth rate distribution—that more accurately estimates individual growth rate distributions when growth is positively autocorrelated over time. The passage distribution is the distribution of growth rates of trees that pass through a given size (Fig. 1b). As is evident from the figure, the resident distribution will always include a higher relative proportion of slow-growing individuals than the passage distribution regardless of the underlying distribution of individual growth rates. Therefore, it is axiomatic that the average growth rate of the passage distribution is larger than the average growth rate of the resident distribution and that the passage distribution is less positively skewed than the resident distribution.

(a) Resident distribution



(b) Passage distribution

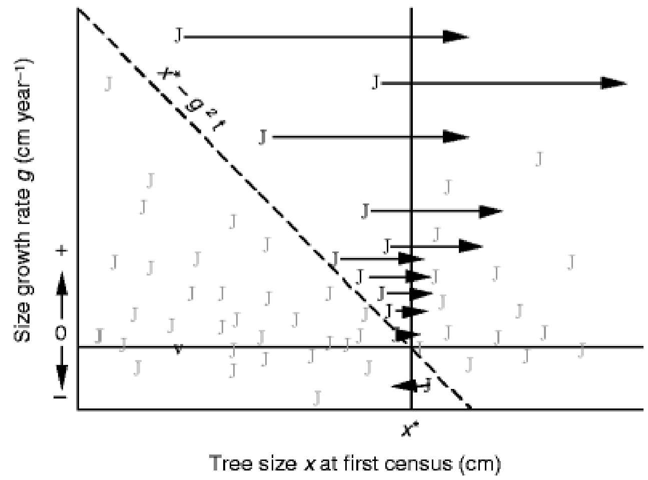


Fig. 1 Hypothetical resident and passage distributions of size growth rate g for a size class near or passing the size x^*. **a** The resident distribution is operationally obtained for trees within a small size range between $x^* - \Delta x$ and $x^* + \Delta x$; while **b** the passage distribution during a time period Δt is defined by trees between $x^* - g\Delta t$ and x^* (*black dots with arrows*)

When growth rates are not temporally autocorrelated, the resident distribution provides an unbiased estimate of the probability distribution of individual growth rates. When temporal autocorrelation in growth rates is perfect (i.e., equals one), the passage distribution accurately estimates the probability distribution of individual growth rates. While the reality within any natural stand lies somewhere between these two extremes, the studies cited above suggest that temporal autocorrelation may be high and reliance on resident distributions may yield systematically biased estimates of individual growth rate distributions.

Define $\Phi\ (x, g)$ as the joint density distribution of the resident distribution of trunk diameter x (cm) and tree growth rate g (cm year^{-1}) of a tree population. Let us suppose

$$\Phi(x,g) = f(x)\phi(g), \tag{1}$$

where $f(x)$ is the density distribution of tree size x (cm) of a population and $\phi(g)$ is the probability density distribution of size growth rate g (cm year^{-1}). Equation 1 holds if the covariance between x and g of $\Phi\ (x, g)$ is negligible within a limited size range of interest. Given Eq. 1, the passage distribution of growth rate, $\gamma\ (x, g)$, is defined (cf. Fig. 1b), if $g \geq 0$,

$$\begin{aligned}\gamma(x,g) &= \lim_{\Delta t \to 0} \tfrac{1}{\Delta t} \textstyle\int_{x-g\Delta t}^{x} \Phi(x',g)\mathrm{d}x' \\ &= \phi(g) \lim_{\Delta t \to 0} \tfrac{1}{\Delta t}[F(x) - F(x - g\Delta t)] \\ &= \phi(g) \lim_{\Delta t \to 0} \tfrac{1}{\Delta t}\left[f(x)g\Delta t - \tfrac{1}{2!}\tfrac{\mathrm{d}f(x)}{\mathrm{d}x}(g\Delta t)^2 + \tfrac{1}{3!}\tfrac{\mathrm{d}^2 f(x)}{\mathrm{d}x^2}(g\Delta t)^3 - K\right] \\ &= gf(x)\phi(g),\end{aligned}$$

otherwise,

$$\gamma(x,g) = \lim_{\Delta t \to 0} \frac{1}{\Delta t} \int_{x}^{x-g\Delta t} \Phi(x',g)\ \mathrm{d}x' = -gf(x)\phi(g),$$

where Δt is a finite duration of time t and $F\ (x)$ is the primitive of $f\ (x)$. To summarize, we have

$$\gamma(x,g) = |g|f(x)\phi(g) = |g|\Phi(x,g). \tag{2}$$

Equation 2 specifies the numerical relationship between the two distributions, showing that the passage distribution of growth rate g at a given size x is equivalent to the $|\ g\ |$-weighted resident distribution of g at that size.

Given that the growth distribution is properly normalized so that

$$\int_{-\infty}^{\infty} \phi(g)\mathrm{d}g = 1,$$

the expectation of the passage growth rate, μ_γ, is

$$\mu_\gamma = \frac{\int_{-\infty}^{\infty} g\gamma(x,g)\mathrm{d}g}{\int_{-\infty}^{\infty} \gamma(x,g)\mathrm{d}g} = \frac{\langle g^2\rangle f(x)}{\langle g\rangle f(x)} = \frac{\langle g^2\rangle}{\langle g\rangle}$$

where

$$\langle g^a\rangle = \int_{-\infty}^{\infty} g^a\phi(g)\mathrm{d}g.$$

Similarly, the expectation of the resident growth rate, μ_Φ, is

$$\mu_\Phi = \frac{\int_{-\infty}^{\infty} g\Phi(x,g)dg}{\int_{-\infty}^{\infty} \Phi(x,g)dg} = \frac{\langle g\rangle f(x)}{f(x)} = \langle g\rangle.$$

Therefore, the ratio of these expectations is expressed by the coefficient of variation (the standard deviation divided by the expectation) of the resident distribution, c_Φ:

$$\frac{\mu_\gamma}{\mu_\Phi} = c_\Phi^2 + 1. \tag{3}$$

Because $c_\Phi{}^{2\Phi} \geq {}^{\Phi}0$, Eq. 3 confirms that the expectation of passage distribution is always as large or larger than that of the resident distribution. We also see that the difference between the estimated means increases as variability in the growth rates increases. Estimates from natural rain forests suggest that c_Φ is often around 1 (Kohyama 1989; Kohyama and Hara 1989; Kohyama et al. 2001). Thus in such forests, the average growth rate of the passage distribution is close to twice the average of the resident distribution.

As an example, we examine a mixed-species stand located on a 2-ha permanent plot in Gunung Berui, West Kalimantan, Borneo (Kohyama et al. 2001, 2003). All trees larger than 5 cm in trunk diameter at breast height (dbh) were censused in 1992 and 1995. Figure 2 compares the resident distribution (across all species) of the 9–11 cm dbh class and the passage distribution at 10 cm dbh. The passage distribution is less skewed and has a larger average growth rate than the resident distribution. The observed passage distribution is closely estimated by the | *g* |-weighted resident distribution.

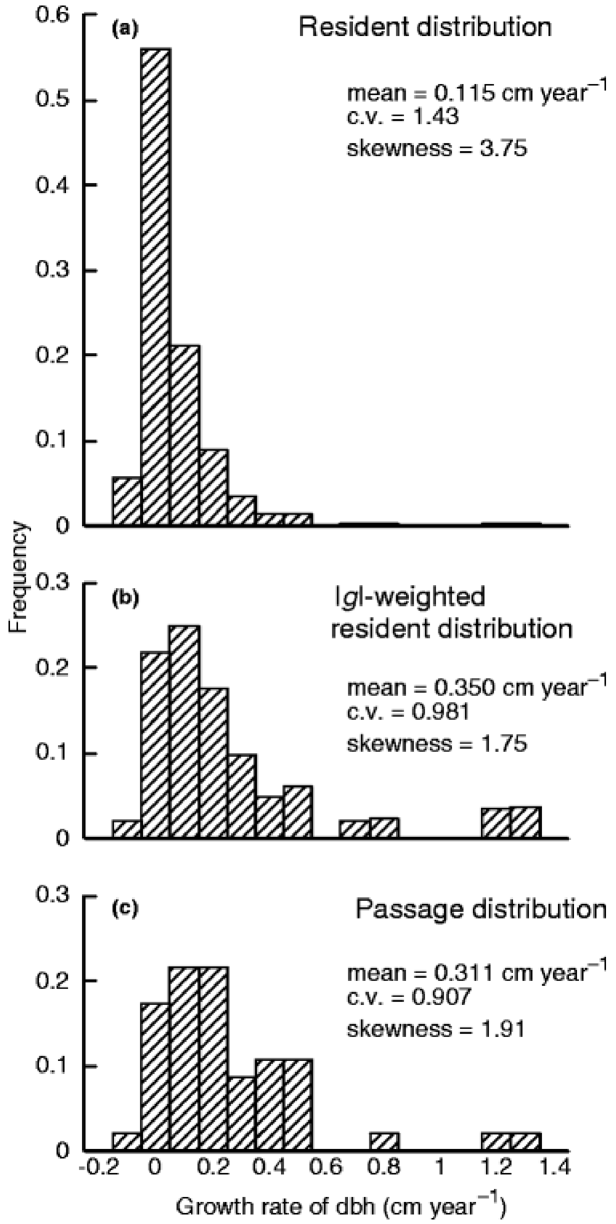


Fig. 2 Observed distribution of growth rate in trunk diameter of trees from 2-ha plots in a mixed dipterocarp forest in West Kalimantan observed during 1992 and 1995. **a** Resident distribution for trees of 9.0–11.0 cm in initial diameter (*n*=278); **b** absolute-growth-rate-weighted distribution for resident trees of 9.0–11.0 cm diameter; and **c** passage distribution for trees that passed across 10.0 cm during 1992–1995 (*n*=46). Distribution mean, coefficient of variation (SD divided by mean) and skewness (third central moment divided by SD^3) are shown

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Gf estimation of recruitment rate

Kohyama and Takada (1998) proposed a procedure of estimating transition rates through specified tree sizes. The Gf estimate of the transition rate of a stand through a given tree size *x* is calculated as the density (f) of trees in the size class surrounding *x* in the stand of interest, multiplied by the mean growth rate (*G*) of trees in this size class. For mean growth rate *G*, they did not use the average passage growth rate (μ_γ) but instead used the average resident growth rate ($\mu_{\Phi\phi}$. Though they did not give any derivation of the Gf estimate when there is variance in growth rate at the size of interest, we give a derivation here. Let *R* (*x*) be the transition rate, or the net forward flux, at size *x* of a tree population. *R* (*x*) is expressed as gross forward flux minus gross backward flux using the passage distribution function γ (*x, g*),

$$R(x) = \int_0^\infty \gamma(x,g)\mathrm{d}g - \int_{-\infty}^0 \gamma(x,g)\mathrm{d}g.$$

This is rewritten with Eq. 1 as

$$\begin{aligned} R(x) &= f(x)\left\{\int_0^\infty g\phi(g)\mathrm{d}g + \int_{-\infty}^0 g\phi(g)\mathrm{d}g\right\} \\ &= f(x)\int_{-\infty}^\infty g\phi(g)\mathrm{d}g \qquad , \\ &= \mu_\Phi f(x) \end{aligned} \qquad (4)$$

where μ_Φ is the mean growth rate of the resident distribution. This provides a generalized proof of the Gf model, where *G* is the average growth rate of the resident distribution as originally proposed.

Discussion

To reconstruct growth trajectories of tropical tree individuals, Lieberman and Lieberman (1985) proposed a stochastic simulation procedure based on size versus growth rate data obtained from periodic censuses. At every time step in the reconstruction, the growth rate of each simulated tree was assigned the observed growth rate of a randomly selected tree of similar size. Replicate simulations yielded a distribution of growth trajectories for individuals. Stochastic reconstructions such as these are appropriate when growth rates are variable among trees and when temporal autocorrelation of growth is negligible across short census intervals. However, if growth rate is strongly temporally correlated, such techniques will yield downwardly biased estimates of individual growth trajectories. Lieberman and Lieberman used census data with an interval of 13 years for their growth reconstruction. Growth behavior during a period this long is likely to demonstrate temporal autocorrelation.

Individual based models and size-frequency based models are often used to simulate stand development and size-structure dynamics of forest populations. Many models ignore variation in growth rates except as determined by tree size and environment (Botkin 1993; Kohyama 1989;

Kohyama et al. 2001). Others include variation in growth rates (Hara 1993; Kubo and Ida 1998), but these generally assume a memory-less Markov process that models growth at a given time step solely as a function of tree size and local environment during the previous time step plus some instantaneous random fluctuation. The overall size distribution dynamics of a tree population can be sufficiently reconstructed by this method when the resident growth rate distribution is used. However, we must be aware that reconstructed growth trajectories of individual trees from such models suffer the bias described above if growth rates are in fact temporally autocorrelated. For purposes of evaluating life history strategy, accurate prediction of individual trajectories must account for temporal autocorrelation of growth rates.

Residual variation in individual growth rates not explained by species identity, individual size, or microenvironments, could be the result of one or more of the following: (1) noise at each census (measurement error, temporary desiccation, etc.), (2) individual history bringing about temporal autocorrelation (slow recovery from broken crown, etc.), and (3) genetic variation. If the unexplained variance is completely of type (1), then the resident growth rate distribution accurately estimates instantaneous stochastic fluctuation. If the unexplained variance is completely of type (3), then the passage growth rate distribution accurately estimates genetic variation in individual growth rates. Even in this case, we need to be aware that the frequency of slow-growing genotypes decreases with tree size if tree mortality occurs independently of growth rate. Actually, slow-growing trees suffer higher mortality than fast-growing trees (Kohyama and Hara 1989), which will accelerate the decline of the frequency of slow-growing genotypes with tree size. In a natural stand, unexplained variance is likely to be a mixture of all three types. Only from a long series of censuses could one hope to separate the three sources of growth-rate variation. When growth rates are estimated from only one inter-census interval, two simulations, one assuming that all unexplained variation is of type (1) and using the resident growth rate distribution and one assuming that all unexplained variation is of type (3) and using the passage growth rate distribution, should be run to identify the upper and lower extremes which bound reality.

When modeling growth distributions, we suggest that the Gamma distribution may serve as a convenient approximation:

$$\phi(g) = \frac{1}{\sigma\Gamma(\lambda)}\left(\frac{g}{\sigma}\right)^{\lambda-1}\exp\left(-\frac{g}{\sigma}\right), \tag{5}$$

where $\Gamma(\lambda)$ is the gamma function. A Gamma distribution with shape parameter λ and scale parameter σ has the following properties: a mean of $\sigma\lambda$, a variance of $\sigma^2 \lambda$, a coefficient of variation of $1/\sqrt{\lambda}$, and a skewness of $2/\sqrt{\lambda}$. This model is only defined for non-negative growth rate, but this is an acceptable approximation for the case of trunk diameter growth (Fig. 2). The passage distribution is the resident distribution multiplied by growth rate itself (Eq. 2). If the resident distribution $\Phi(g)$ is defined as a Gamma distribution with parameters (σ, λ) as in Eq. 5, then the corresponding passage distribution $\gamma(g) = g\Phi(g)$ is also a Gamma distribution with parameters ($\sigma, \lambda+1$), and one can directly relate the two distributions in terms of their expected means, variances, coefficients of variation, skewness and so on.

Acknowledgements We thank Toshihiko Hara, Milton Lieberman, Tohru Nakashizuka, Matthew Potts and Akio Takenaka for helpful comments on an earlier manuscript. T.K. thanks Yota Yokoi for his suggestion 15 years ago, on the explanation we proposed (Kohyama and Hara 1989) for the observed positive skewness of growth rate, which inspired this study, with a quite long lag period.

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Tradeoff and diversity of leaf/shoot traits among plant life forms in nonseasonal environment

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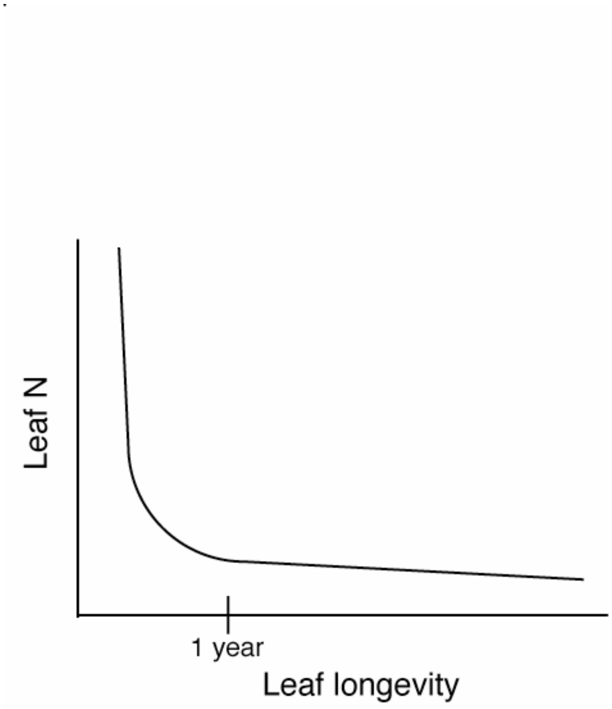
INTRODUCTION

In the tropical regions, many plant species live together to form rainforest ecosystems. Human-caused disturbance and destruction on forest ecosystems is coming to be a problem particularly in species-rich tropical regions. It is important question to be answered how such a many species coexist in rainforest and how the forests will change in future. Reich et al. (1993) studied the relationship between photosynthetic rate and quantity of leaves from the view of ecophysioloigy in Amazon region, and indicated the importance of trade-off between leaf longevity, photosynthetic rate, and leaf N contents. However, they studied only tree species and the role of ecological differentiation across life forms in a particular community level is not yet fully. Each species character should reflect its adaptation to environments for a long time, thus to compare across life forms and species will give us some insight to the maintenance mechanisms of species diversity in tropical regions.

The purpose of this research is to describe the trade-off between leaf longevity, leaf morphology, and leaf stoichiometry through comparing species and life forms in a montane rain forest. In forest understory, plant individuals live usually at uniformly uncomfortable situation in terms of light shortage, while somewhat stable environment in temperature and precipitaiton. When plants are compared among functional types, it is thought that the way of growth, turn over of leaves and the chemical composition of leaves can be different reflecting their respective ways of adaptation. The difference in shoot and leaf performance enables many plants to live at the same place. This study is based on the hypothesis that tradeoff at the scale of individual leaf and shoot contributes to the life form diversity under mild nonseasonal conditions in tropical montane forests. To test this hypothesis, we examine morphological, phenological and physiological differentiation in leaf and shoot functions, in relation to life forms and temporal growth performance.

MATERIALS & METHODS

The study site TNGH (Gunung Halimun National Park) is located at the west of Java Island, in Indonesia. The park is characterized by well-preserved montane forest ecosystems on volcanic substratum (the altitude of study site is 1,000 - 1,200 m) and the weather differences between dry season and rainy season are very week, and low desiccation stresses may be coupled with high diversity of plant life forms. The research was started in August 2002. For the basis of comparative study, about 110 species were selected and marked around the Plot II and nearby tea plantation (Table 1). The Plot II is entirely covered by forest canopy. The site near the tea plantation is exposed condition. Samples



were selected from a wide range of life forms and phylogenetic lineages; which were classified into six functional types (Tables 2-3). They are sapling of tree and small tree, shrub, herb, grass and fern. Measured for sample individuals were height, leaf number of main stem and the degree of feeding by insects in each leaf. The heights of sample plants ranged about 0.2 - 2 m and collected 3 individuals per one species. White and red magic markers were used to mark three leaves attached at the top of plants and the top of main stem. The emergence and the senescence of leaves as well as shoot elongation were researched every month over 2 years. From this research, the growth and leaf turnover ratio of main stems were estimated. Some leaf samples were collected to analyze protecting materials of leaves (phenol and tannin), leaf hardness, SLA and C/N ratio.

RESULTS

From 2 years of continuous censuses, a variety of growth patterns was recorded for the plants of Gn. Halimun National Park. The number of emerging leaves were much fewer than plants of cool temperate forests. There were some species that did not grow or did not flush any new leaf over 2 years. Plants growth was fairly slow in dry seasons (from March to August) and after that, following rain seasons (from September to February), the growth speed of many plants were increased. It was most clear for climbing plants. Growth and leaf turnover of tree species were very late.

Table 1 The list of sample species in Gn. Halimun National Park (D, dicotyledon; M, monocotyledon; G, gymnosperm, P; Pteridophyta)

Species	Family	Class	Functional type	Low light site	Middle light site	High light site
Strobilanthus bibracteata	Acanthaceae	D	herb		○	○
Strobilanthus cernua Blume	Acanthaceae	D	herb	○		
Acer laurinum Hassk.	Aceraceae	D	small tree	○		
Saurauia nudiflora DC.	Acthinidiaceae	D	tree	○		
Doryopteris ludens (Wall. ex Hook.) J. Sm.	Adiantaceae	P	fern		○	
Curculigo latifolia Dryand ex W. T. Ait	Amaryllidaceae	M	herb	○		
Goniothalamus macrophyllus (Blume) Hook. f. & Thomas	Annonaceae	D	small tree	○		
Neouvaria acuminatissima (Miq.) Airy-Shaw	Annonaceae	D	climber(?)	○		
Willughbeia flavescens Dyer ex Hook. f.	Apocynaceae	D	climber	○		
Alocasia longiloba Miq.	Araceae	M	herb	○	○	
Alocasia macrorrhiza (L.) Schott.	Araceae	M	herb	○	○	○
Anadendrun microstachyum (Miq.) Back. & v. A. v. R.	Araceae	M	climber	○		
Araceae sp.	Araceae	M	herb		○	
Schismatoglottis calyptrata (Roxb.) Z. & M.	Araceae	M	herb	○		
Scindapsus cf. *pictus* Hassk.	Araceae	M	climber	○		
Scindapsus hederaceus (Z. & M.) Miq.	Araceae	M	climber	○		
Scindapsus pictus Hassk.	Araceae	M	climber	○		
Agathis dammara (Lamb.) L. C. Rich.	Araucariaceae	G	tree	○		
Calamus heterodeus Blume	Arecaceae	M	tree	○	○	○
Calamus javensis Blume	Arecaceae	M	tree	○	○	
Caryota mitis Lour.	Arecaceae	M	tree	○	○	
Pinanga coronata (Blume ex Mart.) Blume	Arecaceae	M	tree	○		○
Plectocomia elongata Mart. ex Blume	Arecaceae	M	tree	○		
Athyrium bantamense (Bl.) milde.	Aspidiaceae	P	fern		○	
Diplazium bantamense Blume	Athyriaceae	P	fern	○		
Begonia multangula Blume	Begoniaceae	D	herb		○	
Begonia robusta Blume	Begoniaceae	D	herb	○	○	○
Neesia altissima (Blume) Blume	Bombacaceae	D	tree	○	○	
Sarcandra glabra (Thumb.) Nakai	Chloranthaceae	D	shrub	○		
Garcinia rostrata	Clusiaceae	D	tree		○	
Commelina sp.	Commelinaceae	M	herb		○	
Commelina/Medinella?	Commelinaceae	M	herb			○
Forrestia mollissima (Blume) Merr. & Perry	Commelinaceae	M	herb	○	○	○
Eupatorium	Compositae	D	shrub			○
Cyathea contaminans (Hook) Copel.	Cyatheaceae	P	tree fern	○		
Carex cruciata Wahlenb. var. *rafflesiana* (Boott.) Noot.	Cyperaceae	M	herb	○		

Species	Family	Class	Functional type	Low ight site	Middle Light site	High light site
Cyperus	Cyperaceae	M	herb			○
Elaeocarpus glaber Blume	Elaeocarpaceae	D	tree	○	○	
Antidesma montanum Blume	Euphorbiaceae	D	small tree	○		
Macaranga tanarius (L.) M. A.	Euphorbiaceae	D	tree	○		
Macaranga triloba (Reinw. ex Blume) M. A.	Euphorbiaceae	D	tree	○		
Sauropus sp.	Euphorbiaceae	D	tree			○
Castanopsis acuminatissima (Bl.) A. DC.	Fagaceae	D	tree		○	
Castanopsis javanica (Blume) DC.	Fagaceae	D	tree	○		
Castanopsis tungurrut (Blume) DC.	Fagaceae	D	tree	○		
Quercus argentata Korth.	Fagaceae	D	tree	○		
Quercus sp.	Fagaceae	D	tree			○
Gleichenia linearis (Burm.) Clarke	Gleicheniaceae	P	fern			○
Dinochloa scandens (Blume ex Nees) O. K.	Gramineae	M	tree	○		○
Gigantochloa apus (Schult. & Schult. f.) Kurz (GRIN)	Gramineae	M	tree			○
Gigantochloa atter (Hassk.) Kurz (GRIN)	Gramineae	M	tree			○
Paspalum conjugatum P. J. Bergius	Gramineae	M	herb			○
Altingia excelsa Norona	Hamammelidaceae	D	tree	○	○	
Platea excelsa Blume	Icacinaceae	D	tree		○	
Litsea cassiaefolia Blume Merr. var. *pubcrula* Ketv.	Lauraceae	D	tree	○		
Litsea javanica Blume	Lauraceae	D	tree	○		
Litsea resinosa Blume	Lauraceae	D	tree	○		
Bolbitis sinuata (Presl.) Hanipman	Lomariopsidaceae	P	fern	○		
Magnolia elegans (Blume) H. Keng.	Magnoliaceae	D	small tree	○		
Michelia montana Blume	Magnoliaceae	D	small tree	○		
Phrynium capitatum Willd.	Marantaceae	M	herb			○
Clidemia hirta (L.) D. Don	Melastomataceae	D	shrub	○	○	○
Disochaeta gracilis Blume	Melastomataceae	D	climber	○		
Dissochaeta fallax Blume	Melastomataceae	D	climber	○		
Medinella sp. 1	Melastomataceae	D	climber	○		
Medinella sp. 2	Melastomataceae	D	shrub			○
Melastoma malabathricum Auct.	Melastomataceae	D	small tree	○		
Pternandra azurea (Blume) Burk.	Melastomataceae	D	small tree	○		
Aglaia argentea Blume	Meliaceae	D	tree	○		
Toona sinensis (A. Juss.) Roem.	Meliaceae	D	tree	○		
Ficus lanata Blume	Moraceae	D	climber	○		
Ficus lepicarpa Blume	Moraceae	D	tree	○		
Ficus obscura Blume var. *angustata (Miq.) Corner*	Moraceae	D	tree	○		
Ficus subulate	Moraceae	D	tree		○	
Ficus vasculosa Wall. ex Miq.	Moraceae	D	small tree	○		

Species	Family	Class	Functional type	Low ight site	Middle Light site	High light site
Ardisia zollingeri DC.	Myrsinaceae	D	tree	○	○	
Labisia pumila (Blume) F. Vill.	Myrsinaceae	D	herb	○	○	
Syzygium acuminatissimum (Blume) Merr. & Perry	Myrtaceae	D	tree	○		
Syzygium cf. *rostratum* (Blume) DC.	Myrtaceae	D	small tree	○		
Syzygium laxiflorum (Blume) DC.	Myrtaceae	D	tree	○		
Syzygium lineatum (DC.) Merr. & Perry	Myrtaceae	D	small tree	○		
Syzygium sp. 1	Myrtaceae	D	tree		○	
Syzygium sp. 2	Myrtaceae	D	tree		○	
Syzygium sp. 3	Myrtaceae	D	tree		○	
Syzygium sp. 4	Myrtaceae	D	tree		○	
Syzygium umbilicatum (K. & V.) Amsh.	Myrtaceae	D	tree	○		
Nephrolepis hirsutula (Forst.) Presl	Nephrolepidaceae	P	fern			○
Neprolepis falcata (Cav.) C. Chr.	Nephrolepidaceae	P	fern	○		
Oleandra fistillaris	Oleandraceae	P	fern			○
Oleandra neriiformis Cav.	Oleandraceae	P	fern	○		
Oleandra pistillaris (Sw.) C. Chr.	Oleandraceae	P	fern		○	
Appendiculata pendula Blume	Orchidaceae	M	herb	○		
Spathoglottis plicata	Orchidaceae	M	herb		○	○
Freycinetia javanica Blume	Pandanaceae	M	climber	○		
Freycinetia sp.	Pandanaceae	M	climber	○		
Pandanus sp. 1	Pandanaceae	M	herb		○	
Pandanus sp. 2	Pandanaceae	M	climber?		○	
Piper arcuatum Blume	Piperaceae	D	climber	○		
Helicia robusta (Roxb.) R. Br. ex Wall.	Proteaceae	D	tree	○		
Rubus sp.	Rosaceae	D	climber			○
Lasianthus inodurus Blume	Rubiaceae	D	small tree	○		
Lasianthus rhinocerotis Blume	Rubiaceae	D	shrub	○		
Lasianthus sp. 1	Rubiaceae	D	shrub		○	
Lasianthus sp. 2	Rubiaceae	D	tree		○	
Lasianthus sp. 3	Rubiaceae	D	tree	○		
Mussaenda frondosa L.	Rubiaceae	D	climber(?)	○		
Psychotria laxiflora Blume	Rubiaceae	D	climber	○		
Psychotria robusta Blume	Rubiaceae	D	shrub	○		
Psychotria sarmentosa Blume	Rubiaceae	D	climber	○		
Psychotria sarmentosa Blume	Rubiaceae	D	climber		○	
Psychotria viridiflora Reinw. ex Blume	Rubiaceae	D	tree	○	○	
Syzygium sp.	Rubiaceae	D	tree		○	
Urophyllum glabrum Wall.	Rubiaceae	D	shrub		○	
Urophyllum sp.	Rubiaceae	D	tree		○	
Euodia macrphylla Blume	hamammelidaceae	D	tree	○		
Euodia sp.	Rutaceae	D	tree		○	

Species	Family	Class	Functional type	Low ight site	Middle Light site	High light site
Polyosma ilicifolia Blume	Saxifragaceae	D	tree	○		
Polyosma integrifolia Blume	Saxifragaceae	D	tree	○		
Smilax zeylanica L.	Smilaxaceae	M	climber	○		○
Sterculia coccinea Jack var. *coccinea*	Sterculiaceae	D	tree	○		
Symplocos cochinchinensis (Lor.) Morre. *ssp. cochinchinensis var. cochinchinensis*	Symplocaceae	D	tree	○		
Symplocos fasciculata Zoll.	Symplocaceae	D	small tree	○		
Symplocos odoratissima Chaisy ex Zoll *var. odoratissima*	Symplocaceae	D	tree	○		
Symplocos sp.1	Symplocaceae	D	shrub		○	
Symplocos sp.2	Symplocaceae	D	tree		○	
Tacca cristata Jack	Taccaceae	M	herb	○		
Heterogonium subglabrum Hollt.	Tectariaceae	P	fern	○		
Gordonia excelsa (Blume) Blume	Theaceae	D	small tree	○		
Schima wallichii (DC.) Korth	Theaceae	D	tree	○		
Cyclosorus sp.	Thelypteridaceae	P	fern	○		
Elatostema sinuatum (Blume) Hassk.	Urticaceae	D	herb	○		
Cissus cf. *nodosa* Blume	Vitaceae	D	climber	○		
Cissus sp.	Vitaceae	D	climber			○
Teteashigma/Acantaceae?	Vitaceae	D	herb			○
Tetrashigma	Vitaceae	D	tree		○	
Alpinia scabra Blume	Zingiberaceae	M	herb	○	○	○
Amomum cf. *compactus* Soland. ex Maton	Zingiberaceae	M	herb	○		
Amomum sp.	Zingiberaceae	M	herb	○		
Costus speciosus (Koen.) J. E. Smith	Zingiberaceae	M	herb	○	○	

Table 2 Number of research species in taxonomic phylum.

Classification	Low light site	Middle light site	High light site
Spermatophyta			
Angiospermae			
Dicotyledoneae (D)	62	29	10
Monocotyledoneae (M)	25	13	14
Gymnospermae (G)	1	-	-
Pteridophyta (P)	7	3	3
Total	95	45	27

Table 3 Number of research species. It classified according to functional type.

Functional type	Low light site	Middle light site	High light site
Tree	39	23	7
Small tree	13	-	-
Shrub	4	4	3
Herb	16	13	11
Climber	16	2	3
Fern	6	3	3
Tree fern	1	-	-
Total	95	45	27

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PRIMER NOTE

Microsatellite loci for the weaver ant *Oecophylla smaragdina*

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Abstract

We developed 13 microsatellite loci in *Oecophylla smaragdina* from random amplified polymorphic DNA (RAPD) fragments. These loci showed two to 14 alleles in *O. smaragdina* with expected heterozygosity of each locus from 0.10 to 0.89, and six were also polymorphic in the related species, *O. longinoda*. The results suggested that the loci will be useful to analyse the genetic structure of *Oecophylla* species at both the colony and population levels.

Keywords: microsatellite DNA, *Oecophylla longinoda*, *Oecophylla smaragdina*, random amplified polymorphic DNA, weaver ant

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The weaver ant *Oecophylla* (Hymenoptera, Formicidae) is a relatively old genus in the subfamily Formicinae, with only two extant species, *Oecophylla longinoda* (Latreille) distributed in tropical Africa, and *O. smaragdina* (Fabricius) in Southeast Asia and Australia (Wheeler 1922; Bolton 1995). Both are arboreal and make peculiar global or elliptical nests of leaves spun with silk supplied by larvae. They form exceptionally aggressive and territorial colonies that occasionally dominate a wide range of forest canopies. Although these characteristics have attracted many researchers, the mating structure and the genetic structures of the colonies are still controversial in *O. smaragdina*. Fraser & Crozier (1999) stated that, on average, *O. smaragdina* has a monoandrous mating system with rare polyandry. However, because their estimation was based on only three microsatellite loci, additional genetic markers should be used for a more precise conclusion to be made. Also, the queen numbers in mature colonies should be tested because *O. smaragdina* had been regarded as a monogynous species (Hölldobler & Wilson 1990), but Peng *et al*. (1998) reported multiple queens in well-established colonies. Suitable genetic markers are needed to resolve this conflict. Therefore, as a preparation for these investigations, in this study we describe polymorphic microsatellite loci isolated from *O. smaragdina*.

Total genomic DNA was extracted by the cetyltrimethyl ammonium bromide (CTAB) method of Hillis *et al*. (1990) and Navarro *et al*. (1999). Microsatellite loci were searched from random amplified polymorphic DNA (RAPD) fragments, according to the method of Takahashi *et al*. (in preparation). The total DNA of *O. smaragdina* was randomly amplified using a 10-bp primer of random nucleotide sequence (Operon Technologies Inc.) by polymerase chain reaction (PCR). A total of 120 primers (OPA, OPB, OPH, OPI, OPY and OPZ01–20) were used in this study. Each RAPD reaction (15 µL) contained 15 ng of template DNA, 1.5 µL of 10 × reaction buffer, 1.5 µL of dNTP mix (1 mM of each dNTP), 18 pmol of one of the 120 primers, and 0.6 U of *Taq* DNA polymerase (TaKaRa *Taq*, TaKaRa). The thermal cycle profile consisted of 45 cycles of 1 min at 94 °C, 1 min at 35 °C, a 0.3 °C/s temperature transition to 72 °C and 2 min at 72 °C. For the first screening, 1 µL of product from each different primer was dropped separately onto a positively charged nylon membrane (FMC). After drying at room temperature, DNAs on the membrane were blotted by normal alkaline transfer. RAPD products containing microsatellite regions were detected using a biotinylated DNA detection kit (Imaging High-Color, Toyobo) and biotin-labelled oligonucleotides [$(GA)_{10}$, $(AT)_{10}$, $(GC)_{10}$, $(AGC)_7$, $(AGT)_7$, $(ACG)_7$, and $(ATG)_7$] as probes for the microsatellites. Here, 22 of the 120 primers' products were positive. These were then mixed together and purified using a QIAamp PCR purification kit (Qiagen) in a final volume of 15 µL. Both ends of the purified fragments were blunted, kinased using TaKaRa BKL kit (TaKaRa), and ligated into *Sma*I-cut pUC19 plasmids using the same kit, following the manufacturer's instructions. Recombinant plasmids were transformed into competent *Escherichia coli* cells (Competent High-JM109-, TaKaRa). A total of 550

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Table 1 Characterization of 13 polymorphic microsatellite loci isolated from *Oecophylla smaragdina*. The product size and repeat region data are based on the sequenced allele submitted to the GenBank with expressed Accession no. Number of alleles detected for each species are shown in parentheses following observed heterozygosity (H_O). NP = no scorable product

Locus name	Repeat pattern	Size (bp)	Primer sequence (5′–3′)	T_a (°C)	GenBank Accession no.	*O. smaragdina* (*n* = 20)	*O. longinoda* (*n* = 1)
MS2.2.2	$\mathrm{(GCA)_6}$	107	F: GTCTTATGTGTGGCCACTGCGA R: GTGAAATGAACGTGACTTG	48	AB174735	$H_O = 0.45$ (4) $H_E = 0.61$	(2)
MS2.3	$\mathrm{(GT)_5GC(GT)_5}$	134	F: TCCAGGTGACCGTCGTGT R: CATACACATTCGCGTACG	48	AB174736	$H_O = 0.10$ (4) $H_E = 0.63$	NP
MS2.14	$\mathrm{(CGA)_4CGT(CGA)_6CAA{-}(CGA)_{10}TGA(CGA)_3}$	235	F: TCTACGTGTCTAACCCAAC R: GCGAGTCTACTCCATCGTATAG	52	AB174734	$H_O = 0.40$ (13) $H_E = 0.89$	(1)
MS3.2	$\mathrm{(GA)_6}$	93	F: GTGACATTGTCGGCGA R: CGAGCGCGAAAATTTCGTC	52	AB174737	$H_O = 0.00$ (2) $H_E = 0.10$	(1)
MS5.2	$\mathrm{(CT)_{11}(CTTT)_3GTTT(CTTT)_2}$	129	F: AATTACAGTTCGGTCTCG R: ATCGAACTTCGCTTCGGTTGTA	48	AB174740	$H_O =0.60$ (7) $H_E = 0.77$	(2)
MS5.10	$\mathrm{(GA)_3AA(GA)_5A_8(GA)_4}$	103	F: GAGAGGAAGTGCACCACAATG R: CGAACCGTGAGGAAATGTCGA	52	AB174738	$H_O = 0.05$ (3) $H_E = 0.52$	(1)
MS5.13	$\mathrm{(GA)_9}$	133	F: AGGCATGCATTAAGCTTC R: AGGCATGCATTAAGCTTC	48	AB174739	$H_O = 0.4$ (6) $H_E = 0.67$	(2)
MS6.29	$\mathrm{(GA)_3AA(GA)_4A(GA)_3}$	176	F: CAATCCAGTTGCACGGCTA R: GTAACTTCGAGTTCGC	49	AB174741	$H_O = 0.15$ (4) $H_E = 0.23$	(1)
MS6.45	$\mathrm{(GTT)_3GCT(GTT)_9(GCT)_4(GTT)_2(GCT)_4}$	235	F: GGTCGTTGCTGACCGT R: CAGATACAGGCAATGCT	49	AB174742	$H_O = 0.60$ (6) $H_E = 0.70$	(2)
MS6.47	$\mathrm{(GA)_9}$	137	F: AGCCCTCTTGTTCATGA R: TTAAATTCGGCCGCA	45	AB174743	$H_O = 0.20$ (3) $H_E = 0.66$	(2)
MS7.1	$\mathrm{(GAT)_8}$	95	F: AAAGGACGTTGACGCGAC R: ACGTGCAATCCATTCACG	52	AB174744	$H_O = 0.25$ (3) $H_E = 0.52$	(2)
MS7.1.3	$\mathrm{(GAT)_9{-}(GTT)_4{-}(GCC)_4}$	248	F: TGATGATACGATTGCAGA R: TGCTGGAGTCGAGCAGT	48	AB174745	$H_O = 0.15$ (4) $H_E = 0.42$	(1)
MS8.24	$\mathrm{(CTT)_5TCT(CTT)_3{-}(GA)_3AA(GA)_{11}AATA(GA)_9}$	289	F: GCAGACAATGGCTATTTGT R: CGATGTGATTTAGCCGA	50	AB174746	$H_O = 0.56$ (6)* $H_E = 0.83$	(1)

*The primer pair for MS8.24 could not amplify proper PCR products in five individuals from India of *O. smargdina*.

recombinant colonies were chosen and suspended independently in 30 µL of Tris-EDTA (10 mM Tris-HCl pH 7.4, 1 mM EDTA pH 8.0). Each suspended colony was heated at 98 °C for 5 min and then centrifuged for 1 min at 8000 ***g***. Inserts were amplified by PCR using a primer pair for the multicloning site pUC19 (Bca BEST TM Sequencing Primer RV-M and M13-47, TaKaRa) with TaKaRa *Taq* (TaKaRa) according to the manufacturer's instructions. Temperature cycles were as follows: 30 cycles of 1 min at 95 °C, 1 min at 55 °C and 2 min at 70 °C. After PCR, 1 µL of each amplified product was used to detect clones containing the microsatellite sequences in the same manner as the first screening. It was seen that 20 of 550 clones were positive. For each positive clone, 4 µL of the remaining PCR product was verified for its length on 1% agarose gel in Tris-borate-EDTA, and 18 unique insert lengths were found (350–1800 bp). The remaining product of each positive clone was purified using a QIAamp PCR purification kit (Qiagen) and sequenced using the automated sequencer, Genetic Analyser 3100 (Applied Biosystems).

Proper PCR primer regions could be determined for 14 loci from the results of sequencing, and to test the effectiveness of these loci, 20 individuals of *O. smaragdina* from mainland Asia, Indonesia and Australia, and one of *O. longinoda* were used. PCR amplifications were carried out in a total volume of 15 µL, which contained *c*. 10 ng of template DNA, 3 pmol of each primer [forward was labelled with 6-FAM, PET, VIC or NED fluorescent dyes (Applied Biosystems)], 1.5 µL of 10× reaction buffer, 1.5 µL of dNTP mix (1 mM of each dNTP), and 0.6 U of *Taq* DNA polymerase (AmpliTaq Gold, Applied Biosystems), by thermal cycling parameters of 5 min at 95 °C for hot start, 30 cycles of 45 s at 92 °C, 45 s at 48 or 52 °C (according to the annealing temperature for each primer set, see T_a in Table 1) and 1 min at 72 °C. The PCR products were electrophoresed along with GeneScan 500 LIZ size standard on Genetic Analyser 3100 (Applied Biosystems), and allele sizes were assigned using GeneScan analysis software (Applied Biosystems). We found 13 polymorphic loci with two to 14 alleles in *O. smaragdina* (expected heterozygosity,

H_E from 0.10 to 0.89), and six heterozygous loci in *O. longinoda* (Table 1). Although observed H_E was remarkably lower than that in *O. smaragdina* at some loci, apparently due to fragmentated population structure of this species, we totally concluded that these microsatellite markers would be useful in genetic analysis on both species at colony and population levels.

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Note and Comment

Social behaviors of all-male proboscis monkeys when joined by females

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In a riverine forest along the Menanggul River, which is a tributary of the Kinabatangan River, Sabah, Malaysia, I observed an all-male group of proboscis monkey (*Nasalis larvatus*) consisting of 27–30 (mean: 28.8) individuals. This large size of the all-male group seems to be attributed to habitat fragmentation because of the expansion of oil palm plantations. A few females joined this all-male group. Sub-adult females copulated with subadult or large juvenile males. Since the mean male tenure period of this monkey was estimated to be longer than female maturity, and prematured females might leave their natal one-male groups to avoid inbreeding and temporarily participate in the all-male group where males were permissive to them. Even when females joined this group, no conflicts occurred among males.

Key words: all-male group; copulation; inbreeding avoidance; male replacement; *Nasalis larvatus*; proboscis monkey.

Introduction

In primate species with male-biased dispersal, young males are usually solitary or otherwise belong to all-male groups until they mature to adults who immigrate into bisexual groups for reproduction. Since many species of Asian colobine monkeys form one-male groups as bisexual groups, the all-male groups are common across these species (Newton & Dunbar 1994)., Compared with bisexual groups, however, the all-male groups have rarely been studied so far, partly because their home ranges are larger (Hrdy 1977; Mohnot 1984; Sommer 1988 Newton 1992, 1994) and the membership is less stable than in bisexual groups. The proboscis monkey (*Nasalis larvatus*) is known to have all-male groups which are occasionally joined by females (Yeager & Kool 2000; Boonratana 2002). However, the social interactions between males and females are not studied yet. As a part of comprehensive studies on proboscis monkey, this paper reports the size and composition of an all-male group and social behaviors that have not been described.

Materials and methods

Proboscis monkey (*Nasalis larvatus*) is endemic to Borneo Island, inhabiting mangroves, peat swamps or riverine forests. This species belongs to subfamily Colobine which includes at least 30 species of four to nine genera (Oates & Davies 1994; Oates *et al.* 1994) characterized by a multichambered stomach that is an adaptation to almost obligatory folivory (Bauchop & Martucci 1968; Hladik 1977; Bauchop 1978; Waterman 1984). The social unit of proboscis monkey is basically a one-male group consisting of one male, several females and their offspring, though young males are rarely solitary but form all-male groups (Bennett & Sebastian 1988; Yeager 1990; Boonratana 1999). The present study was conducted for 29 months from June 1999 to October 2001, and in May and June 2002 (total 529 days) along the Menanggul River (5°30′N/118°30′E) which is a tributary of the Kinabatangan River (mainly 4 km from the mouth of the tributary), Sabah, Malaysia. The riverside of this tributary is covered by a riverine forest in which several species are noticeable such as *Mallotus mutics* (Euphorbiaceae), *Ficus condensa* (Moraceae), *Dillenia indica* (Dilleniaceae), *Neonauclea giganta* (Rubiaceae) (Boonratana 1993). The mean temperature was about 27°C and the mean annual precipitation was 2804 mm from 1999 to 2002 (Meteorological Service of Malaysia).

I found eight one-male groups and one all-male group of proboscis monkeys in the study site. Whenever

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the all-male group was found, the membership and their behaviors were recorded by event sampling method using binocular and video camera (DCR-TRV 900, Sony, Japan) with a field scope (VCL-FS 2K, Sony, Japan). The video scene could be enlarged *in situ* by up to ×120.

The relative age of each individual was determined by following Bennett & Sebastian (1988) who categorized the age into adult, subadult, juvenile and infant (I & II). In this study, adult males were subdivided into three categories which include (i) old adult with fully developed nose, many cheek wrinkles and well-developed fat layer on waist, (ii) middle-aged adult with fully developed nose and well-developed fat layer but only a few cheek wrinkles, and (iii) young adult with fully developed nose but undeveloped fat layer and few cheek wrinkles. I tried to identify subadult and large juvenile males based on their scars, nose shapes and other physiognomic features, although females had few personal features and their discrimination was impossible. When the males emigrated from the all-male group, I continued to monitor them within the range of the study area.

Results

Group composition and social behavior between males

During the 29-month study period, I could ascertain the size and composition of the all-male group in eight surveys and the average size of the all-male group was 28.8 (range: 27–30), but the membership was not so constant and a few females occasionally joined this group (Table 1). The all-male group did not include old and middle-aged adult males who were usually the harem male of each one-male group. There were neither intense fights nor dominant/subordinate relationships between males, although juveniles often wrestle and mount. Because this group ranged through a wide area (at least 6 km along the tributary), males of this group have a greater chance to encounter harem groups to take over.

At the beginning of the study period, four subadult (A–D) and two large juvenile males (E–F) were in the all-male group. I identified these six males and monitored their life histories (Fig. 1). When they matured to young adults, A, B and C became harem males of one-male groups, although C gradually lost his control over females and finally became solitary after all females left him. D disappeared from this all-male group and E and F stayed in this group until the end of my observation.

In the total of eight one-male groups, male replacement occurred three times during 3 years and new harem males came from the all-male group (Fig. 1). Following the formula used by Sterck (1997), the mean period of male tenure was estimated to be approximately 8 years (three replacements/3 years/eight one-male groups).

Male-joined female social behavior

When females joined this group, I observed a total of seven copulations between subadult females and young

Table 1 Size and composition of an all-male group of proboscis monkey

	1999	2000			2001			2002
	July	February	July	October	April	June	July	May
Adult male								
Old	0	0	0	0	0	0	0	0
Middle-aged	0	0	0	0	0	0	0	0
Young	0	0	1	1	0	0	1	0
Sub-adult male	4	4	3	2	1	1	0	3
Juvenile male								
large	4	5	5	5	6	5	4	7
small	18	20	15	18	18	17	19	12
Infant male								
II	1	1	2	1	1	2	2	2
I	0	0	0	0	0	0	0	0
Subtotal	27	30	26	27	26	25	26	24
Sub-adult female	0	0	3	2	2	2	2	2
Juvenile female								
large	0	0	1	1	1	1	1	1
small	0	0	0	0	0	0	0	0
Subtotal	0	0	4	3	3	3	3	3
Total	27	30	30	30	29	28	29	27

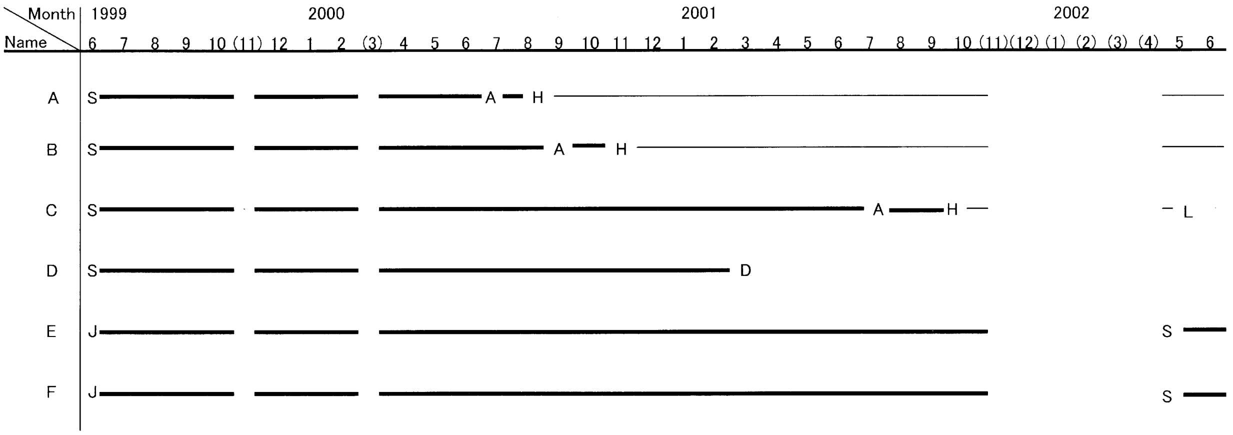

Fig. 1. Life histories of males. (—), stay of each male in the all-male group and (–), stay in one-male groups. In parenthesized months, the observation was not conducted. (A), adult; (D), disappeared; (H), head of a one-male group; (J), large juvenile; (L), lost the head position; (S), sub-adult.

adult, subadult or large juvenile males. One juvenile female solicited with pouting her lip and shaking her head toward a large juvenile male but could not elicit his mating behavior. The mean duration was 26.3 ± SD 7.0 seconds per mount (range: 17–35 seconds). Of the seven copulations, five were solicited by males and two by females. The mean number of mounts per copulation was 1.4 (range 1–3). Females showed sexual swelling in four of the seven copulations. However, I could not confirm the pregnancy of these copulated females. Even when the females were in this group, there were no conflicts among males.

Discussion

According to Yeager & Kool (2000), all-male groups have been reported from 17 Asian colobine species, and the mean group size is 7.2 individuals, with a maximum of 15 in hanuman langur (*Semnopithecus entellus*) (Newton & Dunbar 1994). Thus, young males of colobine monkeys usually form small groups. Even in proboscis monkey, the size of all-male groups has been reported to be between three and twelve (Bennett & Sebastian 1988; Yeager 1991a; Boonratana 2002). The all-male group found in this study is evidently the largest in colobine monkeys. Although members of an all-male group cooperate to oust resident harem male in hanuman langur (Hrdy 1977), the male replacement in proboscis monkey seems relatively peaceful without any evidence of fighting (Murai unpubl. data). Pusey & Packer (1987) mentioned that larger all-male groups seem more effective against predators in many terrestrial primate species. Whereas estuarine crocodiles (*Crocodylus porosus*), clouded leopards (*Neofelis nebulosa*), reticulated pythons (*Python reticulatus*) and some hawks and eagles have been suggested as predators of proboscis monkeys (Boonratana 1993). The direct observations of predator's attack have been reported only by Galdikas (1985) and Yeager (1991b) who watched a false gavial (*Tomistoma schlegeli*) preying upon a proboscis monkey, and even in my 3-year observation, the direct evidence of predation was not obtained. Instead, the habitat fragmentation can facilitate the growth of the all-male group size. In the same area where I conducted this study, Boonratana (2002) found three all-male groups consisting of eight, nine and 10 individuals, respectively, in 1990–1991 when oil palm plantations were not yet extensively developed and the habitat fragmentation was not so serious as the current situation.

Rudran (1973) found purple-faced langur (*Presbytis senex*) females mingling in all-male groups but they were all juvenile. For proboscis monkeys, Boonratana (2002) and Yeager & Kool (2000) reported that some all-male groups contained a few females but copulation was not observed in these groups. The present study first demonstrates that the copulation of proboscis monkeys occurs not only in one-male groups but also occasionally in all-male groups. The mean duration of copulation (26.3 ± SD 7.0 seconds) and the mean number of mounts per copulation (1.4) in the all-male group were not significantly different from those in one-male groups (Murai unpubl. data: 27.4 ± SD 10.1 seconds and 1.3). The mean period of male tenure is estimated to be approximately 8 years and my unpublished data indicates that the female maturity takes approximately 5 years, suggesting that some subadult females leave their natal one-male groups before sexual maturity to avoid inbreeding. Because the number of females controlled by a harem male is limited in each one-male group, some subadult females can temporarily stay in an all-male group which is permissive to females.

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Temporal, spatial, and ecological modes of evolution of Eurasian *Mus* based on mitochondrial and nuclear gene sequences

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Abstract

We sequenced mitochondrial (cytochrome *b*, 12S rRNA) and nuclear (IRBP, RAG1) genes for 17 species of the Old World murine genus *Mus*, drawn primarily from the Eurasian subgenus Mus. Phylogenetic analysis of the newly and previously available sequences support recognition of four subgenera within *Mus* (*Mus*, *Coelomys*, *Nannomys*, and *Pyromys*), with an unresolved basal polytomy. Our data further indicate that the subgenus *Mus* contains three distinct 'species groups': (1) a *Mus booduga* Species Group, also including *Mus terricolor* and *Mus fragilicauda* (probably also *Mus famulus*); (2) a *Mus cervicolor* Species Group, also including *Mus caroli* and *Mus cookii*; and (3) a *Mus musculus* Species Group, also including *Mus macedonicus*, *Mus spicilegus*, and *Mus spretus*. Species diversity in Eurasian *Mus* is probably explicable in terms of several phases of range expansion and vicariance, and by a propensity within the group to undergo biotope transitions. IRBP and RAG1 molecular clocks for *Mus* date the origin of subgenera to around 5–6 mya and the origin of Species Groups within subgenus *Mus* to around 2–3 mya. The temporal pattern of evolution among Eurasian *Mus* is more complex than that within the Eurasian temperate genus *Apodemus*.

Keywords: Mus; Eurasian subtropics; Niche transition; Molecular phylogeny; Cytochrome *b*; IRBP; RAG1; 12S rDNA

1. Introduction

The late Tertiary and Quaternary periods, spanning the last 10 million or so years, was a time of rapid diversification within the rodent subfamily Murinae (Jacobs, 1985; Jacobs and Downs, 1994). Today, this group dominates the small gramnivore/omnivore niche among Old World mammals, with highly speciose radiations in each of Eurasia, Africa and Australasia (Musser and Carleton, 1993).

Recent advances in knowledge of murine taxonomy and phylogeny support several general observations regarding the biogeography of this important group. The first is that the murine radiations of Africa, the Eurasian region and Australasia each occurred largely independent of the others, albeit with zones of secondary mixing in the region between North Africa and the Indian subcontinent, and in the Moluccan islands of eastern Indonesia. A second observation is that, in the Eurasian region, the more speciose murine genera typically are confined either to the temperate zone (e.g., *Apodemus*) or to the tropical and subtropical zones (e.g., *Rattus*, *Niviventer* and *Maxomys*).

The genus *Mus*, comprising 39 species of small to minute-bodied murines (Musser and Carleton, 1993), appears to counter both of these generalities. In the first place, *Mus* has a geographic distribution that spans the entire Old World region, from southern Africa to eastern Asia. And second, it is represented in all major habitat types of the Eurasian region, from tropical montane forests of mainland Southeast Asia to

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temperate open plains of central Asia and Western Europe.

Not surprisingly, doubts have surfaced periodically regarding the unity of the genus *Mus* (see Catzeflis and Denys, 1992; Ellerman, 1941; Misonne, 1969). In particular, some authors have advocated separation of some or all of the African mice into a genus *Nannomys* Peters, 1876. Marshall (1977) adopted a cautious position by allocating *Mus* species into four subgenera, i.e., *Mus*, *Nannomys*, *Coelomys*, and *Pyromys*. The first application of biochemical methods to this problem, using the method of isozyme electrophoresis (Bonhomme et al., 1984; see also Bonhomme, 1986), pointed to a very distant relationship between African '*Nannomys*' and several Eurasian species of *Mus*, perhaps equivalent with the separation between *Mus* and each of *Rattus* and *Apodemus*. However, subsequent analyses using the more appropriate methods of DNA–DNA hybridization (Catzeflis and Denys, 1992; Chevret et al., 2003; She et al., 1990) and gene sequencing (Auffray et al., 2003; Chevret et al., 2003; Karn et al., 2002; Lundrigan et al., 2002; Schubert et al., 2000; Sourrouille et al., 1995; this study) have invariably supported the monophyly of *Mus*. Nevertheless, it should be noted that the relevant molecular investigations typically either include good coverage within *Mus* but include few other genera, or they include numerous other genera but poor taxon sampling within *Mus*.

Setting aside the issue of *Mus* monophyly for the present, the growing body of molecular evidence shows good agreement on the following features of *Mus* phylogeny: (1) deep divergence between the four subgenera as defined (with some modification) by Marshall (1977); (2) unity of a mainland Southeast Asian clade that includes *Mus cervicolor*, *Mus caroli*, and *Mus cookii*; (3) unity of a Palearctic clade that includes *M. musculus* (with its subspecies including *domesticus*, *castaneus*, etc.), *Mus spretus*, *Mus spicilegus*, and *Mus macedonicus*. Two poorly known Asian *Mus* species are tentatively grouped by some authors with the Mediterranean clade. The first of these is *Mus famulus* Bonhote, 1898 of the Nilgiri Mountains in southern India, a species that Marshall (1977) had erroneously included in the subgenus *Coelomys* (but see Chevret et al., 2003). The second is *Mus fragilicauda* Auffray et al., 2003, a recently described and still poorly known taxon from northeastern Thailand. In each case, these taxa were linked by single gene analyses to the Palearctic clade within subgenus *Mus*, albeit as distant sister taxa to the core members. However, a significant weakness of these analyses is the absence from the molecular datasets of any representatives of the subgenus *Mus* from the Indian subcontinent, among which *Mus booduga* and *Mus terricolor* (= *Mus dunnii*) are the best known taxa (Chatterjee et al., 1994; Sharma, 1996). A recently published 'evolutionary tree' of the genus *Mus* (Guénet and Bonhomme, 2003; Fig. 1) shows *M. famulus* and *M. fragilicauda* as sister taxa that together form a sister clade to the European *Mus* assemblage. Unfortunately, the genetic and computational basis of this tree is not specified.

This study aims to reveal new details of the temporal and spatial patterns of evolution of Eurasian *Mus*, based on a wider taxon sampling than previously available and on a combination of mitochondrial and nuclear gene sequences. Our additional goal is to effect a comparison with the evolutionary pattern of the Eurasian Temperate genus *Apodemus*, as revealed by directly comparable molecular phylogenetic markers (Michaux et al., 2002; Serizawa et al., 2000; Suzuki et al., 2003). To this end, we determined nuclear gene sequences of interphotoreceptor retinoid-binding protein (IRBP), recombination-activating gene 1 (RAG1), and mtDNA sequences of cytochrome *b* (cyt *b*), 12S ribosomal RNA (rRNA), and 16S rRNA genes in a range of mouse species so as to complement and extend previously published datasets. Our materials include samples from a newly identified population of *M. fragilicauda* from Laos, as well as several populations of *M. booduga* and *M. terricolor*.

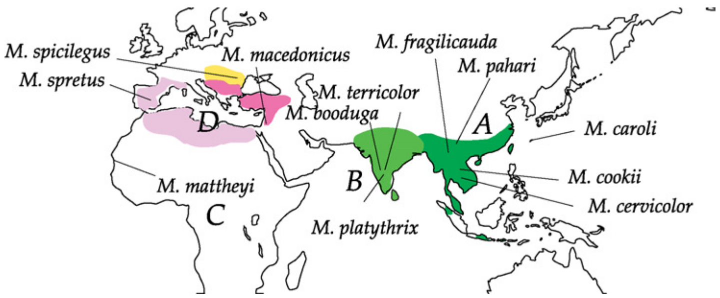

Fig. 1. Generalised distributions of the Eurasian species of *Mus*, excluding the cosmopolitan species *Mus musculus* (Corbet and Hill, 1992). Three of the four subgenera of *Mus* are associated with each of Southeast Asia (A), India (B), and Africa (C); these are represented by *M.* (*Coelomys*) *pahari*, *M.* (*Pyromys*) *platythrix*, and *M.* (*Nannomys*) *mattheyi*, respectively. The remaining subgenus *Mus* can be separated into three geographic Species Groups that occur in largely exclusive areas: Southeast Asia (A), India (B), and Europe (D). In most cases, members of each group show sympatric or parapatric distributions. In India, *M. booduga* and *M. terricolor* are broadly sympatric. In Europe, *M. spicilegus*/*M. macedonicus* and *M. spretus* allocate into northern and southern regions, respectively. Collection localities are shown for samples examined for mitochondrial and nuclear genes (specimens indicated with code 'a' in Table 1).

Both nuclear IRBP and RAG1 gene are single-copy genes (Borst and Nickerson, 1988; Verkoczy et al., 1998). Parts of exon regions have been used for comparisons across mammalian orders (Huchon et al., 2002; Springer et al., 1997; Stanhope et al., 1992, 1996) and the same region in IRBP has also proven a useful marker for defining relationships among lower-level taxa (DeBry and Sagel, 2001; Jansa and Voss, 2000; Serizawa et al., 2000; Suzuki et al., 2000).

2. Materials and methods

2.1. Samples

The sources of nucleotide sequences used in this study are listed in Table 1. These include new sequences obtained from liver samples of 34 specimens representing 16 taxa within the genus *Mus*. RAG1 sequences also were produced for three outgroup taxa (*Apodemus agrarius*, *Micromys minutus*, and *Rattus norvegicus*). The samples of *M. fragilicauda* from Sekong Province in Laos are identified as such on morphological grounds and on the close similarity in 16S rRNA sequence between these animals and the type series from northeastern Thailand (Auffray et al., 2003; see below). Additional information on this new population of *M. fragilicauda* will be presented elsewhere.

2.2. Nucleotide sequencing

Polymerase chain reactions and direct sequencing of the cyt *b* (1140 bp), IRBP (1152 bp), and RAG1 (1002 bp) genes were performed according to previously described methods (Sato et al., 2003, 2004; Serizawa et al., 2000; Suzuki et al., 2000). A 0.9-kb fragment of the 12S rRNA gene was determined according to the methods of Suzuki et al. (1997) and Yamada et al. (2002). A partial 16S rRNA gene sequence (240 bp) was determined for two taxa (*M. booduga* and *M. fragilicauda*) according to the methods described in Auffray et al. (2003). The sequence fragments obtained with the different primers were assembled into a single sequence with the aid of the computer program DNASIS (Hitachi, Japan).

Sequences obtained from the databases are listed in Table 1. The new nucleotide sequences reported in this paper are deposited in the DDBJ, EMBL, and GenBank nucleotide sequence databases with the following Accession Nos. AB125760–AB125851 and AB183249–AB183258 (see Table 1 for sample details).

2.3. Construction of phylogenetic trees

The 12S and 16S rRNA sequences were aligned manually, with introduction of gaps to maximize local homology. Genetic distances between taxa and clusters were calculated using the software PHYLTEST (Kumar, 1996), with Kimura's two-parameter distances (*d*, Kimura, 1980). Trees were constructed using three methods with contrasting optimality criteria: (1) the neighbor-joining (NJ) method of Saitou and Nei (1987); (2) a maximum parsimony (MP) method; and (3) a maximum likelihood (ML) method. For the NJ analysis, we used a variety of distance measures but obtained similar topologies in all cases; the trees presented here are based on Kimura's two-parameter distance. The MP and ML methods were implemented within PAUP* 4.0b10 (Swofford, 2003). *Apodemus argenteus*, *Micromys minutus*, and *Rattus norvegicus* were used in various combinations as outgroups to the genus *Mus*.

For MP analyses, 10 heuristic searches were conducted with the tree-bisection reconnection (TBR) option, in which the input order of taxa is randomized. Consensus trees were constructed using the strict consensus method. We chose the best-fit model of DNA evolution for ML analyses on the basis of hierarchical likelihood ratio tests, as implemented in PAUP* 4.0b10 (Swofford, 2003) and Modeltest v3.06 (Posada and Crandall, 1998). ML model parameters were estimated from a heuristic search with PAUP* 4.0b10 (Swofford, 2003).

We performed a saturation analysis for the cyt *b*, 12S rRNA, IRBP, and RAG1 datasets (18 taxa including three outgroup taxa) according to the method of Hassanin et al. (1998). We calculated the numbers of observed differences and corresponding values for inferred substitutions in the MP method under the conditions mentioned above, using PAUP* 4.0b10 (Swofford, 2003). We produced scatter plots for each dataset and calculated the slope of the linear regression (*S*) as an index of the level of saturation.

Bootstrap analysis was carried out 1000, 1000, and 100 in the NJ, MP, and ML analyses, respectively. Significance of Incongruence Length Differences (ILDs) were calculated using the Partition Homogeneity Option in PAUP* 4.0b10 (Swofford, 2003).

We analyzed each of the individual gene datasets and then combined the three protein encoding genes (cyt *b*, IRBP, and RAG1) for a multigene analysis that included the maximum number of taxa. The 12S and 16S rRNA datasets were not included in the multigene analysis so as to avoid potential problems of non-independence among the mitochondrial genes.

For each individual dataset and additionally for the multigene concatenation, we tested the hypothesis of a molecular clock for a given set of data using the branch-length test as implemented by the software program LINTREE (Takezaki et al., 1995). Molecular divergence times (expressed as Time Since Event—TSE) were estimated by assuming a simultaneous divergence at 12 million years ago (mya) of the major lineages

Table 1
List of species used in this study

Subgenus species	Specimen code		Source	16S	12S	cyt *b*	IRBP	*H*	RAG1	*H*
Coelomys (Southeast Asian lineage)										
Mus crociduroides	1a	—	Indonesia; Sourrouille et al. (1995)[a]	—	X85949[a]	—	—		—	
Mus pahari	2a	HS511	Kunming, China; Suzuki et al. (2003)[a]	—	AB125793	AB096839[a]	AB096855[a]	12	AB125844	3
	2b	—	Thailand; Sourrouille et al. (1995)[a]	—	X84383[a]	—	—		—	
Mus (Eurasian lineage)										
Mus booduga	3a	HS2399	Mysore, India	AB183249	—	AB125760	AB125795	5	—	
	3b	HS894	Gorkha, Nepal	—	AB125783	AB125761	AB125796	0	AB125817	0
	3c	HS895	Gorkha, Nepal	—	AB125784	—	—		AB125818	0
	3d	HS896	Gorkha, Nepal	—	—	—	—		AB125819	0
Mus caroli	4a	HS598	Okinawa, Japan; Suzuki et al. (2000)[a]	AB183250	AB125785	AB033698[a]	AB033707[a]	1	AB125820	0
	4b	HX22/HS2951 (CM30344)	Hatsua, Luang Prabang, Laos	AB183251	—	—	AB125797	1	AB125821	2
	4c	CM28366/HS2958	Houay Khot, Luang Prabang, Laos	AB183252	—	AB125762	—		—	
	4d	A93/HS2961 (CM30342)	Cu Chi District, Viet Nam	—	—	AB125763	AB125798	3	AB125822	3
	4e	—	Thailand; Chevret et al. (2003)[a]	—	AJ279437[a]	—	—		—	
Mus cervicolor	5a	SX8/HS2926 (CM30345)	Somrong, Kampong Cham, Cambodia	—	AB125786	AB125764	AB125799	3	AB125823	3
	5b	SX6/HS2964 (CM30346)	Somrong, Kampong Cham, Cambodia	—	—	AB125765	AB125800	3	AB125824	2
	5c	SX7/HS2965 (CM30347)	Somrong, Kampong Cham, Cambodia	—	—	AB125766	AB125801	1	AB125825	2
	5d	—	Thailand; Lundrigan et al. (2002)[a]	—	AY057797[a]	—	—		—	
Mus cookii	6a	HX41/HS2921 (CM30348)	Hatsua, Luang Prabang, Laos	AB183253	AB125787	AB125767	AB1257802	6	AB125826	1
	6b	HX64/HS2922 (CM30349)	Hatsua, Luang Prabang, Laos	—	—	AB125768	AB1257803	3	AB125827	2
	6c	HX54/HS2950 (CM30350)	Hatsua, Luang Prabang, Laos	—	—	AB125769	AB1257804	2	AB125828	1
	6d	—	Thailand; Sourrouille et al. (1995)[a]	—	X85946[a]	—	—		—	
Mus famulus	7a	—	India; Chevret et al. (2003)[a]	—	AJ279442[a]	—	—		—	
Mus macedonicus	8a	HS537	Haifa, Isral	AB183254	AB183257	AB125770	AB1257805	0	AB125829	1
Mus musculus castaneus	9a	CO1/HS2924 (CM30351)	Comilla, Chittagong Province, Bangladesh	—	AB125788	AB125771	AB1257806	0	AB125830	0
	9b	CO69/HS2925 (CM30352)	Comilla, Chittagong Province, Bangladesh	—	—	AB125772	—		AB125831	0
	9c	HS2400	Taitong, Taiwan	AB183255	—	AB125773	AB1257807	0	AB125832	1
M. m. domesticus	9d	—	Lab. strain: BALBc; Acin-Perez et al. (2003)[a],	AB183256	AJ512208[a]	AB125774	—		AB125833	0
		Stanhope et al. (1992)[a]	—	—	—	AF126968[a]	0		—	
M. m. molossinus	9e	—	Japan; Lab. strain: MOA; Suzuki et al. (2000)[a]	—	—	AB033699[a]	AB033711[a]	0	AB125834	0
	9f	—	Japan; Lundrigan et al. (2002)[a]	—	AY057793[a]	—	—		—	
M. m. musculus	9g	HS682	Peklyong I., South Korea	—	—	—	AB1257808	0	—	
Mus spicilegus	10a	—	Bulgaria; Lab. strain: ZBN	—	AB125789	AB125775	AB1257809	0	AB125835	0
	10b	—	Austria; Lundrigan et al. (2002)[a]	—	—	AY057809[a]	—		—	
Mus spretus	11a	—	Spain; Lab. strain: SEG; Suzuki et al. (2000)[a]	—	—	AB033700[a]	AB033708[a]	0	AB125836	0
	11b	—	Morocco; Lundrigan et al. (2002)[a]	—	AY057796[a]	—	—		—	
Mus terricolor	12a	HS2334	Mysore, India	—	—	AB125776	AB1257810	6	AB125837	3
(=*M. dunnii*)	12b	HS1468	Nepal	—	AB125790	AB125777	AB1257811	5	—	
	12c	FE16/HS2962 (CM30353)	Feni, Chittagong Province, Bangladesh	—	—	AB125778	—		AB125838	0
	12d	NV3/HS2999 (CM30354)	Comilla, Chittagong Province, Bangladesh	—	—	—	—		AB125839	0
Mus fragilicauda	13a	SK8/HS2923 (CM30354)	Sekong Province, Laos	AB125849	AB125791	AB125779	AB1257812	1	AB125840	0
	13b	SK7/HS2952 (CM30355)	Sekong Province, Laos	AB125850	AB125792	AB125780	AB1257813	0	AB125841	0
	13c	SK6/HS2994 (CM30219)	Sekong Province, Laos	AB125851	—	—	AB1257814	0	AB125842	0
	13d	—	Thailand; Auffray et al. (2003)[a]	AF479394	—	—	—		—	
	13e	—	Thailand; Auffray et al. (2003)[a]	AF479395	—	—	—		—	

(*continued on next page*)

Table 1 (*continued*)

Subgenus species	Specimen code		Source	16S	12S	cyt *b*	IRBP	*H*	RAG1	*H*
Nannomys (African lineage)										
Mus mattheyi[b]	14a	KT3030/HS865	Senegal	—	AB125794	AB125781	AB1257815	5	AB125843	2
Mus setulosus	15a	—	Gabon; Sourrouille et al. (1995)[a]	—	X85949[a]	—	—		—	
Pyromys (Indian lineage)										
Mus platythrix	16a	HS628	Mysore, India	—	—	AB125782	AB1257816	0	AB125845	0
	16b	—	Thailand; Sourrouille et al. (1995)[a]	—	X85947[a]	—	—		—	
Outgroup										
Apodemus agrarius	17a	HS1253	Ussurisky, Russia; Serizawa et al. (2000)[a]	—	—	AB032851[a]	AB032858[a]		AB125846	4
Micromys minutus	18a	KT3068/HS1148	Ito, Japan; Suzuki et al. (2000)[a]	—	—	AB033697[a]	AB033710[a]		AB125847	0
Rattus norvegicus	19a	HS649	Lab. strain: SD; Serizawa et al. (2000)[a]	—	AB183258	AB033713[a]	AB033714[a]		AB125848	0

Specimens with a CM number are vouchered in the Australian National Wildlife Collection, CSIRO, Canberra. *H*: Number of heterozygotic sites along the IRBP (1152 bp) and RAG1 (1002 bp) fragments.

[a] Sequences were obtained from the databases.

[b] The specimen may otherwise be referable to *M. haussa*, according to Musser and Carleton (1993) who doubt the distinction of *mattheyi* from more widespread *M. haussa*.

of the subfamily Murinae (see Michaux et al., 2002 and references therein) and calculating an appropriate conversion factor for pairwise genetic distances *d*. To calculate the intergeneric distance, we averaged the individual distances between all *Mus* species and each of the three outgroup taxa.

3. Results

For each individual gene, essentially the same tree topology was obtained under the contrasting NJ, MP and ML methods of analysis. While this methodological congruence does not guarantee accuracy of the trees (Grant and Kluge, 2003), it nonetheless indicates a degree of robusticity of our main conclusions. In Figs. 2 and 3, we present the NJ trees for each individual gene and for the multi-gene dataset. In each case, we indicate the level of bootstrap support for nodes that are represented in trees constructed under all three optimality criteria. Nodes that lack such annotation were not common to the wider set of trees.

3.1. 16S rRNA gene analysis

We sequenced a short portion (ca. 240 bp) of 16S ribosomal RNA gene in each of *M. booduga* and our Lao samples of *M. fragilicauda* and compared these those previously reported sequences from seven species of the subgenus *Mus*, including typical *M. fragilicauda* (Auffray et al., 2003).

As is seen in the NJ tree (Fig. 2), our three specimens from Sekong in southern Laos associate consistently with *M. fragilicauda* from Thailand, with an average *d* of 0.014. This level of genetic difference is comparable to that between two subspecies of *M. musculus*, *M. m.*

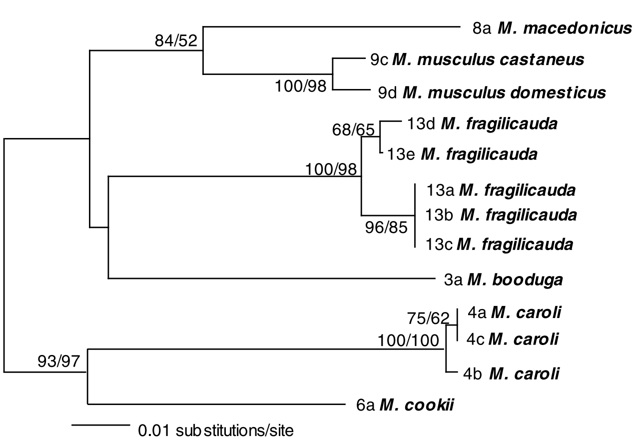

Fig. 2. A neighbor joining (NJ) tree showing phylogenetic relationships among the members of the subgenus *Mus*, using 16S rRNA sequences obtained from the databases (Auffray et al., 2003) and from this study. Bootstrap analyses (1000 replicates) were performed with NJ and maximum parsimony (MP) methods; the resultant values (NJ/MP; as percentages, only if $>$ 50%) are shown at each node.

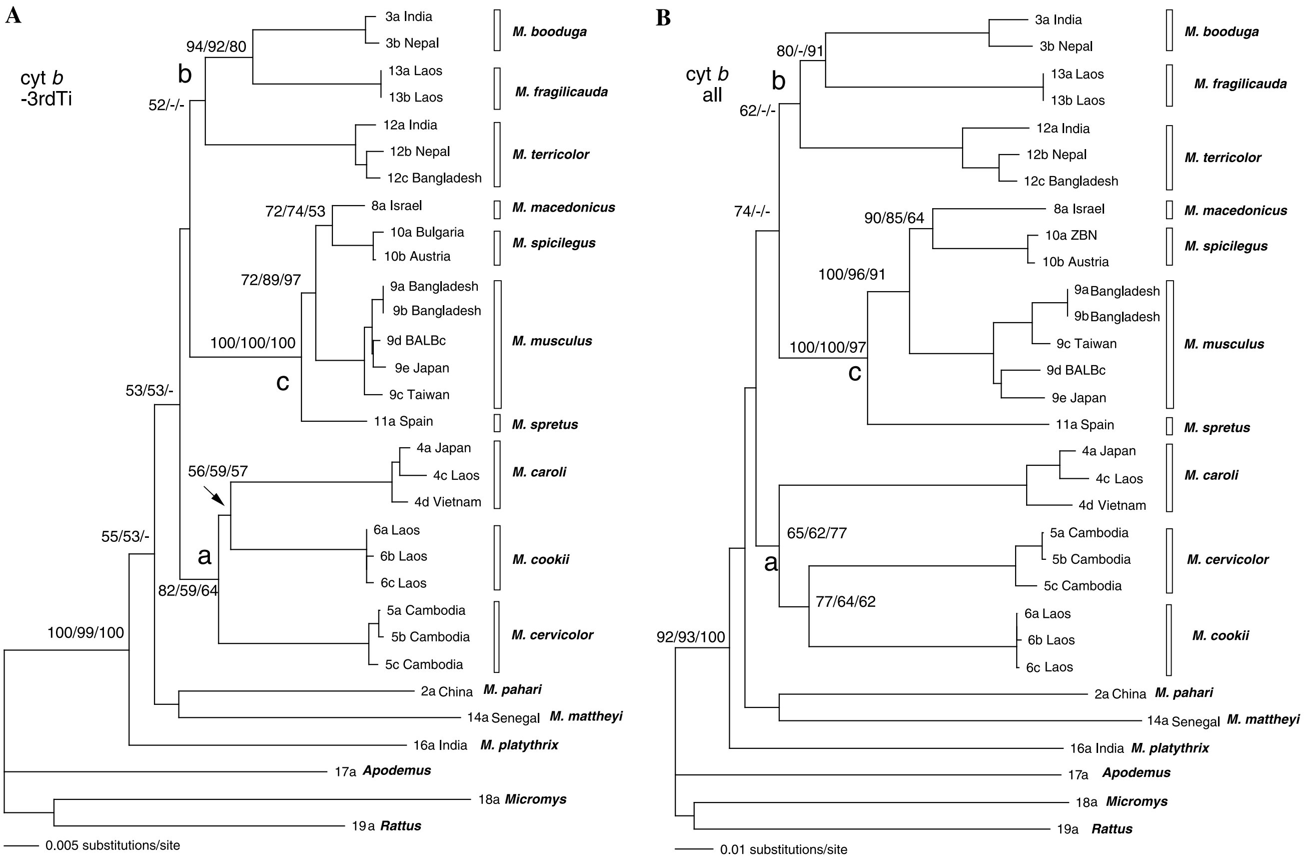

Fig. 3. Phylogenetic relationships among the four subgenera of the genus *Mus* and among the members of the subgenus *Mus*, based on the mitochondrial genes of cyt *b* (1140 bp; A: without 3rd codon transitions; B: with all substitutions) and 12S rRNA (ca. 850 bp; C) and nuclear genes of IRBP (1152 bp; D) and RAG1 (1002 bp; E). The phylogenetic trees were constructed using the neighbor joining (NJ) method, with combination of *Apodemus agrarius*, *Micromys minutus*, and *Rattus norvegicus*, as outgroup taxa. Bootstrap analyses were performed with NJ (1000 replicates), maximum parsimony (MP; 1000 replicates) and maximum likelihood (ML; 100 replicates) methods. The resultant values (NJ/MP/ML; as percentages, only if >50%) are shown at each node. Three major groups are indicated within the subgenus *Mus*; European (or Palearctic), Indian, and Southeast Asian, which are represented by nodes a, b, and c, respectively, for the cyt *b*, 12S rRNA, and RAG1 trees. In the IRBP tree, *M. caroli* lie on the Indian clade (node b′) and is absent in the Southeast Asian clade (node a′).

castaneus and *M. m. domesticus* ($d = 0.012$), but is substantially lower than that between two Palearctic species (*M. musculus* and *M. macedonicus*; $d = 0.072$ to 0.077) and that between two closely related Southeast Asian species (*M. caroli*, and *M. cookii*; $d = 0.107$ to 0.112).

3.2. Cyt *b* gene analysis

We compared a ca. 1140 bp segment of cyt *b* of 29 individuals from 13 species of *Mus*. Saturation analysis of the cyt *b* dataset showed that substitutions at all codon positions were highly saturated ($S = 0.34$). Substitutions were less affected by homoplasy ($S = 0.51$) when 3rd codon transitions were excluded. Transversions at all codon positions were moderately saturated ($S = 0.66$). For phylogenetic analysis of the cyt *b* dataset, we ran separate analyses that either included or excluded transitions at the 3rd codon positions. To exclude them, we replaced A and T with G and C, respectively (Nickrent et al., 2000).

Of the 1140 cyt *b* sites, 290 sites were variable and 222 sites were parsimony informative. Our sequences of *M. booduga* and *M. terricolor* corroborate well with restriction enzyme map of the mitochondrial DNA with respect to the absence or presence of an *Eco*RI site in the cyt *b* gene (Chatterjee et al., 1994). The three subspecies of *M. musculus* are distinctive in the cyt *b* sequences, with genetic distances (d) ranging from 0.021 to 0.034. Similar levels of inter-population divergence are seen in each of *M. booduga* and *M. terricolor* with d of 0.021 and 0.034, respectively, between individuals from Nepal and India (Mysore). Individuals of *M. terricolor* from eastern Bangladesh are grouped with those from Nepal. Substantial intraspecies variation also is seen in *Mus caroli*, with d of 0.012–0.027 between individuals from Okinawa Island (Japan), Laos and Vietnam (see Terashima et al., 2003 for details of additional sampling and analysis).

Phylogenetic trees were constructed with 31 individual cyt *b* sequences representing 13 species of *Mus* and

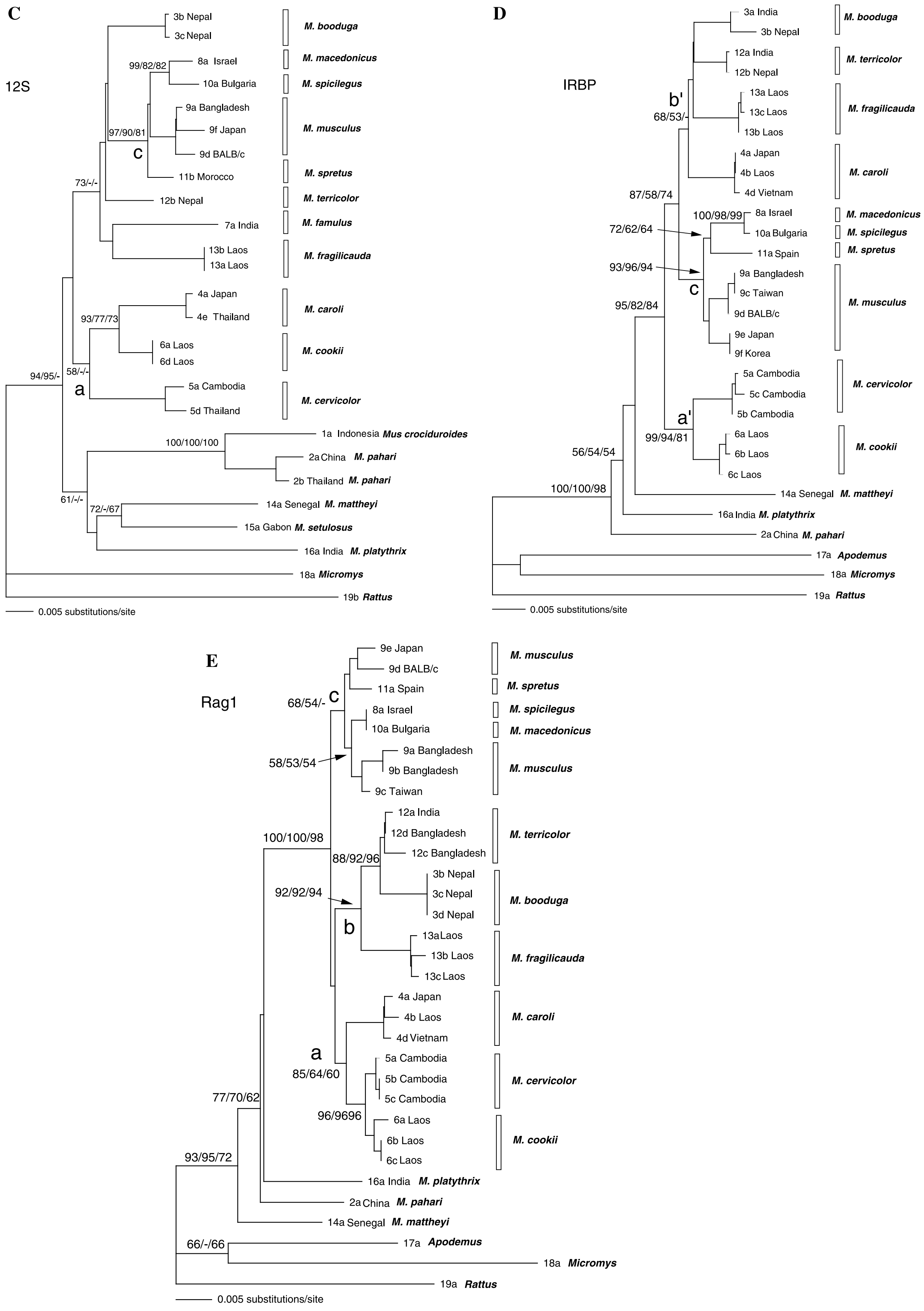

Fig 3. (*continued*)

the three outgroup taxa. For the ML analysis, we used a HKY85 + G + I model ($-\ln L = 3364.9044$; $A = 0.1688$, $C = 0.3339$, $G = 0.2702$, $T = 0.2272$; Ti/Tv ratio = 3.4436; gamma shape parameter = 0.7306; assumed proportion of invariable sites = 0.5448) with a dataset excluding the 3rd codon transitions (−3rdTi) and a GTR + G + I model ($-\ln L = 4390.3138$; $A = 0.3175$, $C = 0.2655$, $G = 0.1216$, $T = 0.2955$; gamma shape parameter = 0.8273; assumed proportion of invariable sites = 0.5647) with a dataset that included all substitutions.

The separate analyses that either excluded (Fig. 3A) or included (Fig. 3B) 3rdTi show similar topologies but contrasting resolution of deeper and shallow lineage relationships, respectively. Analyses without 3rdTi (Fig. 3A) shows a very weak level of bootstrap support under the NJ and MP methods (<53%) for the monophyly of the subgenus *Mus*, represented by 10 species. The other three subgenera are each represented by a single species in this analysis, as follows: subgenus *Nannomys*: *M. mattheyi* (African); subgenus *Pyromys*: *M. platythrix* (Indian); and subgenus *Coelomys*: *M. pahari* (Southeast Asian). The lineage relationships of the four subgenera are unresolved in all analyses of the −3rdTi dataset.

Within the subgenus *Mus*, the −3rdTi analyses suggest a tripartite division of species along essentially geographic lines. The highest bootstrap support (100%) is observed for a close knit 'Palearctic' group that comprises *M. musculus*, *M. macedonicus*, *M. spretus*, and *M. spicilegus*. Within this group, the branching order (((*macedonicus*, *spicilegus*) *musculus*) *spretus*) has bootstrap support in the range 53–97%. Moderate to high bootstrap support (59–82%) is also observed for a 'mainland Southeast Asian' group that comprises *M. cervicolor*, *M. caroli*, and *M. cookii*, with weaker support (56–59%) for a specific association of *M. caroli* with *M. cookii*. Lower level and less consistent bootstrap support (<52%) is observed for a third cluster of species that comprises *M. terricolor*, *M. booduga*, and Lao *M. fragilicauda*. Two members of this group are found on the Indian subcontinent, while *M. fragilicauda* is known from two small areas in southern Laos and northeastern Thailand. Within this 'Indian + Lao/Thai' group, *M. booduga* and *M. fragilicauda* are grouped together with strong support (80–94%). The relationship between the three groups is not resolved by the −3rdTi analyses. A final noteworthy feature of the −3rdTi analyses is the disproportionate level of sequence divergence within each of the three groups within subgenus *Mus*. This is approximately twice as great within each of the 'mainland Southeast Asian' and 'Indian + Lao/Thai' groups as within the 'Palearctic' group.

The analysis using all codon positions (Fig. 3B) features weaker support for monophyly of the subgenus *Mus* but increased resolution among and support for branching patterns within this group. Hence, there is increased support for the branching pattern within the 'Palearctic' group and for the 'Indian + Lao/Thai' group. Within the 'mainland Southeast Asian' group, the branching pattern is different from that seen in the −3rdTi analysis, with *M. cookii* now grouping with *M. cervicolor*, again with relatively weak bootstrap support (62–77%). A sister lineage relationship between the 'Palearctic' and 'Indian + Lao/Thai' groups has weak or moderate bootstrap support values with the all-positions cyt *b* dataset.

3.3. 12S rRNA gene analysis

We sequenced a ca. 850 bp segment of the 12S rRNA gene in 13 mice representing all of the subgenera of *Mus* and combined these with 11 sequences from the databases that include *M. famulus* and *M. crociduroides*. Newly sequenced taxa in our dataset are *M. booduga*, *M. terricolor*, and *M. fragilicauda*.

Saturation analysis of the cyt *b* dataset showed that substitutions at all nucleotide sites were moderately saturated ($S = 0.58$). Of 835 sites available for all taxa, 187 sites were variable and 106 were parsimony informative. Positions featuring gaps in one or more taxa were excluded from the analysis. Substantial levels of genetic variation were found in each of *M. pahari* (Yunnan vs. Thailand; $d = 0.007$), *M. cervicolor* (Cambodia vs. Thailand; $d = 0.007$), and *M. musculus* (e.g., Japan vs. Bangladesh; $d = 0.006$).

Phylogenetic trees were constructed with *Rattus norvegicus* and *Micromys minutus* as outgroups (Fig. 3C). For the ML analysis, we used a GTR + G + I model ($-\ln L = 3057.1593$; $A = 0.3740$, $C = 0.0.1970$, $G = 0.1612$, $T = 0.2678$; gamma shape parameter = 0.5333; assumed proportion of invariable sites = 0.5990) with a dataset that included all substitutions. In most respects, the 12S rRNA trees are topologically consistent with those obtained from the cyt *b* dataset. Features of particular note include the relatively deep separation of the subgeneric lineages and moderate to strong support for the monophyly of the subgenus *Coelomys* (*M. pahari* + *M. crociduroides*: 100%; supporting the earlier conclusion of Sourrouille et al., 1995). In contrast, there is only a weakly supported indication of monophyly in the NJ tree for the subgenus *Nannomys* (*M. mattheyi* + *M. setulosus*: 70%). Monophyly for the subgenus *Mus* was not indicated in this analysis. Within this group, there is moderate support (79%) in NJ for the recognition of two major units, one consistent with the 'mainland Southeast Asian' group as defined by the cyt *b* analysis, and the other consisting of those taxa forming the 'Palearctic' and 'Indian + Lao/Thai' groups. Within the 'mainland Southeast Asian' group, *M. cookii* is paired with *M. caroli* with a moderate degree of bootstrap support (73–93%). Among the remaining taxa, the only strongly supported clade is formed among the Palearctic species *M. musculus*, *M. spretus*, and *M. spicilegus*. In contrast, the 'Indian + Lao/Thai' cluster of species is weakly supported.

Interestingly, the endemic Indian taxon *M. famulus* appears to be more closely related to the geographically proximate 'Indian + Lao/Thai' cluster of species than to members of the true 'Palearctic' group, a finding that extends the earlier findings of Chevret et al. (2003). However, bootstrap support values are weak throughout this portion of the tree and no firm conclusions are warranted regarded the affinities of *M. famulus*.

As observed in the analysis of the −3rdTi dataset, the level of interspecific divergence in 12S rRNA in the 'Palearctic' group is approximately 50% of that seen in the other groups. The sequence divergence between the two species of subgenus *Coelomys* (0.030) is comparable to the levels of the divergences within the 'mainland Southeast Asian' (0.020–0.040) and 'Indian + Lao/Thai' (0.020–0.038) groups of the subgenus *Mus*.

3.4. IRBP gene analysis

We compared sequences of the IRBP exon 1 region (1152 bp) for 27 individuals from 13 species of *Mus* (Table 1). Sequences for three outgroups were available from our previous studies of this gene (Serizawa et al., 2000; Suzuki et al., 2000, 2003). Of the 27 *Mus* individuals, 15 individuals exhibit heterozygotic sites in the sequences (Table 1). The number of intragenomic polymorphic sites ranged from one (e.g., 4a, *M. caroli*) to 12 (2a, *M. pahari*). We treated the polymorphic sites as ambiguous characters for the phylogenetic analyses. Of the 1152 sites, 232 sites were variable and 123 sites were parsimony informative. Saturation analysis plots of all species including the three outgroup taxa revealed a slope (S) of 0.73. For the ML analysis, we used a HKY + G + I model ($-\ln L = 3574.6843$; A = 0.1995, C = 0.3010, G = 0.3031, T = 0.1964; gamma shape parameter = 0.7306; assumed proportion of invariable sites = 0.5448).

The phylogenetic trees obtained from analysis of the nuclear IRBP gene (Fig. 3D) show many features in common with those derived from each of the mitochondrial genes (Fig. 3A–C). The four subgeneric lineages of *Mus* are each very distinct with only weakly resolved associations among them. Monophyly of the 10 species of the subgenus *Mus* is better supported than in any of the mitochondrial gene trees, with bootstrap values of 82–95%. Within this subgenus, two groups are strongly supported, namely a 'Palearctic' group (bootstrap support 93–96%) and a partial 'mainland Southeast Asian' group comprised of two species only (*M. cervicolor* and *M. cookii*; bootstrap support 81–99%). A third, less well-supported group (68%, NJ; 53%, MP) is comprised in this analysis of four species—*M. booduga*, *M. terricolor*, *M. fragilicauda*, and *M. caroli*. The last mentioned species is anomalously placed in comparison with each of the mitochondrial gene trees, in which it invariably groups with *M. cervicolor* and *M. cookii*. Phylogenetic relationships among the 'Palearctic' group are not well resolved in the IRBP trees. As in the cyt *b* analyses, *M. macedonicus* and *M. spicilegus* are closely associated ($d = 0.002$), with *M. musculus* and *M. spretus* each more distant ($d = 0.001$–0.002). Mice belonging to *M. m. domesticus* and *M. m. castaneus* shared near identical IRBP sequences ($d = 0.001$; i.e., one base substitution); both are more divergent from *M. m. musculus* ($d = 0.006$–0.007).

In contrast to the mitochondrial datasets, the IRBP data show only a minor distinction in the level of genetic divergence within the 'Palearctic' (maximum $d = 0.012$) and the other indicated groups within the subgenus *Mus* ($d = 0.012$–0.015). Another important difference is that the IRBP show a relatively greater divergence among the subgenera ($d = 0.031$–0.048) when compared with the inter-group divergences within the subgenus *Mus* ($d = 0.018$–0.021). This result is consistent with the less saturated condition of the IRBP gene.

3.5. RAG1 gene analysis

RAG1 gene sequences (1002 bp) were obtained from 29 individuals representing 13 species of *Mus* and one individual of each outgroup taxon. A total of 13 individuals were heterozygous for sites in the RAG1 gene, with a maximum of three polymorphic sites (e.g., 4d, *M. caroli;* Table 1). Of these 1002 sites, 172 sites were variable and 78 sites were parsimony informative. Saturation analysis plots of all species including the three outgroup taxa revealed a slope (S) of 0.81. The rate of nucleotide substitution in RAG1 is clearly slower even that in the conservation IRBP gene. For the ML analysis, we used a K80 + G + I model ($-\ln L = 2839.2861$; Ti/Tv ratio = 3.5788; gamma shape parameter = 0.8265; assumed proportion of invariable sites = 0.5429).

The RAG1 gene trees (Fig. 3E) show many of the same features as those described for the other genes but provide slightly different emphasis. The four subgeneric groups of the genus *Mus* are all approximately equidistant from each other but with moderate bootstrap support (62–77%) for a topology that identifies the African *M. mattheyi* as the sister taxon to all other *Mus*. The subgenus *Mus* is strongly supported with bootstrap values of 98–100%. Good support was also observed for each of the three groups within subgenus *Mus* including the otherwise poorly supported 'Indian + Lao/Thai' group (bootstrap values 92–94%). Within this group, the RAG1 gene tree indicates a sibling relationship between the two 'Indian' species *M. booduga* and *M. terricolor* to the exclusion of *M. fragilicauda*. In this analysis, *M. caroli* is included with moderate bootstrap support (60–85%) within the 'mainland Southeast Asian' group, as found also in the cyt *b*, 12S rRNA, and 16S rRNA gene trees but in contrast to the IRBP gene trees. A sibling relationship is indicated between *M. cervicolor* and *M. cookii*, supported by high bootstrap values (96%). The 'Palearctic' group is the least well supported of the three lineages within subgenus *Mus* in the RAG1 analysis (bootstrap values <68%). Within this group, individuals of *M. macedonicus* and *M. spicilegus* share an identical RAG1 haplotype. In contrast, RAG1 trees do not always feature monophyly for the three subspecies of *M. musculus* (*M. m. musculus*, *M. m. castaneus*, and *M. m. domesticus*).

The RAG1 dataset, as in IRBP, agree in the proportionally greater differentiation of the subgeneric lineages ($d = 0.026$–0.033) relative to the three major lineages within the subgenus *Mus* ($d = 0.014$–0.018). However, the RAG1 data differ in the more contrasting level of divergence within each of the subgeneric groups. In this regard, the RAG1 data are more consistent with the various mitochondrial datasets.

3.6. Combined gene phylogenies

The best overlap in species coverage is available between the cyt *b* (−3rdTi), IRBP, and RAG1 datasets, with a total of 18 taxa including three subspecies of *M. musculus* and three outgroup taxa. We ran additional phylogenetic analyses for these taxa using all possible combinations of the three datasets, either as paired concatenations or with all three sequences combined. All datasets were analyzed under NJ, MP, and ML methods and with the same number of bootstrap replicates as in the single-gene analyses. For the ML analysis, we used a HKY + G + I model ($-\ln L = 11086.8117$; $A = 0.2091$, $C = 0.2935$, $G = 0.2800$, $T = 0.2175$, gamma shape parameter $= 0.7554$; assumed proportion of invariable sites $= 0.5803$).

All analyses produced the same, by now familiar, topology that features: (1) an unresolved polychotomy among the four subgenera and (2) an unresolved trichotomy between three groups within subgenus *Mus*. The bootstrap results from the single-gene and multi-gene analyses are summarised in Table 2. Not unexpectedly, the multi-gene phylogenies feature stronger bootstrap support for each of the groups within the subgenus *Mus*. This support is unambiguous in the case of 'Palearctic' group and consistently stronger in all gene concatenations for the 'Indian + Lao/Thai' group than the 'mainland Southeast Asian' group. An incongruence length difference test rejected the null hypothesis (at $P < 0.05$) of a homogeneous phylogenetic signal in all pairwise comparisons that involve the cyt *b* sequences and in the three-way concatenation (Table 2).

A NJ tree for the 15 taxa and using the full three-gene dataset (3294 bp; Fig. 4) encapsulates all of the common features of the individual analyses. Bootstrap support is strong for each of the three groups within subgenus *Mus*. The greatest ambiguity is over the monophyly of the 'mainland Southeast Asian' group, a feature that reflects the contrary evidence from IRBP over the affinities of *M. caroli*. There is strong support for inclusion of *M. fragilicauda* within an otherwise Indian group (*M. booduga* + *M. terricolor*) rather than with the Palearctic group clustered around *M. musculus*. A clear difference is observed in the level of differentiation between the close-knit 'Palearctic' group and each of the two Asian groups within subgenus *Mus*.

3.7. Estimates of divergence time

The saturation analyses indicate that individual sequences of IRBP, RAG1, the combined sequences (IRBP + RAG1 + cyt b_{-3rdTi}), and the transversional substitutions of cyt *b* (cyt b_{Tv}) might each be useful, independent indicators of the temporal framework of evolution in the genus *Mus*. For each dataset, the assumption of a molecular clock was tested and upheld at $P \leqslant 0.01$.

The TSE estimates are summarised in Table 3 for each of the following significant evolutionary events in the evolution of *Mus*: (1) divergence of the four subgenera; (2) divergence of the three major groups within the subgenus *Mus*; (3) speciation within each of the three

Table 2
Bootstrap values for hypothetical monophyletic groups of the subgenus *Mus*

Dataset	Length (bp)	P[a]	Southeast Asian			Indian + Lao/Thai			Palearctic		
			NJ	MP	ML	NJ	MP	ML	NJ	MP	ML
cyt b_{-3rdTi}	140	—	82	59	64	66	<50	<50	100	100	100
IRBP	1152	—	<50	<50	<50	<50	<50	<50	93	96	94
RAG1	1002	—	85	64	60	92	92	94	68	54	<50
cyt b_{-3rdTi}+ IRBP	2292	0.024	67	75	73	75	89	93	100	100	100
cyt b_{-3rdTi} + RAG1	2142	0.015	88	98	86	95	99	93	100	100	100
IRBP + RAG1	2154	0.081	<50	<50	<50	96	96	92	100	100	100
cyt b_{-3rdTi} + IRBP + RAG1	3294	0.002	84	88	90	99	91	97	100	100	100

Southeast Asian: *M. caroli*, *M. cervicolor*, *M. cookii*; Indian + Lao/Thai: *M. booduga*, *M. terricolor*, *M. fragilicauda*; Palearctic: *M. macedonicus*, *M. musculus*, *M. spicilegus*, *M. spretus*.

[a] Partition homogeneity test with 18 taxa including the three outgroup taxa.

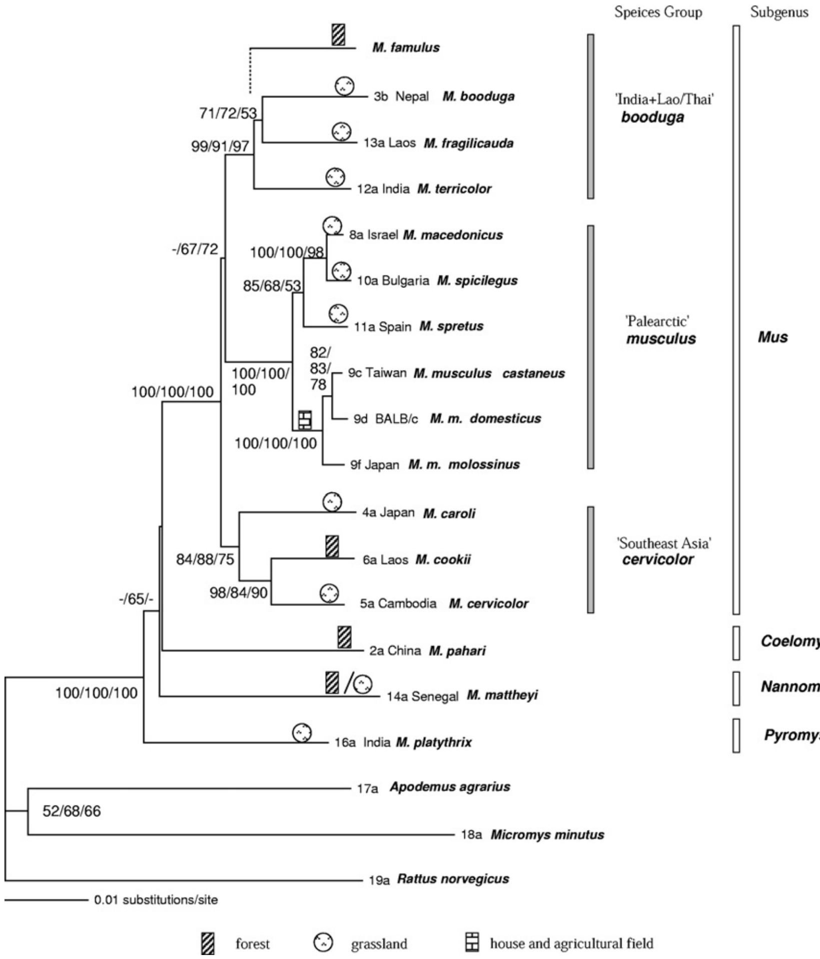

Fig. 4. Schematic representation of the evolution of *Mus*, with special emphasis on the phylogenetic relationships among the members of the subgenus *Mus.* Biotope associations are shown for a NJ tree constructed with the 18 representative species including three outgroup species and combined dataset (3294 bp) of the three genes of cyt *b* (excluding third codon transitions), IRBP and RAG1. Bootstrap analyses were performed with NJ (1000 replicates), maximum parsimony (MP; 1000 replicates) and maximum likelihood (ML; 100 replicates) methods. The resultant values (NJ/MP/ML; as percentages, only if >50%) are shown at each node. The position of *M. famulus* was assessed from the phylogenetic inference of the 12S rRNA gene (Fig. 3C).

major groups; and (4) intraspecific divergence within *M. musculus*. The IRBP and RAG1 datasets are similarly scaled, with TSE estimates for each of these events of 5.1–5.2 mya (subgenera), 2.4–2.7 mya (within subgenus *Mus*), 1.4–2.4 mya (within 'mainland Southeast Asian' group), 1.7–2.2 (within 'Indian + Lao/Thai' group), 1.2–1.6 mya (within 'Palearctic' group), and 1.1–1.5 mya (within *M. musculus*). In contrast, the cyt b_{Tv} TSE estimates suggest a more extended time frame, with divergence of the subgenera at 8.1 mya and initial diversification within the subgenus *Mus* at 5.4 mya. However, at the lower end (e.g., speciation within the 'Palearctic' group), the cyt b_{Tv} TSE values are closer to those derived from IRBP and RAG1. This apparent distortion of the cyt *b* timescale and the higher TSE values for the more distant events are clearly a product of the slightly greater degree of saturation of cyt *b* compared with the two nuclear genes. Not surprisingly, TSE estimates based on the combined IRBP + RAG1 + cyt $b_{-3\mathrm{rdTi}}$ data are intermediate between those obtained from the nuclear and mitochondrial genes.

For the older events, the TSE estimates based on the two nuclear genes are probably more reliable. By contrast, the cyt *b*-based estimates are probably more sensitive for the younger evolutionary events. To place these estimates into a geological context, our results suggest the following time frame for key cladogenic events:

(1) initial origin of the genus *Mus* sometime before 5 mya, during the Late Miocene to Early Pliocene;
(2) cladogenesis during the Early Pliocene (ca. 5 mya) to produce the four extant subgenera;
(3) further cladogenesis during the latest Pliocene or earliest Pleistocene to produce the three major lineages within the subgenus *Mus*;
(4) additional speciation in the Southeast Asian and Indian regions during the Early Pleistocene to produce the extant species lineages;

Table 3
Comparison of degrees of averaged genetic distance and its range for various groupings in *Mus* and *Apodemus*

Grouping/clade	Taxa used in pairwise comparison	cyt *b*		IRBP		RAG1		Cyt b_{-3rdTi} IRBP+RAG1	
		$d_{Tv} \times 100$	mya	$d \times 100$	mya	$d \times 100$	mya	$d \times 100$	mya
Murinae	*Apodemus*, *Micromys*, *Mus*, *Rattus*	8.2 (7.5–9.8)	**12**	9.0 (8.5–9.9)	**12**	7.1 (6.0–8.0)	**12**	9.0 (8.3–9.3)	**12**
Mus									
Subgenera	*Coelomys*, *Mus*, *Nannomys*, *Pyromys*	5.5 (4.8–6.0)	8.1	3.9 (3.1–4.8)	5.2	3.0 (2.6–3.3)	5.1	4.9 (4.7–5.1)	6.5
Subgenus *Mus*	Three Species Groups (1, 2, 3)	3.7 (3.5–3.9)	5.4	1.8 (1.7–1.9)	2.4	1.6 (1.4–1.8)	2.7	3.2 (3.1-3.3)	4.3
1. Southeast Asia	*caroli*, *cervicolor*, *cookii*	2.8 (1.8–3.2)	4.1	1.8 (1.2–2.2)	2.4	0.8 (0.4–1.1)	1.4	2.5 (1.9–2.9)	3.3
2. India + Lao	*booduga*, *terricolor*, *fragilicauda*	2.6 (1.8–3.2)	3.8	1.3 (1.2–1.4)	1.7	1.3 (1.2–1.8)	2.2	2.5 (2.4–2.6)	3.3
3. Palearctic	*macedonicus*, *musculus*, *spicilegus*, *spretus*	1.1 (0.7–1.5)	1.6	1.2 (1.1–1.2)	1.6	0.6 (0.0–0.9)	1.1	1.1 (0.5–1.4)	1.5
Subsp. *M. musculus*	*castaneus*, *domesticus*, *musculus*	0.06 (0–0.09)	0.1	0.5 (0.1–0.7)	1.1	0.9 (0.6–1.1)	1.5	0.4 (0.3–0.6)	0.5
Apodemus[a]									
Subgenera	*agrarius*, *argenteus*, *gurkha*, *sylvaticus*	5.9 (5.1–6.6)	8.6	4.8 (4.1–6.1)	6.4				
Subgenus *Apodemus*	*agrarius*, *draco*, *peninsulae*, *speciosus*	4.6 (4.0–4.9)	6.7	3.9 (2.9–4.8)	5.2				
Subgenus *Sylvaemus*	*alpicora*, *flavicollis*, *sylvaticus*, *uralensis*	2.1 (1.7–2.4)	3.1	1.1 (0.9–1.5)	1.5				

Note. The numbers in boldface correspond to the calibration point,12 Myr for the separation between members of Murinae (see Text). d, d_{Tv}: genetic distance in pairwise comparison, with all substitutions and only transversions, respectively. mya, million years ago.

[a] Data were obtained from Serizawa et al. (2000) and Suzuki et al. (2003).

(5) additional speciation with the Palearctic regions during the Early to Middle Pleistocene to produce the extant species lineages; and
(6) differentiation of subspecies lineages in *M. musculus* during the Middle Pleistocene.

4. Discussion

As noted in Section 1, the genus *Mus* is unusual among murine rodents both for its wide geographic distribution, spanning almost the entire Old World region, and for its broad biotopic association, with species found in all major habitat types, especially in the Eurasian region. These observations invite numerous questions regarding the historical biogeography of the genus, especially in regard to its place of origin, the mode and time of its dispersal, and the sequence and timing of ecological transitions. Because our taxon sampling is most complete within the subgenus *Mus*, most of the discussion will pertain to this restricted group. However, our wider results also invite comment on several aspects of the wider evolutionary history of the genus.

4.1. Classification and phylogeny of Mus

To date, 15 of the 39 species of *Mus* have been subject to molecular phylogenetic assessment, under a variety of methods including DNA/DNA hybridization (Chevret et al., 2003) and gene sequence analyses of 12S rRNA (Chevret et al., 2003; this study), 16S rRNA (Auffray et al., 2003; this study), cyt *b* (Lundrigan et al., 2002; this study), Tspy (Schubert et al., 2000), Abpa (Karn et al., 2002), Sry (Lundrigan et al., 2002), B2m (Lundrigan et al., 2002), Zp-3 (Lundrigan et al., 2002), Tcp-1 (Lundrigan et al., 2002), IRBP (this study), and RAG1 (this study).

By far the most complete taxon sampling coverage is available for members of the subgenus *Mus*. Indeed, with the addition of our new sequence data for *M. booduga* and *M. terricolor*, all 11 currently recognized species are represented in at least one molecular dataset. Monophyly of this group is strongly supported by analyses of the two nuclear gene datasets (RAG1 and IRBP; all species except *M. famulus*) but less convincingly so by any of the mitochondrial gene datasets. Lundrigan et al. (2002) similarly found strong support for monophyly of subgenus *Mus* from four nuclear genes (Sry, B2m, Zp-3 and Tcp-1) but poor support at this level from cyt *b* and 12S rRNA datasets. Within this group, the least studied taxon is *M. famulus*, for which DNA/DNA hybridization and 12S rRNA sequence data only are available. As demonstrated by Chevret et al. (2003), both data sets clearly associate *M. famulus* with the subgenus *Mus* rather than with *Coelomys*, as suggested by Marshall (1977). Our analysis of an expanded 12S rRNA dataset further supports this conclusion.

In most previous analyses of molecular data, the subgenus *Mus* has shown a strong bipartite division between a Palearctic group (*M. musculus*, *M. macedonicus*, *M. spicilegus*, and *M. spretus*) and a mainland Southeast Asian group (*M. caroli*, *M. cervicolor*, and *M. cookii*). Recently however, this clear geographic picture was challenged by single-gene analyses of two poorly known Asian species—*M. famulus* from India (Chevret et al., 2003) and *M. fragilicauda* from Thailand (Auffray et al., 2003). In both cases, these taxa appeared to group with the Palearctic group rather than with the geographically more proximate, mainland Southeast Asian group. Our study differs from all previous molecular analyses of Eurasian *Mus* in the inclusion of two species from the Indian subcontinent, *M. booduga* and *M. terricolor*. In addition, we have also produced a much expanded molecular dataset for *M. fragilicauda*, based on a newly discovered population in Laos. This broader taxon sampling has resulted in a significantly different view of interspecific affinities within subgenus *Mus*. In particular, our results suggest that *M. booduga*, *M. terricolor*, and *M. fragilicauda* make up a third, hitherto unrecognized group that is approximately equivalent in rank to the 'Palearctic' and 'Asian' groups of previous authors. This third group probably also includes *M. famulus* and thus equals or exceeds the species diversity found within each of the other two groups.

Although in the Results section we referred to the three groups within the subgenus *Mus* according to geographic origin, the lack of a clear geographic separation between the two Asian groups makes this system of nomenclature cumbersome and imprecise. Accordingly, we would like to propose an alternative nomenclature for what are in reality well-defined 'species groups' within the subgenus *Mus*. We further suggest that these be identified by the earliest named taxon in each group—hence, a *Mus musculus* Species Group for *M. musculus*, *M. macedonicus*, *M. spicilegus*, and *M. spretus*; a *Mus cervicolor* Species Group for *M. cervicolor*, *M. caroli*, and *M. cookii*; and a *M. booduga* Species Group for *M. booduga*, *M. terricolor*, and *M. fragilicauda*. *Mus famulus* is tentatively associated with the *M. booduga* Species Group on the basis of our analysis of the expanded 12S rRNA dataset; however, additional sequence data are needed to test this conclusion.

Relationships among the three Species Groups within the subgenus *Mus* are not unambiguously resolved by our analyses. However, it may be significant that the *M. booduga* and *M. musculus* Species Groups are united (albeit by very short common branches) in four out of five individual gene trees and additionally in the concatenated, multi-gene trees. Although biogeographic pattern in itself cannot be cited as phylogenetic support, the fact that the *M. booduga* and *M. musculus* Species Groups are also geographically proximate is at least consistent with a hypothesis of sibling lineage status.

Taxon sampling within the other subgenera is far less complete. The subgenus *Coelomys* includes four species, *M. pahari*, *M. mayori*, *M. crociduroides*, and *M. vulcani* (Corbet and Hill, 1992; Marshall, 1977). *Mus pahari* has a relatively large distribution through the upland regions of Southeast Asia to southern China, while the other species are endemic to the islands of Sri Lanka, Sumatra and Java, respectively. Only *M. pahari* and *M. crociduroides* have been examined biochemically; our reanalysis of the expanded 12S rRNA dataset confirms monophyly of these taxa, as reported previously by Sourrouille et al. (1995). The subgenus *Pyromys* contains five species, three of them found on the Indian subcontinent (*M. phillipsi*, *M. platythrix*, and *M. saxicola*), one on Sri Lanka (*M. fernandoni*), and one on mainland South East Asia (*M. shortridgei*). Only two species have been subject to molecular assessment (*M. platythrix* and *M. saxicola*); DNA/DNA hybridization and 12S rRNA sequence data demonstrate that these species are close siblings (Chevret et al., 2003). The African subgenus *Nannomys*, with around 19 species, is particularly underrepresented in all molecular analyses. To date, three species have been examined (*M. mattheyi*, *M. setulosus*, and *M. minutoides*), although most studies have included only one or two of these. *Mus setulosus* groups convincingly with *M. minutoides* in analyses of DNA/DNA hybridization data (Catzeflis and Denys, 1992) and with *M. mattheyi* in analyses of 12S rRNA sequence data (Chevret et al., 2003; this study). Poor taxon sampling within subgenus *Nannomys* is particularly regrettable given the well-documented morphological diversity within this group (Petter, 1963; Catzeflis and Denys, 1992).

Poor taxon sampling within each of the subgenera *Coelomys*, *Pyromys*, and *Nannomys* means that monophyly of these lineages cannot be assumed. Nevertheless, the combined body of molecular evidence, including the new evidence presented herein, clearly supports the notion that each of these lineages is well-differentiated, both from the subgenus *Mus* and from each other. In keeping with earlier analyses of DNA/DNA hybridization data (Catzeflis and Denys, 1992; Chevret et al., 2003) and nuclear gene sequence data (Lundrigan et al., 2002), our results also fail to support any particular branching order among the four lineages. For the present, the phylogenetic structure of the genus *Mus* is probably best represented as a multifurcation, with a minimum of four major branches.

4.2. Time and place of origin of the genus Mus

Determining the time and likely place of origin of *Mus* is important as this constrains many of the issues related to its subsequent diversification. We can employ various lines of evidence to this end, including the geographic distribution of major lineages within the genus, direct fossil evidence, including both presence and absence of a taxon at critical time periods, and the geographic distribution of closely related taxa. Molecular clock estimates of key events in the evolution of *Mus*, based on the nuclear genes, can further help to identify the critical time periods for examination of the fossil and palaeoenvironmental records.

Taken at face value, the geographic distribution of subgenera would appear to favour an Asian rather than African origin of *Mus*. Three subgenera (*Mus*, *Coelomys*, and *Pyromys*) are broadly co-distributed in South and mainland Southeast Asia, in contrast to a single subgenus (*Nannomys*) in Africa. However, the dearth of molecular data for *Nannomys* leaves open the possibility that African *Mus* encompass more than one major lineage. In addition, the lack of resolution of the branching order among the major lineages means that the three Asian subgenera together might form a sibling taxon to *Nannomys*.

The fossil record also appears to favour an Asian origin of *Mus*. The earliest named fossil species of *Mus*, *M. auctor* Jacobs, 1978; comes from the Siwalik Hills of Pakistan and is dated to 5.7 mya (Flynn and Jacobs, 1983). However, an earlier form of *Mus* (or a taxon annectant to the genus *Mus*) is present in an older fauna dated to 6.35 mya (Flynn and Jacobs, 1983). The next fossil occurrences of *Mus* come from widely scattered localities of Lower Pliocene age (ca. 5.0–5.5 mya), most notably in Afghanistan (*M. elegans*: Sen, 1993), Turkey, Morocco and Tunisia (Geraads, 1998 and refs. therein). *Mus* is not generally recorded in eastern and southern Africa until late Pliocene times, around 3.0 mya (Catzeflis and Denys, 1992; Geraads, 1998; Sabatier, 1982; Wesselman, 1984). However, a recent review of the Tugen Hills faunas from Kenya appears to document the appearance of *Mus* in this region sometime between ca. 5.5 and 4.5–4.4 mya (Winkler, 2002). This apparent discrepancy highlights the poor state of knowledge of African fossil faunas in the interval between 10 and 5 mya, as emphasised by Catzeflis and Denys (1992). In contrast, Western Europe has a rich and well-studied fossil record of small rodents spanning the entire late Tertiary period (Geraads, 1998; Martín-Suárez et al., 2001; Mein et al., 1990). Hence, there can be no doubt regarding the absence of *Mus* prior to the terminal part of the Early Pleistocene (ca. 1 mya), when *Mus* makes a sudden and brief appearance in southern France (Chaline, 1971). By middle Pleistocene times *Mus* is recorded more widely across Europe. However, the record of *Mus* in many areas is intermittent, perhaps due to episodic range expansion and contraction in association with glacial cycles (Auffray et al., 1990). The earliest record of a modern 'European' species is of *M. spretus* from the Middle Pleistocene (ca. 1 mya) of north Africa (Thaler, 1986).

The phylogenetic position of *Mus* has been subject to considerable uncertainty. DNA/DNA hybridization experiments reported by Catzeflis and Denys (1992) grouped *Mus* closer to the African *Praomys tullbergi* than to species of either *Rattus* of *Apodemus*. Their tree topology and genetic distance estimates, if correct, would effectively constrain the divergence date of *Mus* to within the period 7.2–8.1 mya. Similar results were obtained using DNA/DNA hybridization by each of Chevret et al. (1994) and Ruedas and Kirsch (1997), although the latter used *Myomys* (a member of the *Praomys* group *sensu* Lecompte et al., 2002) and also included a range of Asian and two Australian murines. In contrast, Watts and Baverstock (1994) found evidence in their extensive Microcompliment Fixation dataset for a closer relationship of *Mus* to an essentially Eurasian clade that includes *Rattus* and *Apodemus*, but which excludes *Micromys* and the African murine assemblage.

More recent studies based on DNA sequencing have also produced variable results. Ducroz et al. (2001) analyzed three mitochondrial genes (cyt *b*, 12S rRNA, and 16S rRNA) from 47 murid taxa including 40 murines, among them five *Mus* species. *Mus* was consistently placed as the immediate sister lineage to an endemic and diverse African lineage comprising the otomyins, the arvincathins and a few other genera, but excluding one member of the *Praomys* group. However, statistical support for this relationship was weak at best. Molecular clock estimates, based on a concatenation of all three genes, date 'the split of the "African lineage" from the rest of the Murinae ... (including *Mus*) ... at around 10 Myr ago" (Ducroz et al., 2001, p. 196). Lecompte et al. (2002) likewise were unable to resolve the intergeneric affinities of *Mus* from their extensive cyt *b* dataset. Their estimated substitution rates imply a divergence of *Mus* from all other compared taxa by 11.5 mya at the latest. However, our own cyt *b* results leave us skeptical of the capacity of cyt *b* to recover stable topologies or provide reliable age estimates for such early events, even after removal or down-weighting of saturated codon positions and mutation types. Lecompte et al. (2002) also noted an apparent 'telescoping' of the cyt *b* timeframe within the *Praomys* group, within which cyt *b* divergence estimates are typically double those obtained under DNA/DNA hybridization.

More promising results are coming from analyses of less rapidly evolving nuclear genes such as LCAT (Robinson et al., 1997; Michaux and Catzeflis, 2000), vWF (Michaux et al., 2001,; Jansa and Weksler, 2004), IRBP (DeBry and Sagel, 2001; Jansa and Weksler, 2004; this study) and RAG1 (this study). To date, the IBRP dataset reported by Jansa and Weksler is most extensive, with representatives of 16 murine genera. This dataset "provides convincing evidence that *Mus* is the sister taxon to the *Praomys* group" (Jansa and Weksler, 2004: 271), an endemic African clade consisting of around 34 species usually arranged in six genera. Interestingly enough, the IRBP results suggest that the *Praomys* group is itself somewhat isolated in regard to other African murines, a result that is supported by previous analyses of mitochondrial genes (Ducroz et al., 2001; Lecompte et al., 2002). Although the IRBP results thus point to a connection between *Mus* and an endemic African lineage, they do not preclude the possibility that *Mus* and the *Praomys* Group together represent an 'exotic' element in the African context.

Some additional certainty as to the place of origin of *Mus* can be gained by considering the implications of the combined fossil and molecular evidence. As indicated earlier, our molecular clock estimates based on the IRBP and RAG1 nuclear genes suggest that diversification of the four subgeneric lineages took place in the time period 5.0–5.2 mya. Encouragingly, these estimates fall within the broader time frame of 4.7–5.7 mya as suggested for these events by the DNA/DNA hybridization results (Catzeflis and Denys, 1992). However, what is particularly interesting is the fact that the earliest fossil evidence of the *Mus* lineage in Asia, at 6.35 mya, is significantly older than the likely time of divergence of the modern subgenera, as indicated by the molecular evidence. This discrepancy in age has very different implications for an Asian, as against an African, place of origin. Under an Asian origin, the obvious interpretation would be that *Mus* evolved several million years prior to differentiation of the extant subgenera. Under this scenario, the origin of subgenus *Nannomys* would be linked to dispersal of *Mus* to Africa, followed by subsequent evolution in isolation. By contrast, under an African origin *Mus* would need to disperse to Asia sometime prior to the appearance of *Mus auctor*. Subsequent events would then involve the origin of the subgeneric lineages from a common ancestor, either in Africa or Asia, sometime around 5 mya, with a second episode of dispersal between the two continents. This scenario would also require extinction, on both continents, of any early offshoots of the genus. An Asian origin of *Mus* thus appears a more parsimonious explanation of the available biogeographic, molecular and fossil evidence. This hypothesis would be challenged either by the discovery in Africa of *Mus* fossils significantly predating 5 mya or by the exposure of even greater genetic diversity among the 18 African species of *Mus*.

4.3. Dispersal and biotope transitions in the evolution of Asian Mus

The phylogeny of Asian *Mus* will now be examined against a backdrop of global environmental changes and regional faunal changes, as documented most completely from the remarkable fossil record of the Siwalik Hills (Barry et al., 1995). By so doing, we hope to reveal some of the major extrinsic factors that have driven speciation and ecological diversification within this fascinating genus, and thereby attempt to account for its success. To assist this process, we mapped the contemporary habitat associations of each species onto a 'consensus' phylogeny (Fig. 4).

The earliest fossil occurrences of *Mus* in the Siwalik sequence are associated with the uppermost mammalian faunas of the *Selenoportax lydekkeri* Interval Zone, spanning the period 7.4–5.3 mya (Barry et al., 1985). This faunal zone is characterised by a suite of forest and grassland-adapted taxa that collectively suggest a strongly seasonal environment with a mosaic of forest types, woodland and grassland communities (Quade et al., 1989). The onset of this zone corresponds to a global expansion of C_4 vegetation of which grasses are the predominant group (Pagani et al., 1999).

Although the genus *Mus* clearly evolved against this backdrop of shrinking forests and expanding grasslands, we believe that the earliest species of the genus were most likely denizens of tropical forests, perhaps similar in habitus to the living species of subgenus *Coelomys*. One observation that supports this view is the obviously relictual distribution of the subgenus *Coelomys* itself, with large disjunctions in range between what are essentially mid-altitude to montane forest isolates. This pattern of distribution is common to many archaic or relictual groups of vertebrates through the Asian region (Heaney, 1991). Also important here is the fact that forest-adapted species are present in all three of the other subgenera (*M. fernandoni* and *M. shortridgei* within subgenus *Pyromys*) and in two of the three subgroups within the subgenus *Mus* (*M. famulus* of the *M. booduga* Species Group and *M. cookii* of the *M. cervicolor* Species Group). In further support of this view, we note the relative scarcity of *M. auctor* in the Siwalik fossil record, suggesting its derivation from a restricted or peripheral habitat.

Our molecular estimates of divergence times within *Mus* date the divergence of the extant subgenera to around 5.2–5.0 mya. In the Siwalik record, this corresponds with the start of the *Hexaprotodon sivalensis* Interval Zone (5.3–3.6 mya; Barry et al., 1985). Climatically, this period commenced with a brief but dramatic global cooling, leading to a surge of Antarctic sea ice and a corresponding fall in sea level of at least 50–70 m (Beu and Edwards, 1984). This event had multiple impacts, including the drying of the Mediterranean Basin—the so-called 'Messinian salinity crisis' (Hodell et al., 1986). From the biotic perspective, the lowered sea levels probably stimulated faunal interchange between all major continental areas. Evidence of this is most clearly observed in the African fossil record, with the sudden appearance of several Asian lineages including a hystricid porcupine and representatives of the family Leporidae (Barry et al., 1985; Winkler, 1994). Chevret (1996) postulated the dispersal of several murine lineages (including *Mus*) between Asia and Africa at this time. We concur, and further suggest that intercontinental dispersal of a *Mus* species from Asia to Africa at 5 mya ago, followed by an adaptive radiation, might explain the origin of the subgenus *Nannomys*.

Possible reasons for the divergence of the three Asian subgenera around the same time are less obvious. One possibility, given the current habitat associations of members of each group, is that one or more species of *Mus* underwent a biotope transition from wetter to drier forest types at this time, thereby initiating the divergence of the environmentally more progressive subgenera (*Mus* and *Pyromys*) from the ancestral stock (represented most closely today by *Coelomys*). Alternatively, given the different geographic emphasis of species level diversity between *Pyromys* (mainly Indian subcontinent) and *Mus* (more widespread, but with its highest diversity in Southeast and East Asia), it is possible that divergence of these lineages occurred as a result of vicariance after a phase of dispersal away from an ancestral area. Unfortunately, much of the molecular and fossil evidence that might help us decide between these alternatives is lacking. In particular, it would be useful to know the extent of divergence between *M. shortridgei* of Thailand and the other, exclusively South Asian members of the subgenus *Pyromys*. It is also regrettable that none of the earlier fossil species of *Mus* from India or central Asia have been allocated to a specific subgeneric lineage (Jacobs, 1978; Khotlia, 1992; Patnaik et al., 1993).

The period 5.0–3.9 mya ago was characterised by warm and stable conditions, as indicated by higher sea levels and a reduced rate of sedimentation of aeolian dust in northern China (Qiang et al., 2001). This period also appears to have been a relatively quiescent one in the evolution of *Mus*, with no molecular evidence thus far of any major cladogenic events dating to this period. However, incomplete taxon sampling within *Pyromys* and *Coelomys* leaves this point rather moot.

In the Siwalik record, the next major faunal changes occur around 3.6 mya, as marked by the arrival of *Elephas* from Africa (Agarwal et al., 1993), and 2.6 mya, as indicated by the appearance of *Equus sivalensis* and many other associated taxa (Nanda, 2002). Both transitions represent periods of rapid climatic change with widespread associated environmental consequences. The climatic changes at 3.6 mya correspond to a period of rapid uplift of the northwestern part of Tibet, leading to a significant strengthening of the East Asian monsoon (Qiang et al., 2001), while the changes at 2.6 mya are coeval with the first evidence of continental glaciation in both North America and Patagonia (Shackelton and Hall, 1984). The origin of the species groups within subgenus *Mus* at around 2.4–2.7 mya thus coincides with the more recent of these two periods of faunal turnover in the Siwalik region and with the period of climatic deterioration that presaged the full glacial cycling of the Quaternary period (Beu and Edwards, 1984; Ciesielski and Weaver, 1974).

The geographic ranges of the three species groups within subgenus *Mus* are almost entirely exclusive, focused individually on mainland Southeast Asia (the *M. cervicolor* Species Group), the Indian subcontinent (the *M. booduga* Species Group), and semi-arid to temperate Eurasia (the *M. musculus* Species Group). Given this clear geographic pattern, it seems reasonable to conclude that the species groups originated through a process of range expansion or long distance dispersal of one or more ancestral taxa, followed by range fragmentation and local diversification. As indicated above, these events took place during a period of global environmental instability at the end of the Pliocene and were part of a more general phase of active dispersal and speciation among many unrelated groups of mammals (Barry et al., 1985; Nanda, 2002).

Mus fragilicauda from Thailand and Laos, a member of the *M. booduga* Species Group, provides the only example of geographic overlap between members of two species groups within subgenus *Mus*. Unfortunately, current molecular datasets do not resolve the phylogenetic position of *M. fragilicauda* relative to other taxa of the *M. booduga* Species Group. Accordingly, its biogeographic significance remains uncertain, with two equally plausible scenarios. One is that this taxon originated through secondary expansion of the *M. booduga* Species Group into Southeast Asia. The other is that the Southeast Asian taxon is a vicariant sibling to those found on the Indian subcontinent. Additional molecular analyses and more extensive sampling of the Indian members of this species group are required to decide between these options.

Mus fragilicauda is sympatric in Thailand with *M. cervicolor* and *M. caroli* of the *M. cervicolor* Species Group. Excluding instances involving humanly translocated populations of *M. musculus*, this represents the only documented example of natural sympatry between members of two species groups within the subgenus *Mus*. However, the presence in *M. caroli* of IRBP sequences with close affinity to those of members of the *M. booduga* Species Group may point to past instances of sympatry with associated opportunities for the interspecific genetic exchange. Ancient introgression of this kind is evident in various rodent taxa, including sympatric *Mus* species (*M. musculus* and *M. spretus*) in eastern Europe (Greene-Till et al., 2000) and voles from the Japanese Islands (Iwasa and Suzuki, 2002,). However, the genealogical discordance seen in the subgenus *Mus* also might be attributable to ancestral polymorphism (Avise, 2000).

Across all species groups of subgenus *Mus*, the majority of the currently recognised species lineages appear to date back to the Early Pleistocene (ca. 1.6–1.0 mya) (Chaimanee, 1998; Chaline, 1971; Patnaik, 1990;

Patnaik et al., 1996; Zheng, 1993). Our knowledge of this most recent phase of speciation is most complete for the *Mus musculus* Species Group, based on numerous studies of chromosomes (e.g., Suzuki et al., 1990) and isozymes (e.g., Bonhomme et al., 1984) and multiple gene sequences (e.g., Karn et al., 2002). However, extant populations of *M. caroli* also show comparable levels of intraspecific variation in cyt *b* gene sequences, with apparent geographic structure (Fig. 3B; Terashima et al., 2003), and our limited population sampling for *M. terricolor* and *M. cookii* (data not presented here) also points to significant geographic variation in these taxa. Clearly, much more work on the phylogeography of Asian mice is required to fully document their true diversity and recent biogeographic history.

The pattern and tempo of evolution of the various subspecies of *M. musculus* has attracted intensive study (Boursot et al., 1993). Using the cyt *b* sequences as a basis for age estimation, we suggest that the *M. musculus* radiation commenced around 0.5 mya (Table 2). However, there is considerable disagreement over the subspecies phylogeny as inferred from each of the mitochondrial, IRBP and RAG1 genes. In particular, it appears that *M. musculus* harbors anciently diverged (ca. 1 mya) gene lineages in each of IRBP and RAG1, implying either that *M. musculus* underwent intraspecies differentiation more or less simultaneously with the main episode of speciation of the Palearctic group, or that exchange of genetic material occurred between various taxa of the Palearctic group during the course of evolution. One instance of apparent gene transfer between *M. musculus* and *M. spretus* was reported by Greene-Till et al. (2000).

The 11 species of the subgenus *Mus* are distributed across a wide range of natural biotopes, from wet evergreen forest (*M. famulus* of Sri Lanka) to dry evergreen forest (*M. cookii* of upland areas of mainland Southeast Asian to southern China), grassland under dry dipterocarp and pine forest (*M. cervicolor* and *M. caroli* of lowland to upland Southeast Asia), semi-arid shrubland (*M. musculus* in the Middle East) and cool temperate woodlands, grasslands and steppe of western Europe to northern China (*M. musculus*, *M. macedonicus*, *M. spretus*, and *M. spicilegus*). Most species are regularly encountered in agricultural landscapes, where they can be significant field pests, and several are known only from such contexts (e.g., *M. fragilicauda*, *M. booduga*, and *M. terricolor*). Two or three members of this subgenus are commonly found in regional sympatry and it is not uncommon to find two species living in immediate syntopy (e.g., two or all of *M. cervicolor*, *M. caroli* and *M. fragilicauda*; *M. booduga* and *M. terricolor*).

Our consensus phylogeny suggests that biotope transitions have occurred on multiple occasions within the subgenus *Mus* (Fig. 4). In particular, it seems likely that the transition from forest or woodland to grassland occurred independently within each of the *Mus cervicolor* and *Mus booduga* Species Groups, and possibly also in the *Mus musculus* Species Group. Unfortunately, the circumstances under which these transitions occurred are not obvious in any particular case. In part, this lack of clarity is due to the fact that many members of this group (e.g., *M. caroli*, *M. cervicolor*, *M. booduga*, *M. terricolor* and *M. musculus*) are today found chiefly in anthropogenic contexts and are likely to have expanded their geographic ranges in recent times (Aplin et al., 2003). Various subspecies of *M. musculus* have taken this trend to its zenith and become household pests on a global scale.

The transition from forest to more open habitats including grassland also appears to have facilitated higher levels of regional sympatry within the subgenus *Mus* compared with the other Asian subgenera. Within the *M. cervicolor* Species Group, *M. cervicolor* and *M. caroli* are commonly found together, albeit in the artificial environment of rice fields, with *M. cookii* also found in adjacent upland regions. Within the *M. booduga* Species Group, *M. booduga* and *M. terricolor* occur together in cropping areas and for many years were confounded as a single taxon (Matthey and Petter, 1968). Natural sympatry is also observed within the *M. musculus* Species Group, as various combinations of *M. musculus* and other taxa; a number of hybrid zones are documented in western and eastern Europe (Boursot et al., 1993; Greene-Till et al., 2000; Orth et al., 2002).

4.4. Comparison with *Apodemus*

The only other Eurasian murine taxon that matches *Mus* in terms of species diversity and geographic range is *Apodemus*, the field and wood mice. This genus contains 21 species (Musser et al., 1996), distributed across the cooler temperate regions of Eurasia, from the British Isles to Japan (Corbet, 1978). *Apodemus* is usually divided into three or more subgenera, some of which are treated by some authors as full genera (reviewed by Musser et al., 1996). The phylogeny of *Apodemus* is documented from several of the same genes as used in this study (Chelomina et al., 1998; Michaux et al., 2002; Serizawa et al., 2000), thereby facilitating detailed comparisons of scale and tempo of evolutionary events between the two genera.

The available molecular datasets for *Apodemus* together include 13 of the 21 species. Although no single study has included all of these taxa, by comparing and combining the various trees, it appears that the genus contains from 3 to 5 major species groups. Two of these groups are quite speciose and have discrete geographic ranges that coincide with morphologically defined subgenera – a subgenus *Apodemus* with seven species in East Asia; and a subgenus *Sylvaemus* with 11 species spread across Europe to the Middle East and north Africa (Musser et al., 1996). In contrast, three species appear to represent isolated lineages of an equivalent degree of molecular divergence to the major clades—*A. gurkha* from Nepal, *A. mystacinus* from southeast Europe to the Middle East (subgenus *Karstomys*) and *A. argenteus* from Japan. The level of molecular differentiation is very unequal between the two major groups. For example, Serizawa et al. (2000) reported interspecific divergences (Kimura *d*) for IRBP of $d = 0.0294$ to 0.0498 within the subgenus *Apodemus* (their *Agrarius* group) compared with $d = 0.0088$ to 0.0105 within the subgenus *Sylvaemus* (their *Sylvaticus* group). The level of divergence for IRBP between the five separate lineages was reported as $d = 0.0368$ to 0.0611.

Our previous estimates of divergence times within *Apodemus* (Serizawa et al., 2000; Suzuki et al., 2003) were based on a suite of outgroup comparisons for IRBP that included a set of pairwise comparisons with *Tokudaia*. Here, we have excluded the *Tokudaia* comparisons because they seem anomalously high in comparison with the other outgroups (*Apodemus*, *Micromys*, and *Rattus*) and lead to elevated estimates of divergence times. The new estimates suggest an initial radiation of major lineages within *Apodemus* at 6.4 mya, the divergence of modern species lineages within the subgenus *Apodemus* at around 5.2 mya, and divergence within the subgenus *Sylvaemus* within the last 1.5 mya (Table 3).

The *Apodemus* and *Mus* radiations clearly differ in several important respects. The most obvious difference concerns the greater time depth of the initial subgeneric radiation—here estimated at around 6.4 mya within *Apodemus* compared with only 5 mya within *Mus*. However, an even more striking contrast concerns the antiquity of the cladogenic events leading to extant species. Within subgenus *Apodemus*, the average 'age' of an extant species is about 5.2 million years. In comparison, the average age of extant species in the subgenus *Mus* is 2.5 million years for members of the *M. cervicolor* Species Group, 1.7 million years for members of the *M. booduga* Species Group and 1.6 million years for members of the *M. musculus* Species Group. The latter values compare closely with the estimate of 1.5 mya for the origin of extant species lineages within the subgenus *Sylvaemus*. This coincidence in time raises the possibility of common causes; however, what these might be remains hidden in the still obscure environmental history of the Early Pleistocene of Europe and the Middle East.

Other notable differences between the two genera include the more restricted biotopic range of *Apodemus* compared with *Mus*, and the generally lower sympatric diversity of *Apodemus*. All *Apodemus* species inhabit broad-leaf forests and woodlands of the Temperate Zone of the Palearctic region (Corbet, 1978). This ancient biotope contains many relictual floristic elements carried through from Miocene times or earlier. *Apodemus*, with its obvious long history of association with the broad-leaf forests and a fossil record dating back as far as the early Vallesian (Martín-Suárez and Mein, 1988), might also be regarded as a relictual genus, despite the evidence for continued speciation through the late Tertiary.

The lack of ecological differentiation within *Apodemus* contrasts sharply with the high biotopic diversity within the genus *Mus* and its subgroups. This points to a fundamental difference between the two genera in the likely causes of speciation in each genus. In *Apodemus*, speciation presumably occurred primarily as a result of the large-scale expansion and contraction of forest and woodland habitats, leading to allopatric speciation in isolated populations. Some speciation also may have occurred on islands. For example, Japan today hosts three different species of *Apodemus*, two of which are endemic and were presumably derived from two separate invasions. In contrast, speciation within *Mus* appears to have occurred partly as a consequence of long distance dispersal and/or vicariance (e.g., the origin of *Nannomys*), but more often through a process of biotope transitions. Indeed it is tempting to speculate that the propensity of members of the genus *Mus* to undergo biotopic transitions is the primary factor behind both its rapid and extensive geographic expansion and its high species diversity.

As a secondary consequence, the greater ecological breadth within *Mus* probably explains the unusually high level of regional and local diversity within the genus. For example, in upland habitats of mainland Southeast Asia we find as many as five species of *Mus* in regional sympatry, with *M. cookii*, *M. pahari* and *M. shortridgei* in forest habitats, and *M. cervicolor* and *M. caroli* in grassland and agricultural land. In contrast, regional diversity in *Apodemus* is usually limited to two or sometimes three co-occurring species (e.g., Michaux et al., 2001).

5. Conclusion

A variety of palaeontological, molecular, and biogeographic evidence points to an Asian origin of the genus *Mus*, most likely in the time interval 7–6 mya. The ancestor of the endemic African subgenus *Nannomys* probably entered Africa during a brief but dramatic episode of sea level depression at 5.2 mya. The subsequent radiation among Eurasian *Mus* can be explained by a three phase radiation involving: (1) divergence of the three Eurasian subgenera around 5.2 mya, probably related to as yet unspecified vicariant events affecting an essentially forest-dwelling suite of small-bodied murines; (2) divergence of three geographically discrete species groups (Europe, South Asia, Southeast Asia) within the subgenus *Mus* around 2.7–2.4 mya, probably in response to climatic deterioration and instability at the very end of the Tertiary; and (3) cladogenesis leading to the extant species, mainly during the Early Pleistocene and in the context of glacial cycling (ca. 1.6–1.0 mya). Biotope transitions from wet to seasonally dry, monsoonal forests, and from these to more open habitats including tropical grasslands and temperate steppe, have occurred several times within each subgenus, and independently in at least two of the three species groups within subgenus *Mus*. Thus, in Eurasia, a complex two phase cladogenic history in largely discrete geographic 'cradles', coupled with a propensity for biotope transitions, has lead to a moderately high total diversity and an unusually high regional diversity with common instances of 2–4 species sympatry. This later factor distinguishes *Mus* from *Apodemus*, another regionally speciose murine genus that shows higher total diversity but lower regional and sympatric diversity.

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Phylogenetic relationships and divergence times of the genus *Tokudaia* within Murinae (Muridae; Rodentia) inferred from the nucleotide sequences encoding the Cyt*b* gene, RAG 1, and IRBP

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Abstract: The phylogenetic relationships of six genera of Murinae (*Apodemus*, *Diplothrix*, *Micromys*, *Mus*, *Rattus*, and *Tokudaia*) were examined using the nucleotide sequences for the mitochondrial cytochrome *b* (Cyt*b*), as well as the nuclear recombination activating gene 1 (RAG1) and interphotoreceptor retinoid-binding protein (IRBP), with special emphasis on the position of the genus *Tokudaia*, which is endemic to the Ryukyu Islands. Compared with Cyt*b* at all codon positions, the first and second codon positions of Cyt*b*, RAG1 (1002 base pairs (bp)), and IRBP (1586 bp) sequences were less prone to saturation. Close affinity between the genera *Tokudaia* and *Apodemus* was observed in the analyses using the IRBP (1586 bp) and combined nuclear (2588 bp; RAG1 + IRBP) sequences. The divergence time for the *Tokudaia*–*Apodemus* clade was estimated at approximately 6.5–8.0 Ma, which is more recent than previously reported, thereby indicating the recent colonization of the Ryukyu Islands by the genus *Tokudaia*. The other relationships among the main genera were highly ambiguous, owing either to saturation or insufficient phylogenetic information. The radiation of the main genera within a relatively short period of evolutionary time may explain the unresolved topologies, although molecular sources that are less subject to saturation are required to resolve the outstanding issues.

Résumé : L'étude des séquences de nucléotides codant pour le cytochrome *b* (Cyt*b*) mitochondrial, ainsi que les séquences nucléaires du gène 1 de l'activation de la recombinaison (RAG1) et de la protéine liant le rétinol entre les photorécepteurs (IRBP), nous a permis d'examiner les relations phylogénétiques de six genres de Murinae (*Apodemus*, *Diplothrix*, *Micromys*, *Mus*, *Rattus* et *Tokudaia*) avec une attention particulière pour *Tokudaia* qui est endémique aux îles Ryukyu. Par comparaison avec Cyt*b* à toutes les positions du codon, les premières et secondes positions du codon des séquences Cyt*b*, RAG1 (1002 paires de bases (pb)) et IRBP (1586 pb) sont moins sujettes à la saturation. Les analyses basées sur les séquences IRBP (1586 pb) et les séquences nucléaires combinées (2588 pb; RAG1 + IRBP) font ressortir la forte affinité entre les genres *Tokudaia* et *Apodemus*. Le moment de la divergence du clade *Tokudaia*–*Apodemus* est estimé à environ 6,5–8,0 Ma, donc plus tardivement que ce qui a été signalé antérieurement, ce qui indique que la colonisation des îles Ryukyu par le genre *Tokudaia* est récente. Les autres relations entre les genres principaux sont très ambiguës, soit à cause de la saturation, soit par manque d'information phylogénétique. La radiation des genres principaux sur une période relativement courte de temps évolutif peut vraisemblablement expliquer les topologies encore irrésolues; il faudra des sources moléculaires moins sujettes à la saturation pour résoudre les questions encore en suspends.

[Traduit par la Rédaction]

Introduction

The Murinae subfamily includes 529 species (Musser and Carleton 1993) within the family Muridae, which also includes the highest percentage (60%) of species within the order Rodentia (Denys 1999). Therefore, the Murinae subfamily contributes significantly to the prominent diversification of the order within eutherian mammals. Numerous phylogenetic studies have been carried out to clarify the evolutionary history of rodent diversification at various levels. Recent molecular phylogenetic analyses have shed light on this issue (Huchon et al. 1999, 2002; Michaux and Catzeflis 2000; Serizawa et al. 2000; Suzuki et al. 2000, 2003; Adkins et al. 2001, 2003; DeBry and Sagel 2001; Michaux et al. 2001, 2002; DeBry 2003). However, these assessments have focused mainly on the phylogenetic relationships among higher taxa, such as among the families within Rodentia (Huchon et al. 1999, 2002; Adkins et al. 2001, 2003; DeBry

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Table 1. Species in the family Muridae examined in this study.

			Accession numbers		
Subfamily	Species	Source (specimen No.)[*]	Cyt*b*	RAG1	IRBP
Cricetinae	*Mesocricetus auratus*	Experimental animal (HS650)	AF119265[†]	AB164039[‡]	AB164047[‡,§]
Murinae	*Apodemus semotus*	Taiwan (HS2)	AB033694[§]	AB164040[‡]	AB032862[‡,§,‖]
	Apodemus sylvaticus	Leiden, Germany (HS1290)	AB033695[§]	AB164041[‡]	AB032863[‡,§,‖]
	Diplothrix legata	Amamiooshima Island, Japan (HS1163)	AB033696[§]	AB164042[‡]	AB033706[‡,§]
	Micromys minutus	Shizuoka Prefecture, Japan (HS1148/KT3068)	AB033697[§]	AB164043[‡]	AB033710[‡,§,‖]
	Mus caroli	Syuri, Okinawa Island, Japan (HS1587)	AB033698[§]	AB164044[‡]	AB033707[‡,§]
	Mus musculus	From DNA database	AB033699[§]	AB125833[¶]	AF126968[‡,#]
	Rattus norvegicus	Miyazaki, Japan (HS131/KT2830)	AB033713[‖]	AB164045[‡]	AB033709[‡,§]
	Tokudaia osimensis	Amamiooshima Island, Japan (HS1162)	AB033703[§]	AB164046[‡]	AB033712[‡,§,‖]

Note: Cyt*b* is the mitochondrial cytochrome *b*; RAG1 is the nuclear recombination activating gene 1; and IRBP is the interphotoreceptor retinoid-binding protein.

[*] Serial numbers of DNA stored by H. Suzuki and skin specimen stored by K. Tsuchiya (Tokyo University of Agriculture).

[†] Conroy and Cook (1999).

[‡] New DNA databank of Japan/European Molecular Biology Laboratory/GenBank accessions numbers from this study.

[§] Suzuki et al. (2000).

[‖] Serizawa et al. (2000).

[¶] Suzuki et al. (2004).

[#] Stanhope et al. (1992).

and Sagel 2001; DeBry 2003), and among the subfamilies within Muridae (Michaux and Catzeflis 2000; Michaux et al. 2001), or among closely related taxa, such as among the species within a given genus (Serizawa et al. 2000; Michaux et al. 2002; Suzuki et al. 2003). Thus, it seems highly appropriate to examine the phylogenetic relationships among the genera of the subfamily Murinae, which have been largely ignored to date, to better understand the evolutionary diversification of rodents.

The subfamily Murinae consists of more than 100 genera and the exact relationships among them have rarely been examined, with a few exceptions (Martin et al. 2000; Suzuki et al. 2000; Michaux et al. 2002). Of these studies, the phylogenetic relationships among six genera of the subfamily Murinae from the Old World (i.e., *Apodemus*, *Diplothrix*, *Micromys*, *Mus*, *Rattus*, and *Tokudaia*) were assessed based on the 782 base pair (bp) nuclear sequence of the interphotoreceptor retinoid-binding protein (IRBP) and the 1140-bp sequence of the mitochondrial cytochrome *b* (Cyt*b*) gene, with special emphasis on the phylogenetic position of the genus *Tokudaia* Kuroda, 1943 (Suzuki et al. 2000), which comprises a single extant species, *Tokudaia osimensis* (Abe, 1933), that is endemic to the Ryukyu Islands in southern Japan. Suzuki et al. (2000) suggested that the genus *Tokudaia* diverged from the other murids at around 12 Ma (Mega annum), which represents a period of radiation of the major murid lineages (Jacobs and Downs 1994). Nevertheless, unambiguous assignment of the relationships among the main genera have proven difficult owing to the high level of saturation of the Cyt*b* sequences seen in comparisons of diverged lineages and to the relatively short length (782 bp) of the IRBP sequences, which provides little phylogenetic information. Although Michaux et al. (2002) recently showed a close relationship between the genera *Tokudaia* and *Apodemus* based on the sequences of the nuclear IRBP gene (782 bp) and two mitochondrial genes (Cyt*b*: 971 bp; 12S rRNA: 904 bp), the support values were low or moderate.

Recent phylogenetic studies that have focused on multiple nuclear sequences have resolved some of the problematic associations among other mammalian taxa. The extended IRBP and recombination-activating gene 1 (RAG1) sequences are effective tools for various phylogenetic analyses (Stanhope et al. 1992, 1996; Springer et al. 1997, 1999, 2001; Jansa and Voss 2000; Serizawa et al. 2000; DeBry and Sagel 2001; Murphy et al. 2001*a*, 2001*b*; Huchon et al. 2002; Sato et al. 2003, 2004; Suzuki et al. 2003), since both of these sequences are less subject to problems of saturation (Sato et al. 2004), thereby justifying the estimated divergence times among higher taxa. In this study, we present the phylogenetic relationships among six genera of the subfamily Murinae, with special emphasis on the phylogenetic position and divergence time of the genus *Tokudaia*, using the mitochondrial Cyt*b* and the nuclear RAG1 and IRBP sequences.

Materials and methods

Samples and DNA sequencing

The species examined in this study are listed in Table 1. The polymerase chain reaction (PCR) and direct-sequencing of the RAG1 and IRBP genes were performed according to previously described methods (Serizawa et al. 2000; Suzuki et al. 2000; Sato et al. 2003, 2004). The sequences of Cyt*b* of *Mesocricetus auratus* (Waterhouse, 1839), RAG1 of *Mus musculus* L., 1758, and IRBP of *Mus musculus* were obtained from the DNA databank of Japan (DDBJ) / European Molecular Biology Laboratory (EMBL) / GenBank nucleotide databases (Table 1). In this study, we used previously reported Cyt*b* (1140 bp) and IRBP (782 or 1152 bp) sequences. We determined additional regions of the IRBP gene that corresponded to nucleotides 1531–1800 (Fong et al. 1990), using the primer pair +IRBP1327 (5′-CTGGACCTCCAGAAGCTGAGAATAGGCCAGT-3′) and –IRBP1801 (5′-ACCACCCCACCCCCCAGCCAGGCCTCACCGTG-3′). For *Mesocricetus auratus*, *Diplothrix legata* (Thomas, 1906), *Mus caroli* Bonhote, 1902, and *Rattus norvegicus* (Berkenhout, 1769), the part of the IRBP gene that corresponded to nucleotides 336–724 (Fong et al. 1990) was also determined, using the primer pair R + IRBP335 and U – IRBP734 (Serizawa et al. 2000; Sato et al. 2003, 2004). Since a 3-bp fragment of IRBP (site 429–431 in the human reference sequence; Fong et al. 1990) was absent from all of the subfamily Murinae examined, this fragment was excluded from the *Mesocricetus auratus* sequences for our phylogenetic analyses. The nucleotide sequences reported in this paper appear in the DDBJ, EMBL, and GenBank nucleotide sequence databases under the accession numbers listed in Table 1.

Saturation analyses

The level of saturation was assessed within a parsimonious framework for four data sets ((1) Cyt*b*, all sites; (2) Cyt*b* excluding the third codon sites; (3) RAG1, all sites; and (4) IRBP, all sites) using the method described by Hassanin et al. (1998) in which the slope of the linear regression between the observed and inferred substitutions that were used to realize the saturation was determined from the amount of homoplasy.

Reconstruction of phylogenetic trees

Outgroup

Suzuki et al. (2000) used *Glirulus japonicus* (Schinz, 1845) and *Cricetulus griseus* Milne-Edwards, 1867 as outgroups. However, as Michaux et al. (2002) pointed out, the genus *Glirulus*, which represents the family Gliridae, is distantly related to the the subfamily Murinae (DeBry and Sagel 2001; Adkins et al. 2003; DeBry 2003), making it an inappropriate outgroup. In this study, we used *Mesocricetus auratus* as the outgroup, based on phylogenetic hypotheses that have been addressed in recent studies (DeBry and Sagel 2001; Adkins et al. 2003) in which the species within the subfamily Cricetinae are more closely related to the subfamily Murinae than species within the family Gliridae.

Separate analyses

Trees were reconstructed using the neighbor-joining (NJ; Saitou and Nei 1987), maximum-parsimony (MP; Swofford and Olsen 1990), and maximum-likelihood (ML; Felsenstein 1981) methods, with the separate Cyt*b* (Cytb_{all}; 1140 bp), Cyt*b* excluding the third codons (Cyt$b_{\text{-3cp}}$; 760 bp), RAG1 (1002 bp), and IRBP (782 and 1586 bp) data sets, using PAUP* version 4.0b10 (Swofford 2001). For the NJ analyses, the distances were calculated using the substitution model that was inferred via the hierarchical likelihood-ratio test as implemented in Modeltest version 3.06 (Posada and Crandall 1998). The optimal parameters and selected model are listed in Table 2. For the MP analyses, 100 heuristic searches were conducted with the tree-bisection reconnection option in which the input order of the taxa is randomized. All of the MP analyses were based on equally weighted nucleotide substitutions. The ML analyses used the same parameters and models as for the NJ analyses, and 10 heuristic searches were conducted for each data set with the tree-bisection reconnetion option.

Statistical reliability was evaluated using nonparametric bootstrap resampling analyses (BS; Felsenstein 1985), thereby generating 1000 random replicates for the NJ, MP, and ML analyses. In addition, the decay index (Bremer 1988,

Table 2. The models and the parameters estimated by the hierarchical likelihood-ratio test with Modeltest version 3.04 (Posada and Crandall 1998).

		Base frequencies (%)					Rate matrix elements								
	Model	A	C	G	T	ti/tv*	rAC	rAG	rAT	rCG	rCT	rGT	Γ-shape†	Pinvar‡	Model source
Cyt*b*	TrN + I + G	34.8	30.9	9.1	25.2	—	1.00	4.27	1.00	1.00	23.23	1.00	0.77	0.52	Tamura and Nei 1993
Cyt$b_{\text{-3cp}}$	HKY + I + G	25.3	25.5	16.6	32.6	3.02	—	—	—	—	—	—	2.05	0.77	Hasegawa et al. 1985
RAG1	K80 + G	25.0	25.0	25.0	25.0	3.46	—	—	—	—	—	—	0.31	—	Kimura 1980
IRBP															
782 bp	HKY + G	20.0	31.0	27.8	19.2	2.68	—	—	—	—	—	—	0.21	—	Hasegawa et al. 1985
1586 bp	HKY + I + G	19.6	31.3	29.4	19.7	2.84	—	—	—	—	—	—	0.65	0.44	Hasegawa et al. 1985
RAG1 + IRBP	HKY + I + G	0.22	0.29	0.28	0.21	3.01	—	—	—	—	—	—	0.73	0.44	Hasegawa et al. 1985

Note: Cyt$b_{\text{-3cp}}$ is the Cyt*b* excluding the third codon; TrN is Tamura and Nei; I is the proportion of invariant sites; HKY is Hasegawa, Kishino, and Yano; and K80 is Kimura. Refer to Table 1 for the definitions of the other terms.

*Ratio of transition (ti) to transversion (tv) rate.

†Shape parameter of the discrete Γ distribution to accommodate rate variation among sites.

‡Proportion of invariant sites.

Table 3. Sequence composition statistics at different codon positions for the Cyt*b*, RAG1, and IRBP fragments from the nine murids

	Cyt*b* (1140 bp)				RAG1 (1002 bp)			
Parameter	First	Second	Third	Total	First	Second	Third	Total
Length (base pairs)	380	380	380	1140	334	334	334	1002
Number of variable sites	103 (23.0)	18 (4.0)	327 (73.0)	448	22 (12.2)	8 (4.4)	151 (83.4)	181
Number of informative sites	58 (18.6)	8 (2.6)	245 (78.8)	311	4 (5.8)	1 (1.4)	64 (92.8)	69
Mean frequency of A	29.8	20.5	43.2	31.2	28.7	33.5	18.7	27.0
Mean frequency of C	24.4	24.2	33.0	27.2	20.7	21.4	27.5	23.2
Mean frequency of G	22.0	13.0	2.9	12.6	31.7	17.6	29.6	26.3
Mean frequency of T	23.8	42.4	21.0	29.1	18.9	27.4	24.1	23.5

Note: Values in parentheses are percentages.

1994), which represents the number of extra steps that are required to make a clade collapse, was calculated for the MP trees using TreeRot version 2b (Sorenson 1999).

Combined analyses

Combined analyses were conducted after concatenating RAG1 and IRBP into a 2588-bp tandem alignment. Combining methods are often used to increase phylogenetic information at the risk of producing false hypotheses by combining two sequences with different histories. Before combining the two data sets into a single analysis, the incongruence length difference test, which is also called the partition homogeneity test (Mickevich and Farris 1981; Farris et al. 1995), was performed to test the significance of incongruence between the data sets. In addition to the algorithms that were used for the separate analyses, we introduced Bayesian analyses (BA; Huelsenbeck et al. 2001) for the combined data. The posterior probabilities were approximated using 10 000 trees that were sampled from 1 000 000 generations using the Metropolis Coupled Markov Chain Monte Carlo algorithm with MrBayes version 3 (Ronquist and Huelsenbeck 2003). HKY (Hasegawa et al. 1985) + I + G was applied for the model of character substitutions to calculate likelihood during the course of the method, and the uniform prior distributions were used for the topology, shape parameter of discrete Γ distribution (0.1–50), and the proportion of invariant sites (0–1). The prior transition/transversion rate ratio and the base frequencies were based on the flat Beta and Dirichlet distributions, respectively. In summarizing the trees in the approximated posterior distribution, a 50% majority rule consensus tree was reconstructed for the sampled trees, the first 1000 samples of which were discarded as samples in the burn-in period. Four independent Metropolis Coupled Markov Chain Monte Carlo runs started simultaneously from randomly chosen trees.

Nodal evaluation was performed as in the separate analyses. The partitioned decay index (Baker and DeSalle 1997) was used to evaluate the contribution of each data partition to the maximum-parsimonious tree summarized, and caution was exercised with respect to the numbers of the most parsimonious trees, a focal node of which is collapsing, in line with the recommendation of Lambkin et al. (2002) regarding the use of these methods. Clade stability was also evaluated with the posterior probabilities (PP) in the Bayesian analyses.

Dating divergence events for the murid taxa

Divergence times were estimated by assuming a constant rate of molecular change over time (i.e., the molecular-clock hypothesis; Zuckerkandle and Pauling 1965). The gene-specific rates of nucleotide substitution were calibrated using the fossil-based time estimate for the *Mus–Rattus* split (12–14 Ma; Jacobs and Downs 1994) and the average genetic distances of *Rattus norvegicus* to either *Mus musculus* or *Mus caroli*, as inferred from the model selected via the hierarchical likelihood-ratio test. The divergence times were calculated separately based on the gene-specific rates for the Cytb_{all}, Cyt$b_{-3\text{cp}}$, RAG1, and IRBP (782 and 1586 bp) sequences.

Results

Nucleotide variation

Heterozygotic sites were found in individuals of *Apodemus semotus* Thomas, 1908 (IRBP, two sites; RAG1, two sites), *Apodemus sylvaticus* (L., 1758) (IRBP, one site), *Mus caroli* (IRBP, one site), and *Rattus norvegicus* (IRBP, one site). These polymorphic sites were treated as missing sites for the phylogenetic analyses. The sequence composition statistics for the data sets examined are listed in Table 3. The null hypothesis for homogeneity in base composition across the murid taxa was not rejected using the χ^2 test for IRBP and RAG1 ($P > 0.05$), but was not valid for Cyt*b* ($P = 0.0006$), mainly owing to the biased base frequencies of the third codon positions among the murid taxa with GC contents that ranged from 24.2% (*Apodemus semotus*) to 48.7% (*Tokudaia osimensis*).

Saturation levels

None of the homoplastic substitutions that were noted in the phylogeny of the examined taxa would delineate a linear regression with a slope of 1 (i.e., $y = x$). Although there were many homoplastic sites in the Cyt*b* sequences (Fig. 1*a*), only the first and second sites were less subject to saturation (Fig. 1*b*). The RAG1 and IRBP sequences also had the less homoplasious slope (Fig. 1*c*, 1*d*).

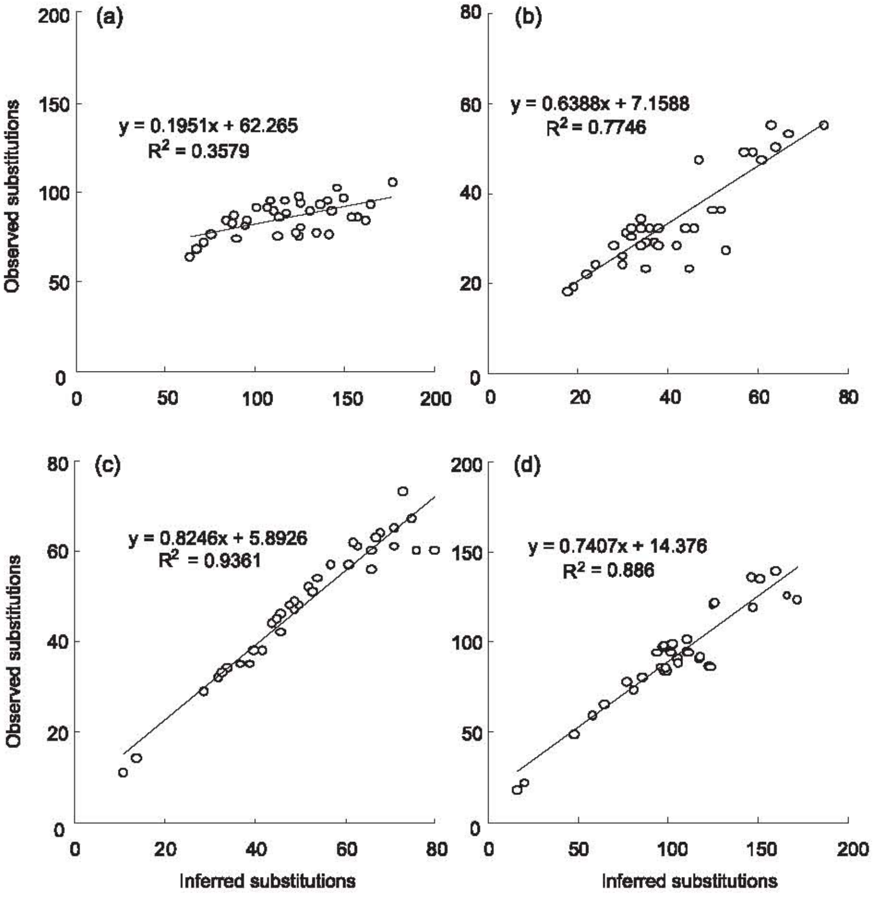
Phylogenetic tree reconstructions

Separate analyses

Notwithstanding the less homoplasious property represented by the Cyt$b_{-3\text{cp}}$ or RAG1 analyses, no relationships among the major murid genera were strongly supported. The only relationship retrieved was the close affinity between the genus *Tokudaia* and the clade encompassing the two *Apodemus* species using the extended IRBP sequences (1586 bp) sampled.

IRBP (782 bp)				IRBP (1586 bp)			
First	Second	Third	Total	First	Second	Third	Total
261	261	260	782	529	528	529	1586
29 (17.8)	14 (8.6)	120 (62.6)	163	59 (16.7)	35 (9.0)	259 (73.4)	353
12 (14.4)	6 (7.2)	65 (78.3)	83	26 (14.4)	14 (7.8)	140 (77.8)	180
20.9	25.0	15.4	20.4	20.3	26.0	13.0	19.7
26.5	26.6	35.9	29.6	30.3	25.2	37.3	30.9
41.0	18.9	33.8	31.2	36.6	18.7	33.6	29.6
11.6	29.5	15.0	18.7	12.8	30.2	16.1	19.7

Fig. 1. Comparisons of the numbers of inferred and observed substitutions among eight murid taxa and one outgroup (i.e., cricetid) under the maximum parsimonious framework for (*a*) all of the codon positions in the mitochondrial cytochrome *b* (Cyt*b*), (*b*) first and second codon positions in Cyt*b*, (*c*) nuclear recombination activating gene 1 (RAG1), and (*d*) interphotoreceptor retinoid-binding protein (IRBP) sequences. The approximated regression lines are delineated for the scatterplots of each analysis with the coefficient of determination (R^2).

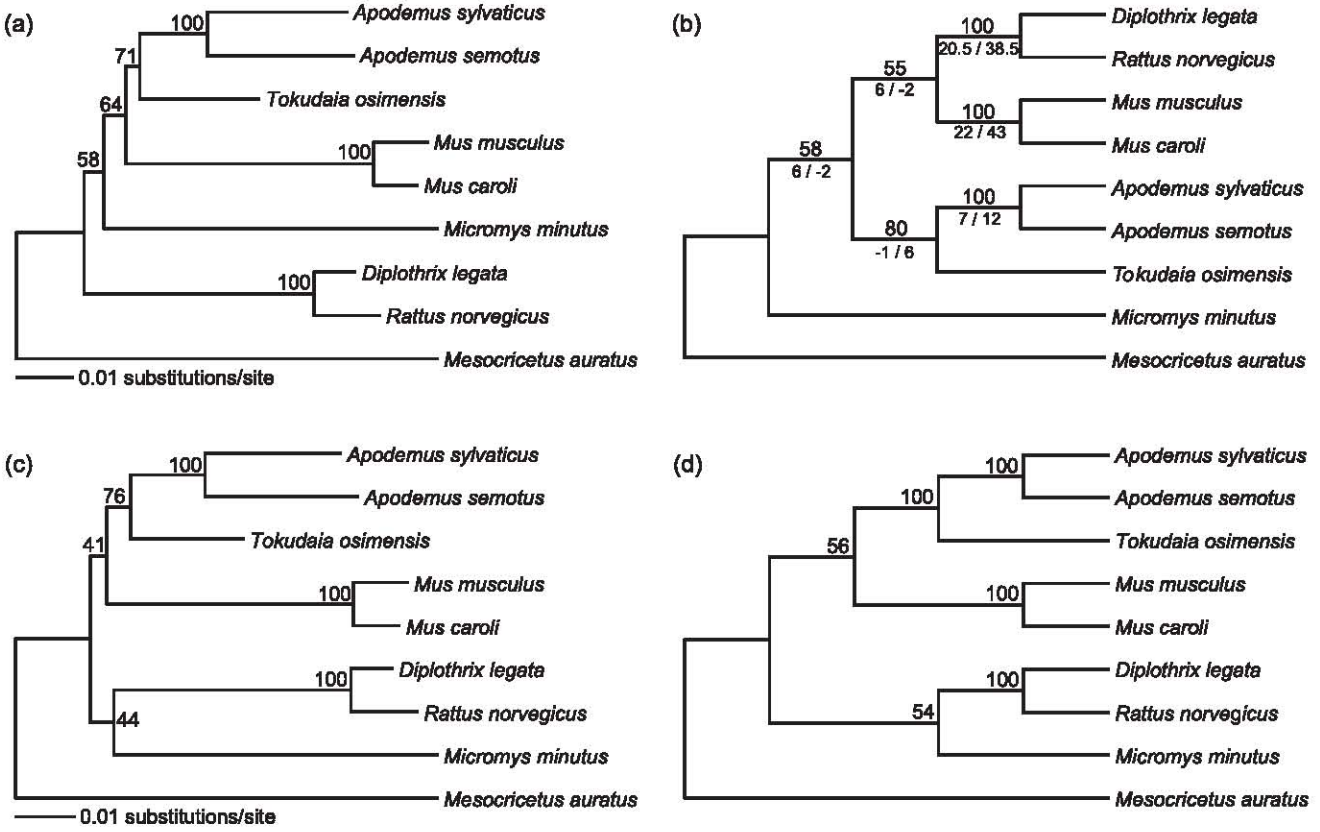


with low to high support values (figures not shown; NJ BS, MP BS / decay index, and ML BS values of 69, 87/5, and 82, respectively).

Combined analyses (IRBP + RAG1, 2588 bp)

The results of 1000 replicates of the incongruence length difference test did not reject homogeneity of the data sets (P = 0.34), which indicates congruence in the phylogenetic signals of the two nuclear genes. The trees that were inferred from the NJ, MP, ML, and BA analyses gave consistent support, with moderate to high reliability, to the monophyly of the genera *Mus* (NJ BS, MP BS / decay index, ML BS, and BA PP values of 100, 100/65, 100, and 100, respectively) and *Apodemus* (100, 100/19, 100, and 100, respectively), and the close relationships between the genera *Rattus* and *Diplothrix* (100, 100/59, 100, and 100, respectively) and between the genera *Tokudaia* and *Apodemus* (71, 80/5, 76, and 100, respectively) (Figs. 2*a*–2*d*). The phylogenetic relationships among these lineages were ambiguous in all of the analyses, which indicates that different topologies with low levels of reliability were produced. Nevertheless, the genus *Mus* consistently occupied a position of close affinity to the

Fig. 2. Phylogenetic relationships among eight murid taxa with an outgroup that is inferred from the combined data set (2588 bp; 1002-bp RAG1 and 1586-bp IRBP). The methods used to reconstruct the phylogenetic trees were as follows: the neighbor-joining method with distances inferred using the HKY + I + G model (*a*); the maximum-parsimony method with equal weighting for all positions (*b*); the maximum-likelihood method with the HKY + I + G model (*c*); and the Bayesian method with the prior model and the parameters described in the text (*d*). The bootstrap scores, which are expressed as percentages of 1000 replicates, are given in support of the adjacent nodes. For the maximum-parsimony analyses, the decay indices are listed under each branch, and the contributions of each data set are measured by partitioning the decay index for each node. The numbers to the left and right of the solidus represent the contributions of RAG1 and IRBP, respectively. The sum of each value from each data set is the decay index for the clade.



Apodemus–Tokudaia clade in the NJ, ML, and BA analyses (NJ BS, ML BS, and BA PP values of 64, 41, and 56, respectively). According to the partitioned decay index for each data partition, derived from the decay index attached to each node of the MP tree, the stability of the *Tokudaia–Apodemus* clade is based mainly on the contribution of the sites in the IRBP gene (1586 bp). Although the two most parsimonious trees that were observed for the tree collapsed in terms of the close affinity of the genera *Rattus* and *Diplothrix* or the monophyly of the genus *Mus*, the problem of averaging these decay indices, as suggested by Lambkin et al. (2002), was not crucial in terms of the interpretation of these values for the phylogenetic trees in this study.

Divergence time

The divergence times for the *Tokudaia–Apodemus* clade were inferred from the separate Cytb_{all}, Cyt$b_{\mathrm{-3cp}}$, RAG1, and IRBP (782 and 1586 bp) sequences, based on the paleontological estimate of 12–14 Ma for the *Mus–Rattus* dichotomy (Jacobs and Downs 1994). The estimate that was derived from the Cytb_{all} sequences was higher than that obtained from the other data sets. Of the remaining data sets, the divergence times inferred from the RAG1 and IRBP (1586 bp) data were more recent than those from the Cyt$b_{\mathrm{-3cp}}$ and IRBP (782 bp) data (Table 4).

Table 4. Genetic distances and divergence times (Mega annum (Ma)) inferred from all data sets.

	*Mus–Rattus**	*Tokudaia–Apodemus*
Cytb_{all} (1140 bp)	0.932 (12–14 Ma)	0.877 (11.3–13.2 Ma)
Cyt$b_{\mathrm{-3cp}}$ (760 bp)	0.083 (12–14 Ma)	0.055 (8.0–9.3 Ma)
RAG1 (1002 bp)	0.078 (12–14 Ma)	0.045 (6.9–8.1 Ma)
IRBP (782 bp)	0.113 (12–14 Ma)	0.076 (8.1–9.4 Ma)
IRBP (1586 bp)	0.126 (12–14 Ma)	0.068 (6.5–7.6 Ma)

*Calibration point.

Discussion

Outgroups, saturation, and other factors that affect phylogenetic analyses

Changing the outgroup did not markedly affect the results, as pointed out by Michaux et al. (2002) in which the major relationships among the murid lineages could not be resolved in separate analyses. Furthermore, the results show that the first and second codon positions in the Cyt*b*, RAG1, and IRBP sequences are less prone to saturation than the complete Cyt*b* sequence using all of the codon positions. However, the phylogenetic relationships at the generic level among the murid taxa, inferred separately from Cytb_{-3cp} or RAG1, could not be resolved (data not shown), probably owing to insufficient phylogenetic information. By contrast, the extended IRBP sequences (1586 bp) demonstrated the close relationship of the *Tokudaia–Apodemus* clade consistently, with relatively high reliability. There were fewer informative sites in the Cytb_{-3cp} or RAG1 sequences within a parsimonious framework than in the extended IRBP sequences (Table 3). Therefore, our findings indicate that the data set needed to resolve phylogenetic relationships among the murid taxa should contain as many informative sites as possible and should include characters that are less subject to saturation.

Phylogenetic position and time scale for the genus *Tokudaia*

Tokudaia osimensis, which represents the genus *Tokudaia*, appears to be the closest relative of the genus *Apodemus*, with relatively high support in the MP and ML analyses of the extended 1586-bp IRBP sequences, and with high posterior probability in Bayesian analyses of the combined sequences (2588 bp). These results corroborate the hypothesis of Michaux et al. (2002) and the paleontological view of Kawamura (1989), who was the first to note the close relationship between the genera *Apodemus* and *Tokudaia* based on molar morphology. The relationships between the genus *Tokudaia* and the other murid species could not be resolved from the topologies that were inferred from the Cytb_{all}, Cytb_{-3cp}, and RAG1 analyses, probably owing to the severe saturation of the Cytb_{all} sequences and insufficient information on the Cytb_{-3cp} or RAG1 sequences. The divergence times for the *Tokudaia* and *Apodemus* clades were inferred using 12–14 Ma for the *Mus–Rattus* split (Jacobs and Downs 1994), although the estimates varied dramatically according to the data sets used. The severe saturation in the Cytb_{all} data set could be one cause of the observed variability in that the genetic distances for the calibration point, the *Mus–Rattus* split, are likely underestimated by multiple substitutions that cause homoplasies. This type of underestimation would lead to an overestimation of the divergence time for the younger clade. Conversely, the data sets that were less prone to saturation produced estimates of divergence time that were relatively more recent than that produced by the Cytb_{all} data set. The estimates derived from the Cytb_{-3cp} and IRBP (782 bp) data sets suggested divergence times for the *Tokudaia–Apodemus* split of 8.0–9.3 and 8.1–9.4 Ma, respectively, which were consistent with the estimate of 9.6 Ma that Michaux et al. (2002) proposed using Cyt*b* sequences. In contrast, the RAG1 and IRBP (1586 bp) sequences gave more recent divergence times of 6.9–8.1 and 6.5–7.6 Ma, respectively. Based on the difference between the estimates for the two different IRBP data sets, it seems unlikely that substitutions are distributed uniformly within the sequences. The estimates derived from the RAG1 sequences were highly consistent with those derived from the IRBP (1586 bp) sequences; neither of these sequences is strongly affected by saturation, which suggests that the estimate of 6.5–8.0 Ma for the divergence time of the *Tokudaia–Apodemus* clade is probably accurate. The biased distribution of substitutions that was observed in the two different lengths of IRBP indicates the risk associated with using a small gene sequence to estimate divergence times.

The different lines of evidence presented here contradict the hypothesis of Suzuki et al. (2000) that the colonization of the Ryukyu Islands of Japan by the genus *Tokudaia* was coordinated with the radiation of the main genera within the subfamily Murinae, and Michaux et al. (2002) also disputed the date of this event. It appears that colonization by the genus *Tokudaia* occurred more recently than previously thought. In addition, during the period after the colonization of small isolated islands, the genus *Tokudaia* may have developed intrinsic morphological characteristics, such as hard spiny hairs, and evolved odd chromosome numbers (Honda et al. 1977, 1978; Tsuchiya et al. 1989) and odd arrangements of the sex chromosome (Arakawa et al. 2002), which may have enabled its endemicity.

Phylogenetic implications for the history of the subfamily Murinae

Whereas the phylogenetic associations for closely related taxa were retrieved with high reliability, those above the generic level were highly ambiguous, which is consistent with previous reports (Martin et al. 2000; Suzuki et al. 2000; Michaux et al. 2002). To date, three molecular markers (the mitochondrial Cyt*b*, 12S ribosomal RNA, and nuclear IRBP (782 bp)) have been used to elucidate these relationships, although none of these sequences has produced an unambiguous resolution. Therefore, the cause of the unresolved relationships has been ascribed to radiation among the murid genera, which occurred within a short period of evolutionary time. The newly determined RAG1 sequences provide no resolved topologies, and have short interior branches relative to the branches that lead to the terminal taxa (data not shown), as observed for topologies that have been inferred from other data sets. The discrepancies in the partitioned decay indices that have been assigned to associations above the level of the main genera provide additional evidence for unresolved topologies. These lines of evidence strengthen the notion of radiation. However, the extended IRBP (1586 bp) sequences produced topologies showing close affinity of the *Tokudaia–Apodemus* clades and relatively recent estimates of divergence time, which suggests that additional characters may help to resolve highly confused relationships. Despite the apparently confounding results, a close affinity was observed between the genus *Mus* and the *Tokudaia–Apodemus* clade in the combined NJ, ML, and BA analyses of the nuclear genes, which is consistent with the results of Michaux et al. (2002). The genus *Micromys* has often been connected to the *Rattus–Diplothrix* clade (all analyses for the Cyt*b* sequences, NJ analysis for RAG1, and ML or BA analysis for the combined nuclear sequences), which is inconsistent with the findings of Michaux et al. (2002) who positioned the genus *Micromys* in the outgroup position relative to the other genera. Interestingly, the model-based analyses of combined data, ML or BA, of the two nuclear gene sequences present a consistent clade arrangement, as observed in topologies that have been inferred from the mitochondrial gene sequences, in which the close affinities between the genus *Mus* and the *Tokudaia–Apodemus* clade and between the genus *Micromys* and the *Rattus–Diplothrix* clade are supported by the combined mitochondrial Cyt*b* and 12S ribosomal RNA gene sequence data sets (Michaux et al. 2002). Although the support values for these associations are very low, this topology is a good candidate to test, using characters from other sources.

In summary, we demonstrated a sister-lineage relationship, with high confidence, between *Apodemus* and *Tokudaia* and present an estimate of relatively recent divergence of these genera. The phylogenetic relationships among the *Apodemus–Tokudaia* clade, *Micromys*, *Mus*, and the *Rattus–Diplothrix* clade remain to be resolved. Although more informative markers that are less prone to saturation are needed to assess the softness or hardness of this type of polytomy, the possibility of coincidental radiation of these four lineages is worthy of consideration.

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3. Collaborative study

(2)

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

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Ici Piter Kulu
Chartina Pidjath
Erry Purnomo
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Suhardi

Genetic variation in yield and its components amongst 71 South Kalimantan local rice varieties tested on acid-sulfate soil

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We have previously demonstrated that local varieties commonly used in South Kalimantan have obvious yield advantages over IR64, a modern improved variety at multiple sites differing in soil acidity in South Kalimantan. Farmers in South Kalimantan plant a number of different local varieties, or at least varieties with different names. To utilize local rice germplasms in the future breeding program, genetic variation in yield and its components amongst local varieties need to be known. We therefore conducted a field trial using 71 local varieties collected at farmers' fields in South Kalimantan on acid sulfate soil at Balandean.

Materials and methods

Seventy-one local varieties listed in Table 1 were collected from major rice growing regions in South Kalimantan. Seedlings were grown in a local Banjareese way; Seed were sown in October on upland field conditions. About one-month seedlings were transplanted to lowland nursery and grown for about two months. The second transplanting was in January and the final transplanting to the main paddock was April. The experimental design was a Randomized complete block with three replicates, the size of each plot being 2 x 3 m. Plant spacing was 25 cm x 25 cm (16 hills/m^2) and no fertilizers nor lime were applied. At maturity 72 hills avoiding edge rows were collected and yield and its components were determined. Paddy yield is expressed on a 14 % moisture content basis.

Results

As shown in Table 1, large genotypic variation existed in yield and its components, which were highly significant. More than a 3-fold difference was observed in paddy yield, the average being 162 g m^{-2}. A similar magnitude of variation was observed in spikelet number per panicle, panicle and spikelet density and percentage of ripened grain, suggesting that genetic variation in yield resulted from almost all yield components excepting single grain mass. The frequency distributions of yield and its components indicated that while yield, panicle density, spikelet density, spikelet number per panicle and aboveground biomass showed a bell-shaped near-symmetric distribution, percent ripened grain and harvest index

Table 1. Yield and yield componets of 71 rice cultivars tested at Balandean, South Kalimantan in 2003. Values are means of three replicates.

No.	Variety	Yield (g/m2)	Panicle density (/m2)	Spikelets/ panicle	Spikelet density (/m2)	% Ripened grain	Single grain wt. (mg)	Biomass (g/m2)	Harvest index	Plant height (cm)	Panicle length (cm)
1	siam penengah	200	111	114	12604	79	20.3	426	0.40	101	24.0
2	siam puntal	181	109	138	14976	66	18.2	423	0.37	109	23.4
3	siam sabar	91	93	127	11624	41	18.2	362	0.21	104	23.2
4	siam halus	149	99	84	8369	85	21.4	303	0.43	102	28.6
5	siam perak	154	93	125	11329	67	19.3	364	0.35	106	24.9
6	siam brandal	235	117	134	15484	81	18.5	510	0.40	119	22.6
7	siam perak halus	140	99	88	8448	79	21.0	283	0.43	95	23.4
8	siam karang dukuh kuning	228	127	115	14658	77	20.5	545	0.36	118	25.9
9	siam ganal	167	97	92	8853	70	26.9	346	0.41	102	23.1
10	siam perak ganal	171	107	74	7737	78	28.2	355	0.42	116	26.5
11	siam adus	144	95	86	8089	89	20.2	297	0.42	107	25.6
12	lakatan gadur	140	106	79	8404	63	25.7	386	0.31	106	24.3
13	lakatan putih	201	167	62	10336	73	26.8	525	0.33	101	24.8
14	bayar pahit	125	104	61	6432	73	26.3	378	0.28	106	24.6
15	lemo kwatik	209	101	110	11103	63	28.8	548	0.32	120	26.2
16	pandak putih	126	80	105	8998	46	28.6	388	0.25	112	26.4
17	bayar papuyu	151	83	139	11618	58	22.3	418	0.31	110	25.8
18	siam sebelas	170	115	107	12338	77	18.1	342	0.43	95	22.6
19	lakatan siam	124	127	72	9165	53	24.2	416	0.25	101	25.2
20	siam suruk	169	110	88	9659	79	22.3	335	0.43	105	22.6
21	siam palas	246	105	134	14283	75	22.6	517	0.40	120	25.8
22	siam unus	226	136	122	17045	71	18.1	484	0.39	114	22.8
23	siam unus putih	144	72	154	10547	76	17.6	319	0.38	113	24.4
24	siam rendah	159	130	67	8764	87	21.0	332	0.41	98	23.6
25	siam kretek	95	101	100	10166	54	17.0	335	0.24	102	22.9
26	pandak arjuna	145	92	105	9607	73	20.5	312	0.40	98	23.1
27	siam ubi	142	130	79	10301	80	17.3	352	0.35	94	20.5
28	siam birik	105	109	72	8311	66	18.5	362	0.23	96	21.5
29	siam putih	156	139	104	14764	68	15.9	444	0.30	98	23.7
30	lemo putih	88	114	143	16458	31	17.2	406	0.18	89	20.6
31	Siyam Wol	85	68	116	7927	47	23.1	352	0.21	108	25.8
32	siyam pandak	173	110	100	11142	69	21.8	398	0.36	95	24.6
33	pandak kambang	113	118	58	6902	70	23.4	339	0.28	83	21.5
34	siyam babirik	224	135	105	14549	69	21.8	489	0.38	105	24.8
35	pandak manggar	169	111	84	9267	74	25.4	410	0.36	88	24.8
36	jurut	201	114	111	12672	71	22.2	536	0.32	118	26.6
37	siam karang dukuh	121	95	83	7922	72	21.3	363	0.29	107	26.6

Table 1. continued.

No.	Variety	Yield (g/m2)	Panicle density (/m2)	Spikelets/ panicle	Spikelet density (/m2)	% Ripened grain	Single grain wt. (mg)	Biomass (g/m2)	Harvest index	Plant height (cm)	Panicle length (cm)
38	siyam kalubut	223	128	109	13730	85	19.2	534	0.36	123	27.1
39	siyam lantik putih	175	112	85	9648	90	20.0	334	0.45	99	26.5
40	lakatan pacar	172	114	107	12285	78	17.8	395	0.37	104	26.1
41	siyam lantik merah	132	107	99	10594	60	20.7	360	0.31	101	26.0
42	pandak	265	110	131	14373	85	21.5	544	0.42	100	27.0
43	lakatan hirang	181	114	79	8992	79	24.6	405	0.37	106	22.5
44	siyam pontianak tinggi	214	105	124	12960	76	21.8	453	0.40	103	27.2
45	siyam teladan	189	143	97	13793	76	18.0	427	0.38	96	23.4
46	ketut	134	116	120	14031	61	15.9	416	0.27	89	21.3
47	siyam unus kuning	191	112	112	12386	84	18.4	404	0.41	106	24.5
48	siyam gampal	177	104	103	10575	84	19.9	403	0.38	102	23.6
49	siyam px	170	153	87	13226	68	19.3	486	0.30	102	23.3
50	siyam arjuna	133	82	111	9345	80	18.7	287	0.40	97	22.8
51	siyam karta	186	133	111	15381	63	19.0	543	0.29	104	23.7
52	siyam rendah putih	130	80	94	7448	78	22.0	262	0.43	104	25.0
53	pal 6	134	131	81	10822	60	20.5	403	0.27	97	22.0
54	pal 11	197	147	84	12383	84	19.1	448	0.37	106	23.7
55	lakatan	133	122	65	7924	68	24.8	329	0.35	93	23.9
56	raden rata	175	96	121	11899	83	17.3	391	0.38	107	23.8
57	kawi	223	137	114	15639	90	15.9	444	0.43	101	23.7
58	siyam puntal	234	128	114	14913	81	18.8	518	0.39	105	22.7
59	siyam kuning rendah	162	116	78	9025	83	21.4	339	0.41	101	24.9
60	perak	187	134	85	11323	89	18.7	387	0.42	95	22.3
61	pandak kembang	110	108	85	8848	57	21.8	357	0.27	87	22.1
62	palun	136	113	140	15946	50	16.2	408	0.28	115	24.1
63	Siyam Rata	133	108	82	8812	85	17.7	276	0.41	92	20.9
64	Bayar Palas	73	102	83	8823	49	18.5	312	0.19	97	23.9
65	Unus Orgnik	169	103	121	12424	76	17.9	357	0.41	105	24.4
66	Siyam Pontianak Halus	133	90	95	8564	85	18.0	272	0.42	98	23.0
67	siyam pangling	111	79	87	6678	88	18.9	233	0.41	103	22.2
68	siyam tanggung	206	152	98	15034	73	18.6	485	0.36	109	27.0
69	unus gampa	137	99	110	10961	72	17.3	316	0.37	102	23.2
70	adil kuning	177	101	126	12789	69	20.1	376	0.40	105	24.6
71	siam cantik	146	105	71	7491	87	22.0	346	0.36	106	23.8
	Analysis of varaiance										
	Variety	***	**	***	***	***	***	**	***	***	***

*** and ** indicate significant differences between varieties at the 0.1, 1 and 5 % probability levels, respectively.

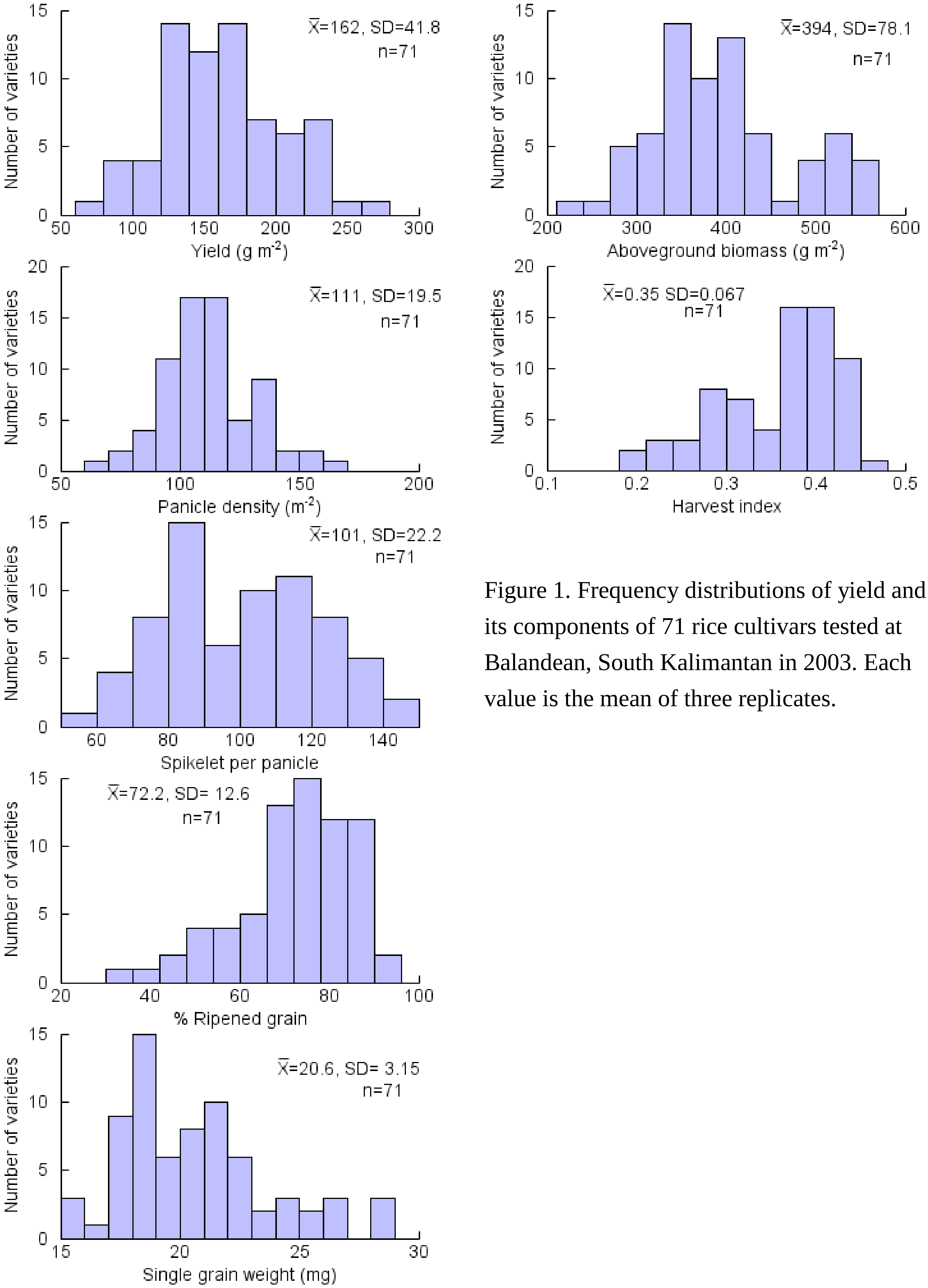

Figure 1. Frequency distributions of yield and its components of 71 rice cultivars tested at Balandean, South Kalimantan in 2003. Each value is the mean of three replicates.

Table 2. Correlation matrix among yield and yield componets of 71 rice cultivars tested at Balandean, South Kalimantan in 2003. Mean values for each variety were used for calculation (df=69).

	Yield	Panicle density	Spikelets/ panicle	Spiklet density	% Ripened grain	Single grain weight	Biomass
Panicle density	0.47 ***						
Spikelets/panicle	0.29 *	-0.27 *					
Spiklet density	0.61 ***	0.48 ***	0.70 ***				
% Ripened grain	0.52 ***	0.14 ns	-0.23 ns	-0.11 ns			
Single grain mass	0.03 ns	-0.13 ns	-0.42 ***	-0.49 ***	-0.11 ns		
Biomass	0.73 ***	0.58 ***	0.33 **	0.72 ***	-0.08 ns	0.09 ns	
Harvest index	0.58 ***	0.02 ns	0.01 ns	0.02 ns	0.86 ***	-0.05 ns	-0.12 ns

***, ** and * indicate significant linear association between two variables at the 0.1, 1 and 5 % probability levels, respectively. ns, not significant.

showed a skewed distribution to the right. These traits are highly dependent on grain set, which is highly sensitive to a number of environmental stresses including drought and extreme temperatures. Some varieties might be more susceptible to those stresses than others or flowered too late to have encountered dry season during the grain filling period.

Paddy yield was highly correlated with all the yield components excepting single grain mass (Table 2). Both sink size represented by spikelet density and grain set capacity represented by % ripened grain are the factors for yield variation, but slightly higher coefficient of the former indicates that sink size variation had a stronger effect on yield variation than did grain set.

We conclude that gain yields of South Kalimantan varieties when grown on acid sulfate soils are highly variable amongst genotypes. All yield components excepting single grain mass were the sources of variation. Further research is needed to understand the critical traits that cause this variability.

Acknowledgement

We thank the Research Institute for Agriculture in Swampy Areas their technical supports of field management.

Growth phenology and photosynthetic traits of tree species native to peat-swamp forests

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Introduction

For reforestation of intensively disturbed sites in peat-swamp areas in Central Kalimantan, it is necessary to understand ecological and silvicultural traits of tree species and to select the suitable species. In the previous planting tests in a disturbed peat-swamp site, *Shorea balangeran* is recognized to be most suitable for the reforestation. In this study, we examined the growth phenology and photosynthesis of some tree species native to peat-swamp forests in Palangka Raya region.

Methods

We examined the height growth and dynamics of the number of leaves of seedlings planted in a disturbed site located near the border between Palangka Raya and Kapuas regions. The planting was established in December 2003, and heights and the number of leaves of seedlings were measured monthly. Employed tree species were *Dyrospherus* sp., *Palaquium leiocarpum*, *Dyera lowii*, Jambu Mente (local name) and *Shorea balangeran*. We also examined diameter growth of natural trees in Kalanpangan area. Dendrometers (diameter band) were set up at 1.3m-high on 40 trees of 14 species in late-November 2003, and diameter growth was measured monthly.

For the measurement of photosynthesis, we used seedlings nursed in the campus of UNPAR. Those seedlings grew with sufficient irrigation and shading. Photosynthesis was measured using LI-6400 (Li-Cor, US).

Results and Discussion

I. *Growth phenology of trees*

1) *Height growth and dynamics of the number of leaves of seedlings planted in a disturbed peat-swamp site*

Fig. 1 shows the mean height and the mean number of leaves of planted seedlings in 2004. In the measurement, a starting month was Dec. 2003. Initial mean heights and survival rates were variable among the species, mean height increased from the beginning of rainy season (October 2004). The number of leaves per seedling decreased after the planting in dry season, but also increased from Oct. 2004. The height growth and leaf production probably occur with the start of rainy season.

2) *Diameter growth phenology of trees in a natural forest*

Fig. 2 shows the diameter growth of natural trees. In Fig. 2, *Cratoxylon arborescens*, *Palaquium leiocarpum*, *Shorea teysmaniana* and *Calophyllum* sp. are shade-intolerant species, and *Dyera lowii*, *Dyrospherus* sp., *Shorea balangeran*, *Compretocarpus rotundatus* and *Tristaniopsis stellata* are shade-tolerant species. Trees of the highest diameter growth in each species are shown in Fig. 2. All of trees were not overtopped by surrounding trees. Diameter growth in 2004 ranged 4 to 19 mm, and was not so large. Diameter growth occurred with the start of rainy season (Oct. 2004). Similar to the height growth of planted seedlings (Fig. 1), the diameter growth of natural trees occurred in the rainy season.

We concluded that tree growth in peat-swamp forests occurs in the early period of rainy season.

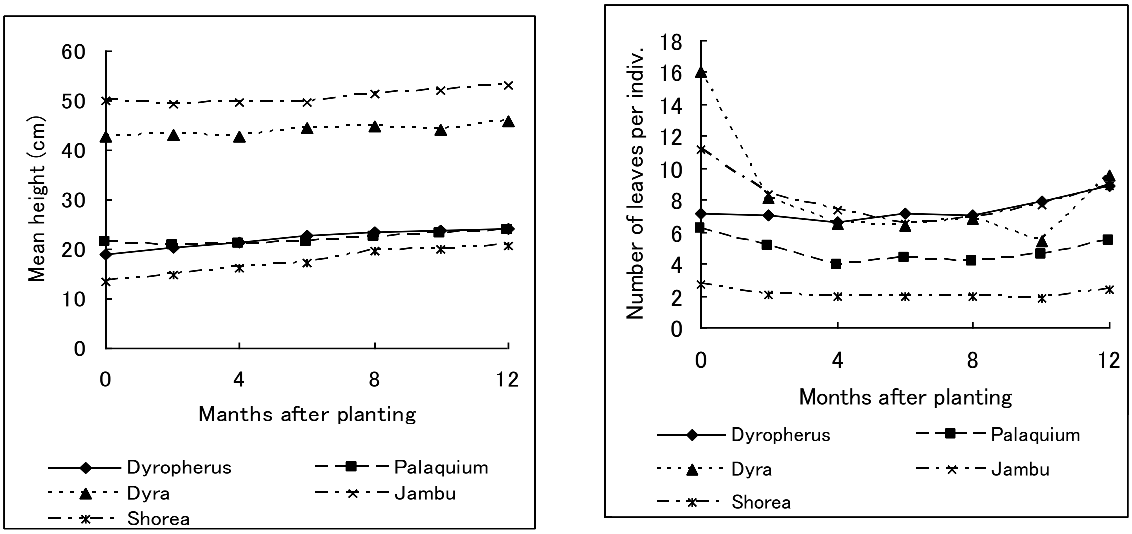

Fig.1. Mean height (left) and the number of leaves per seedlings (right)

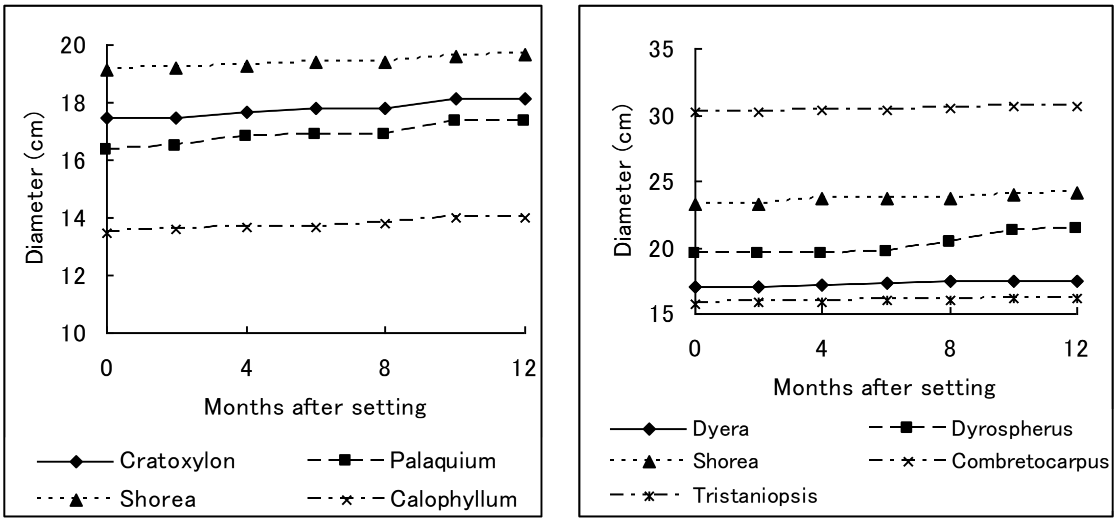

Fig. 2. Diameter of shade-intolerant (left) and shade-tolerant species (right)

II. *Photosynthetic traits*

Table 1 shows photosynthetic traits of seedlings of 4 species nursed in the UNPAR campus. Net CO_2 assimilation rate in Table 1 is the light-saturated photosynthesis and ranged from 3.8 to 6.7 μmol m^{-2} sec^{-1}. In our measurement of the photosynthesis, *Shorea balangeran* was the highest (9.3±1.7 µmol m^{-2} sec^{-1} at 33-35 °C). Photosynthesis of tree species native to peat swamp forests is generally small (range: 2.7-9.3 µmol m^{-2} sec^{-1}). Tree species having relatively high photosynthetic capacity (>6 µmol m^{-2} sec^{-1}) are *Palaquium leiocarpum* (local name: Hangkang), *Combretocarpus rotundatus* (Tumih) and *Shorea balangeran* (Balangeran).

Table 1 Ecophysiological parameters of leaf in Hangkang, Pisangpisang, Ramin and Jeltung seedlings grown in a nursery.

	Palaquium leiocarpum	*Mezzettia sp.*	*Gonystillus bancanus*	*Dyera lowii*
Sample number	4	4	5	1
Leaf mass per area (g m^{-2})	93.0 ± 5.3	79.8 ± 6.8	86.1 ± 14.4	43.1
Nitrogen content (g m^{-2})	1.14 ± 0.10^{a}	0.82 ± 0.10^{a}	1.54 ± 0.26^{b}	0.97
Net CO_2 assimilation rate (µmol CO_2 m^{-2} s^{-1})	6.7 ± 0.3^{a}	5.9 ± 1.9^{ab}	3.8 ± 1.1^{b}	4.6
Transpiration rate (mmol H_2O m^{-2} s^{-1})	1.2 ± 0.2	1.0 ± 0.5	0.8 ± 0.4	0.6
Stomatal conductance (mol H_2O m^{-2} s^{-1})	0.087 ± 0.016	0.078 ± 0.037	0.056 ± 0.025	0.048
Water use efficiency (A_{net}/Tr)	6.0 ± 1.5	6.1 ± 1.4	4.9 ± 0.9	8.2
Nitrogen use efficiency (µmol CO_2 g N^{-1})	5.8 ± 0.3^{ab}	7.5 ± 3.2^{a}	2.5 ± 0.6^{b}	4.7

The relative value of daily sum of photosynthetic photon flux density in the nursery was 17% to open site.
The measuring conditions of photosynthetic photon flux density, leaf temperature, leaf-to-air water vapor pressure deficit, CO_2 concentration were 1500 µmol m^{-2} s^{-1}, 30-33 °C, 1.0-1.5 kPa and 360 ppm, respectively.
Different superscripts indicate significant differences among Hanglkang, Pisangpisang and Ramin (Scheffe's test, $p < 0.05$).

Mycorrhizal symbiosis in several plant species grown in peat soil farmland and peat swamp forest of Central Kalimantan

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1. Ectomycorrhizal sporocarps occurrence on peat swamp forest

Mycorrhizal symbiosis plays many important roles in tree growth and survival. In the tropical forest, many tree species have mycorrhizal relationships with arbuscular fungi. But ectomycorrhizal associations are formed by Dipterocarpaceae and Myrtaceae species which have economically importance. However little is known about ectomycorrhiza forming fungal species in the tropical forest. The purpose of this investigation is to clarify sporocarpus occurrence pattern and species abundance of ectomycorrhizal fungi associated with dominant tree species.

Six fixed plots (2m x 2m) were established in the Tangkiling arboretum. Sporocarpus occurrences were recorded every 10 days from the beginning of rainy season to the end of dry season. Sporocarpus specimen were collected and identified according to morphological characteristics. After morphological observation, specimens were dried in 50C oven, and stored in the decicator.

Table: Plot profiles

Plot No.	Soil pH	Tree species
1	3.24	Nyatoh (*Palaqium* sp.), Meranti (*Shorea* sp.)
2	3.15	Unknown
3	3.01	Tempudan (*Dipterocarpus bornensis*), Balangeran (*Shorea balangeran*) Rambai (*Baccaurea bracteata*)
4	3.50	Balangeran, Jambu-jambuan (*Syzygium* sp.), Medan (*Litsea firma*), *Garcinia* sp., *Timonius* sp.
5	3.13	Balangeran
6	3.82	*Ficus* sp., Medan, Johor (*Cassia sianea*), Sungkai (*Peronema conescens*)

Fourteen species of ectomycorrhizal sporocarps were occurred on the forest floor. The occurrence of sporocarps were centered in the beginning and end of the rainy season (December and March). *Scleroderma* spp, *Russula* spp, *Geastrum* sp.*Boletus* sp.*Cantharellus* sp.*Amanita* sp. *Laccaria* sp. and *Xerocomus* sp. were identified. Most abundant species were *Scleroderma* spp.. *Scleroderma* spp. were observed mainly on plot 3,5 and 6 where soil surface condition were relatively dried, not only in rainy season but also in dry season. According to the dominancy in each plots and occurrence points, *Shorea balangeran* was supposed to be a host of *Scleroderma* spp.

Table: Ectomycorrhizal sporocarps recorded on the arboretum

No	Species	Total
1	*Scleroderma* spp	60
2	*Russula* sp	32
3	*Russula rosaceae*	10
4	*Geastrum* sp.	10
5	*Boletus* sp.	6
6	*Cantharellus* sp.	5
7	*Amanita* sp.	5
8	*Laccaria* sp.	3
9	*Xerocomus* sp.	2
10	Unknown 1	2
11	Unknown 2	4
12	Unknown 3	3
13	Unknown 4	7
14	Unknown 5	2

2. Propagation of arbuscular mycorrhizal inoculum

Arbuscular mycorrhizal fungi are usually propagated by growing them with a living host plant in soil pot cultures, which consist of soil, spores, root pieces and hyphal fragments. The inoculum can be used for pot or farm culture experiments. We had isolated 6 strains of arbuscular mycorrhizal fungi (*Glomus clarum*, *Gigaspora* sp. *Entrophospora* sp., *Glomus* sp., *Glomus* sp.ZEA and *Glomus* sp.ACA) from peat soil of Central Kalimantan. To evaluate ability for plant growth promotion, the 6 isolated strains were propagated by pot cultures. *Pueraria javanica* was used as host plant, and they were propagated in zeolite as a carrier matrix.

No.	Name of isolate	Spores in 50 g zeolite	Spores in 1 g zeolite	AM colonization
1.	*Glomus clarum*	507.2	10.44	78
2.	*Gigaspora* sp	97	1.94	92
3.	*Entrophospora* sp	664.4	13.28	86
4.	*Glomus* sp	1052.8	21.05	77
5.	*Glomus* sp. ACA	160.6	3.33	100
6.	*Glomus* sp ZEA	53.4	1.068	98

Inoculation tests were performed for *Aquilaria malacensis* (gaharu), *Dyera lowii* (jeluton), *Azadirachta indica* (neem), *Aloevera sinensis* (aloe) and *Paraserianthes falcataria* (LEGUMINOSAE). Dual inoculation with free living nitrogen-fixing bacteria were tested for *Leucaena leucocephala* (LEGUMINOSAE), *Swietenia macrophylla* (mahogany). Biomass, colonization rate and NP contents will be measured after cultivation in glasshouse.

3. Seedling propagation

A lot of tree seedlings are required for the field-planting test and reforestation activities. It is difficult to get and store seeds of several kinds of tree species. Therefore cutting propagation is important method to provide tree seedlings continuously. More than 1000 seedlings of *Palaquim* sp. (hangkang), *Dyospiros* sp. (urinpahe), *Shorea balangelan* (kahui) and *Callophylum* sp. were propagated in the nursery, and planted on sabangau area.

Annual Report of Soil Research Group

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1. Visit from Japan to Indonesia in 2004

September 20 to October 1: Investigation in Kalampangan zone
December 7 to December 10: Attendance in Human Dimension workshop
February 17 to February 28: Investigation in Kalampangan zone

2. Summary of research

The study has been partly supported by a Global Environment Research Program, Ministry of Environment, Japan (No. S2-3a) in 2004.

1) Impact of agriculture and forest fire on CH_4 and N_2O fluxes from tropical peat soil in Central Kalimantan, Indonesia

The tropical peatland is important for net carbon (C) storage in the global land surface, but it is also believed to be a major emission source of CH_4 and N_2O. The exploitation of land resources and burning of peat enhance the decomposition of peat inducing N_2O and CH_4 emissions. The IPCC has estimated CH_4 emissions from tropical peatland using the value of 548 kg C ha^{-1} y^{-1} measured in Boreal peatland referring to Matthews (1987) and of 16 kg N ha^{-1} y^{-1} for estimation of N_2O emission from cultivated peat soils.

We have measured CH_4 and N_2O fluxes in a natural forest, a regenerated forest burnt in September 2002, a wasteland burnt in July 2002, a grassland and 3 crop fields cultivated with vegetables in Karampangan zone, near Plangka Raya, since 2002. The peat depth is about 4 m; therefore, the peatland is defined as deep peat. The water table was generally fluctuated from 0 cm in the wet season (October to April) to 100 cm in the dry season (May to September).

CH_4 fluxes

The CH_4 fluxes were strongly influenced by precipitation. In the natural forest, small CH_4 uptake (-0.21 kg C ha^{-1} y^{-1}) was found in 2002 (dry year, annual precipitation was 1994 mm) and small CH_4 emission (+0.34 kg C ha^{-1} y^{-1}) was found in 2003 (wet year, annual precipitation was 2339 mm). In 2002, the regenerated forest soil took up CH_4 (-1.7 kg C ha^{-1} y^{-1}), but in 2003 after the forest fire, the burnt forest emitted CH_4 (+2.5 kg C ha^{-1} y^{-1}). The wasteland showed small CH_4 fluxes within a range of ± 0.5 kg C ha^{-1} y^{-1}, which is similar to that of the natural forest. All agricultural fields emitted CH_4 in both years. The unfertilized grassland showed a smaller CH_4 emission (less than 0.6 kg C ha^{-1} y^{-1}) than the fertilized vegetable fields in both years. In the dry year of 2002, the CH_4 emission was less than 2.7 kg C ha^{-1} y^{-1}, but in the wet year of 2003 very high CH_4 emission of 92 kg C ha^{-1} y^{-1} was recorded in one of the vegetable fields. However, the value was significantly smaller than the value used in the IPCC estimation.

One of the reasons for such small values of CH_4 emissions recorded in the Kalampangan zone is probably the deep water table in the peatland. Therefore, from

April 2004, we established new sites for natural forest in Setia Alam zone, where significantly shallower water table than Kalampangan zone has been reported. A relatively high CH_4 emission rate of 20 μgC m^{-2} h^{-1} was found in June compared to that of 10 μgC m^{-2} h^{-1} measured in Kalampangan forest, but much higher CH_4 uptake rate of -50 μgC m^{-2} h^{-1} was also recorded in September. The CH_4 flux was significantly correlated with the volumetric soil moisture content of the top soil of 0-5 cm depth.

N_2O fluxes

The annual N_2O emissions from the natural forest of Kalampangan was 0.6 kg N ha^{-1} y^{-1} in 2002 of dry year, it increased to 4.4 kg N ha^{-1} y^{-1} in 2003 of wet year. Both burnt forest and wasteland showed almost as same N_2O emissions as natural forest, indicating that burning of peat does not influence N_2O emission. Although there was no fertilization in grassland, relatively high N_2O emissions of 7.1 kg N ha^{-1} y^{-1} in dry 2002 and 22.8 kg N ha^{-1} y^{-1}in wet 2003 were found, which are similar to IPCC value of 16 kg N ha^{-1} y^{-1} for N_2O emission from cultivated peat soils. Furthermore, considerably high N_2O emissions were recorded in vegetable fields which ranged from 21.4 to 131 kg N ha^{-1} y^{-1} in dry 2002 and 52.0 to 239 kg N ha^{-1} y^{-1} in wet 2003. Fertilizer application rate in the field with the highest N_2O emission was estimated as 626 kg N ha^{-1} y^{-1} of urea and 138 kg N ha^{-1} y^{-1} of cattle manure in both years. If we use the value of grassland as background, the emission factor for total N applied with manure and chemical fertilizer was estimated as 0.162 in dry 2002 and 0.310 in wet 2003, which are considerably high compared with the IPCC value of 0.0125. These results indicated that N_2O emissions from cultivated tropical peat soils are mainly influenced by precipitation.

In 2004, N_2O emission rate was almost same as that in 2003, because precipitation is almost same as in 2003. We also measured N_2O emissions from the natural forest soil in Setia Alam zone. The N_2O emission rate ranged from -0.6 to 9.8 μgN m^{-2} h^{-1}, which is significantly lower than the values of the natural forest in Kalampangan zone ranging from 2.4 to 207 μgC m^{-2} h^{-1}. The reason for the difference between N_2O emission rates in both natural forests may be the activities of nitrification and denitrification. The nitrification may be high in Kalampangan forest than in Setia Alam forest, because CH_4 uptake is inhibited by nitrification (Steudler, 1989). We will try to evaluate the denitirification activity next year.

2) Leaching of nitrogen, phosphorus, and carbon from agricultural fields of tropical peatland Central Kalimantan, Indonesia

The tropical peatland is considered to be an important reservoir of minerals. However, it is of a great concern that a lot of accumulated materials will be released when peatlands are used as farmlands. This is because the mineralization increases due to increase in dryness of soils. The objective of this study was to evaluate the leaching losses of minerals from the cropland of tropical peat soils quantitatively.

In order to collect leaching soil solution from upland fields, two tension-free lysimeters were established at a depth of 30cm in grassland and each of three vegetable fields in Kalampangan village. Neither fertilization nor cultivation was done in the grass land. Water samples were collected from a private well (about 7m depth) and from a stream flowing through the adjoining area of the fields. The water sampling was carried out monthly from June 2003. The concentrations of nitrate (NO_3^--N), phosphorous (PO_4^{3-}-P) and total carbon (TC) were analyzed in the laboratory.

The amount of possible evapotranspiration was calculated for every day from 1 June 2003 to 31 May 2004 by Pennman combined method using the meteorological observation data of tower (40m) set up in the natural forest in Kalampangan zone. The balance between the day precipitation and evapotranspiration was assumed to be an infiltration water volume. The infiltration water volume was assumed to be 0 on the day without the rainfall more than the amount of evapotranspiration. The amount of leached nitrogen, phosphorus, and carbon was calculated by multiplying the concentration of soil solutions collected from lysimeters by the infiltration water volume.

The concentration of NO_3^--N in leaching soil solution ranged from 0 to 11.9 mg N L^{-1} in the grassland and 0 to 178 mg N L^{-1} in the vegetable fields. Both the maximum values were observed during the dry season, when there was a little rainfall.

The PO_4^{3-}-P concentration of leaching soil solution ranged from 0 to 40 mg P L^{-1} in the vegetable fields. Relatively high PO_4^{3-}-P concentration (4 mg P L^{-1}) was detected in the grassland during the dry season. These high concentrations show that PO_4^{3-}-P was easily moved in the tropical peat soil.

More than 98% of TC in leaching soil solution was the organic carbon in each sample. There was no difference between TC concentration in the grassland and vegetable field, and the range of TC concentration was 40-60 mg C L^{-1}. Unlikely that of the trend of NO_3^--N and PO_4^{3-}-P concentration, the TC concentration did not show a trend of increasing concentration in the rainy season since October.

The NO_3^--N and PO_4^{3-}-P concentrations were hardly detected in the groundwater samples. Therefore, only the results of TC concentration are described. The TC concentration in the groundwater ranged from 10 to 20 mg C L^{-1}, which was lower than in the soil solution. The proportion of organic carbon decreased to about 70%. There was no increasing trend of concentration in the rainy season as found in the soil solution. The fact that neither NO_3^--N nor PO_4^{3-}-P concentration detected in groundwater suggested that the leached minerals did not reach in the groundwater.

The NO_3^--N concentration in stream water ranged from 0 to 1 mg N L^{-1}. The maximum NO_3^--N concentration was found in he dry season, while it was less than 0.2 mg N L^{-1} during the rainy season, which were considerably lower than that of soil solutions. The PO_4^{3-}-P concentration was highest in the dry season of 1 mg P L^{-1}, and was less than 0.2 mg P L^{-1} in the rainy season, and the concentration was also considerably lower than that of the soil solutions. The TC concentration was in the range of 40-60 mg C L^{-1}, with a maximum concentration of 80 mg C L^{-1}, which was as same as the concentration of soil solution or was higher.

The annual cumulative rainfall was 2400mm and cumulative evaporanspration was 1600mm, thus the total amount of infiltration (800 mm) was estimated from the water balance. The amount of NO_3^--N leached was in the range of 40 – 400 kg N ha^{-1} y^{-1}, and was low in the unfertilized grassland and high in the fertilized vegetable fields. The leached amount of NO_3^--N was 4 times higher in the vegetable fields than grasslands, which indicated the human impacts such as fertilization or cultivation. The amount of PO_4^{3-}-P was in the range of 7–18 kg P ha^{-1} y^{-1} in grassland and two vegetable fields, but the amount was remarkably higher (70 kg P ha^{-1} y^{-1}) for one of the vegetable fields. TC was in a narrow range of 888-1212 kg C ha^{-1} y^{-1}. It appeared that even from the grassland, where cultivation and fertilization were not present, 40 kg of nitrogen, 7 kg of phosphorous and 1060 kg of carbon per ha were flowed out every year.

Effect of sulfuric acid discharge from acid sulfate soil on the limnological environment in Central Kalimantan, Indonesia

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Summary

Human activity affecting tropical peat swamp forest, especially destruction of peat soil due to agricultural land development, leads not only to global warming by emission of green house gases but also to various serious regional environmental problems. One of the regional environmental problems caused by the destruction of tropical peat is the oxidation of pyrite within the sediment underneath the peat layer in the coastal area. Objectives of this study were to evaluate the acidification process of the limnological system by sulfuric acid and to estimate the area of the basin which is chemically affected by the sulfate produced by pyrite oxidation under the peat layer.

In order to estimate the range of area that is affected by the sulfuric acid pollution, water chemistry of two rivers in Central Kalimantan, Indonesia was surveyed in September 2003 (dry season), March 2004 (rainy season) and September 2004 (dry season). Water discharged from canals into the main stream of the Sebangau River and the Kahayan River showed lower pH compared to the mainstream water of the rivers, implying sulfuric acid loading from the canal to the main stream of the rivers. The ratio of concentrations of sulfate ion/chloride ion, which was used as a parameter for estimating the contribution of pyritic sulfate to the river water chemistry, showed that the sulfuric acid loading from pyrite oxidation appeared from the river mouth up to 130-170 km upstream in both the rivers. Water of the mainstream of the rivers as well as water discharged from canals into the mainstream in the rainy season showed much higher acidity and a higher ratio of sulfate ion/chloride ion than those in the dry season. This implies that the discharge of pyritic sulfate from peat soil to the limnological system is much higher in the rainy (high water table) season than the dry (low water table) season. Water in the canal in the rainy season was found to be highly acidic (pH = 2.0-3.0) and the water should affect the inhabitants in the area. Pyrite oxidation after peatland development causes not only acidification of soil but also acidification of the limnological ecosystem. Control of pyrite oxidation should be indispensable for maintaining sustainable land use of the tropical peatland.

Keywords: basin, canal, peat, pyrite, sulfate

Introduction

Peat consists of the accumulated organic remains of dead plants, and peat lands are regarded as important carbon pools which regulate the green-house gases in the atmosphere (Hadi *et al*. 2000; Haraguchi *et al*. 2000; Shimada *et al*. 2001; Nakagawa *et al*. 2002). Tropical areas have large expanses of peat lands (Anderson, 1983) and the tropical peat especially in Kalimantan makes up a large carbon pool (RePPProT 1990).

Maltby & Immirzi (1993) estimated that 3-4% of global peat and carbon (329-525 Pg) is in Indonesian peat swamp forest. Recent agricultural utilization of peat swamp forest in Kalimantan has led to the disappearance of peat in huge areas of the district. The basin of the Sebangau River and Kahayan River, Central Kalimantan, Indonesia, belongs to the tropical forest zone and has very high precipitation in the rainy season, which impedes plant decomposition as a result of the high water table and the consequent anoxicity in the peat layer.

Destruction of tropical peat land due to agricultural land use leads not only to global warming by emission of green house gases but also to various serious regional environmental problems. One of the regional environmental problems caused by the destruction of tropical peat is the oxidation of pyrite within the sediment underneath the peat layer in the coastal area of the tropical region, an effect much like sulfuric acid pollution in coal mining areas of Europe (Monterroso & Macias 1998; Balkenhol *et al*. 2001). After destruction of the peat layer over pyrite-containing sediment, pyrite is biologically oxidized by atmospheric oxygen and sulfuric acid is produced. Then the sulfuric acid concentration increases in the soil, and a large proportion of nutrients will be lost. Discharged sulfuric acid from the soil causes the acidification of river water and subsequent effects on the littoral zone. Peat in the lower basin of Sebangau River was affected by the pyrite in the mineral layer underneath the peat layer (Haraguchi et al. 2000). However, insufficient data are available for clarifying the range of pyrite distribution and the extent to which peat soil and discharged water are polluted by the sulfuric acid after pyrite oxidation.

A major objective of this study is to estimate the area of the basin which is chemically affected by the sulfate produced by pyrite oxidation under the peat layer. We collected surface water from Sebangau River and Kahayan River including discharged water from canals at 1-3 km intervals and analyzed the chemical components in the water. The surveyed area ranged from the river mouth to the uppermost stream of the Sebangau River (ca. 167 km from the river mouth) and Kahayan River (ca. 331 km from the river mouth). From the analytical data for dissolved dominant cations and anions we estimated the range over which the river water is affected by sulfuric acid produced by pyrite oxidation.

Materials and Methods

In order to estimate the range of the area that is affected by the sulfuric acid pollution, water chemistry of two rivers in Central Kalimantan, Indonesia was surveyed in September 2003 (dry season), March 2004 (rainy season) and September 2004 (dry season).

The Sebangau River originates at Kya, 6 km upstream from Kerengbangkirai (the southern part of Palangkaraya city), and flows west of Palangkaraya city. Six main tributaries (Bakung, Rasau, Bangah, Ranang, Paduran and Ketimpun) flow into the main stream of the Sebangau River. Six main canals have been constructed and connected to the Sebangau River from the eastern part of the main stream.

The Kahayan River originates at Kahukung Mountain (ca. 200 km upstream from Palangkaraya) and flows east of Palangkaraya city. Five main canals from the western part and also five canals from the eastern part have been connected to the main stream of the Kahayan River downstream from Palangkaraya. The Kahayan River is connected to the Kapuas River by the Basarang Canal from Pulangpisau to Kualakapuas.

The Rungan River, a tributary that merges 12 km upstream of Palangkaraya, was also studied.

Water samples were collected at the center of the river at intervals of every 1.0-3.0 km along the rivers. Each water sample was directly collected from a boat by using a ca. 1,000 ml plastic tub at each sampling point. The position of each sampling point was determined by GPS. Water temperature, pH and EC (electrical conductivity) of the collected water were measured just after the water sampling by using a portable pH meter and EC meter. Water samples were filtered within 12 hours after sampling using a 0.45 μm cellulose acetate membrane filter (Advantec Co. Ltd., Tokyo, Japan) and stored at room temperature in 2.0 ml plastic tubes before chemical analysis. Major cations and anions were determined using an ion chromatograph (Dionex Model DX-120, Japan Dionex Co. Ltd., Tokyo, Japan).

Results and Discussion

In the Sebangau River, the pH of the river water in dry season tended to decrease from Kya (uppermost stream of the Sebangau River) to the 60-80 km point from the river mouth (Fig. 1a, c), and then the pH increased downstream to the river mouth in the dry season. However, the pH tended to decrease to the river mouth in the rainy season (Fig. 1b). The pH in the Paduran canal was almost the same or lower than in the main stream of the Sebangau River in the dry season; however, the pH in the Paduran canal measured ca. 0.5 units lower than that in the main stream of the Sebangau River in the rainy season.

We estimated the range over which sulfuric acid originating from pyrite oxidation affects the water chemistry of the river. Sulfate ions come both from sea water and from water discharged from pyrite-containing soil. Sulfate ion concentration in the water discharged from soils in which pyrite oxidation occurs is usually much higher than the chloride concentration, and so the ratio of SO_4^{2-}/Cl^- can be used to evaluate the effects of sulfuric acid from pyrite oxidation on the river water chemistry. In the dry season, the SO_4^{2-}/Cl^- ratio in the Sebangau River decreased from the uppermost stream of the river to the 135 km point, and it increased from the 135 km point to the 90 km point (Fig. 2a, c). The ratio decreased from the 90 km point to the 45 km point and it fluctuated around 0.13-0.18, the same value found in the sea water, from the 45 km point to the river mouth. Increases of SO_4^{2-}/Cl^- ratio downstream from the 135 km point implied that the effect of pyrite on the river water chemistry appeared downstream from the 135 km point from the river mouth. In the rainy season, the ratio showed the same tendency as in the dry season; however, the ratio was much higher than during the dry season (Fig. 2b). The SO_4^{2-}/Cl^- ratio started to increase from ca. 140 km from the river mouth, but the maximum was 45 km from the river mouth, 45 km downstream compared to the location in the dry season. This implies that the effect of sea water appeared only in the lower basin in the rainy season because of the high water level of the river. Water of the main stream of the rivers as well as water discharged from canals into the main stream in the rainy season showed much higher acidity and a higher ratio of SO_4^{2-}/Cl^- than the respective results in the dry season (Figs 1 & 2). This implies that discharge of pyritic sulfate from peat soil to the limnological system is much higher in the rainy (high water table) season than in the dry (low water table) season.

In the Kahayan River, the pH decreased from the upper stream to the 200-240 km point and the pH showed a local minimum around the 200-240 km point from the river mouth (Fig. 3). The pH showed another local minimum around the 50-70 km point from the river mouth. In the rainy season, the river water of Kahayan showed lower pH (ca. 4.3) than during the dry season (Fig. 3b). This implies that strong effects of sulfuric acid discharged from pyrite-containing peat appeared in the rainy season. The pH of the tributary Rungan decreased from the upper stream to the confluence with the main stream of the Kahayan. Water in the Pangkoh Canal and the Basarang Canal showed lower pH than that of the main stream of the Kahayan.

In the dry season, the SO_4^{2-}/Cl^- ratio in the Kahayan River was consistently much higher than the ratio in sea water. The ratio in the tributary Rungan was ca. 1.0-2.0, lower than that of the main stream of the Kahayan (Fig. 4). The SO_4^{2-}/Cl^- ratio decreased from the upper stream to the 150-170 km point, and then the ratio increased moving down stream, and it showed a local maximum around the 70-130 km point from the river mouth. The water in the two canals directly connected to the Kahayan River showed extremely high values in dry season for the SO_4^{2-}/Cl^- ratio, implying that the canal water contained greater amounts of pyritic sulfate than the main stream of the Kahayan River (Fig. 5a, c).In the rainy season, the SO_4^{2-}/Cl^- ratio in the Kahayan River showed a much higher value in the lower basin (between 30 and 130 km from the river mouth), implying the loading of large amounts of sulfuric acid to the river system in the rainy season.

Fig. 5 is a map showing the area of sulfuric acid pollution in the limnological system in Central Kalimantan, Indonesia (Fig. 5). The area actually polluted by sulfuric acid is the area with a lower pH, and the area of the threat of sulfuric acid pollution is the area with a higher SO_4^{2-}/Cl^- ratio.

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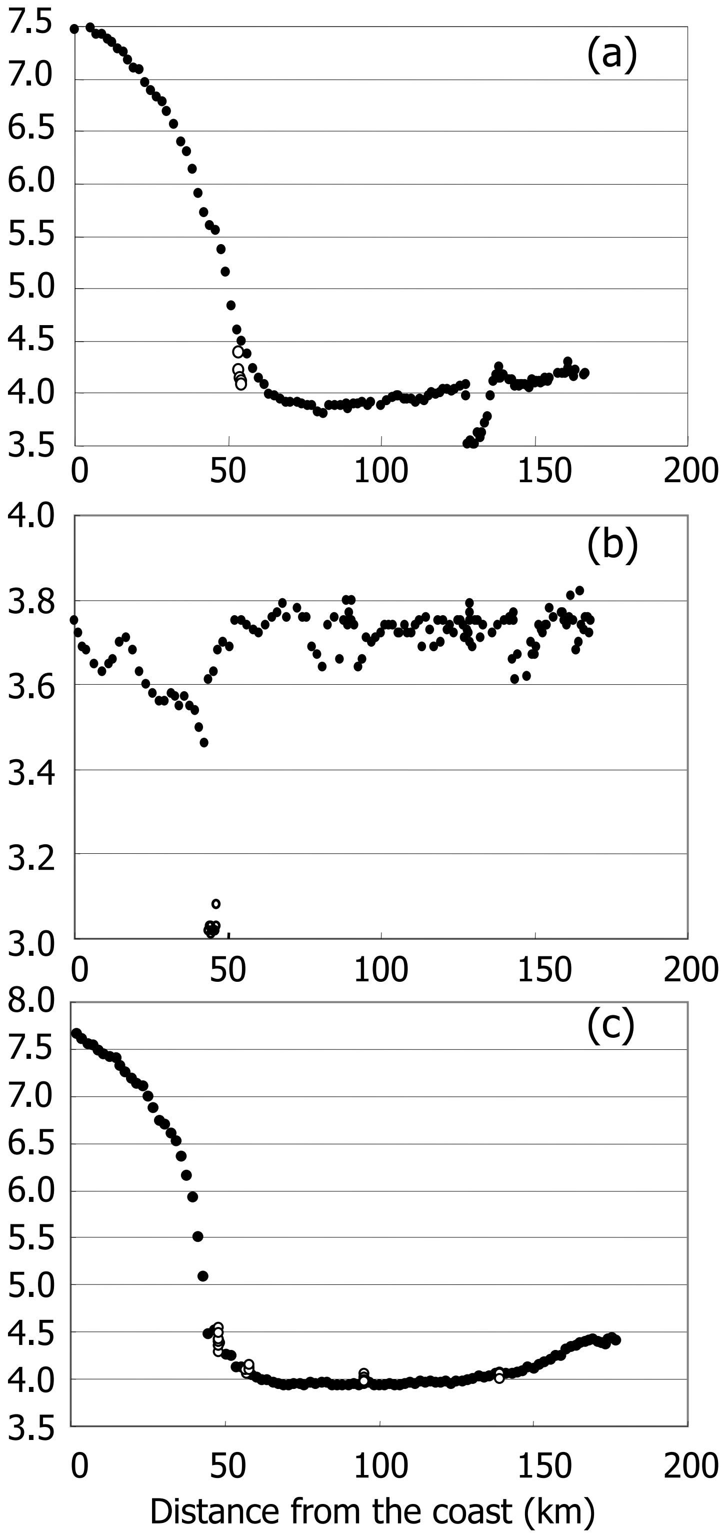

Fig. 1 Surface water pH of the Sebangau River in Central Kalimantan, Indonesia. (a) September 2003 (dry season), (b) March 2004 (rainy season), (c) September 2004 (rainy season). Closed circle: water in the main stream of the Sebangau river, Open circle: water in canals and tributaries.

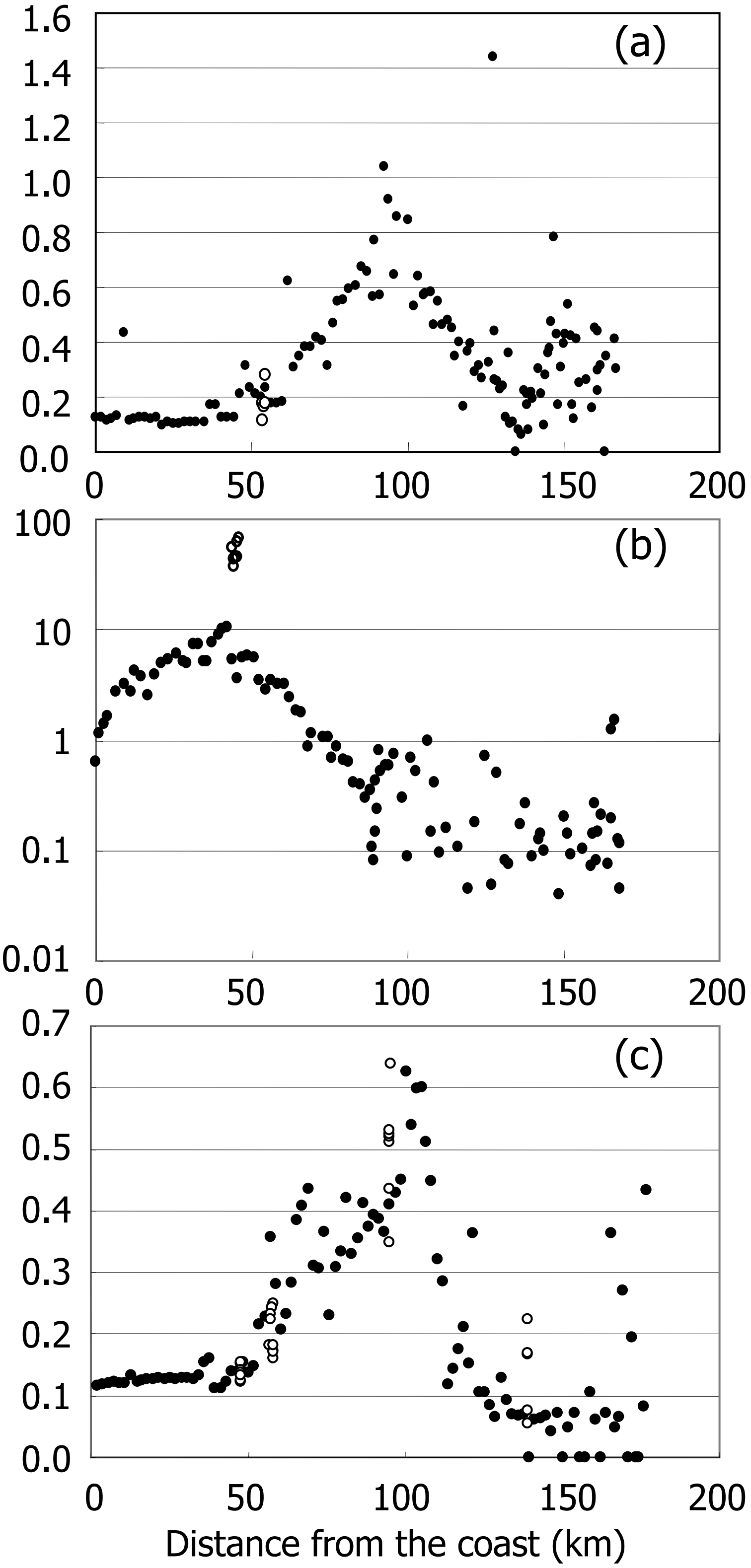

Fig. 2 Ratio of sulfate and chloride ions (weight ratio) of the surface water of the Sebangau River in Central Kalimantan, Indonesia. (a) September 2003 (dry season), (b) March 2004 (rainy season), (c) September 2004 (rainy season). Closed circle: water in the main stream of the Sebangau river, Open circle: water in canals and tributaries.

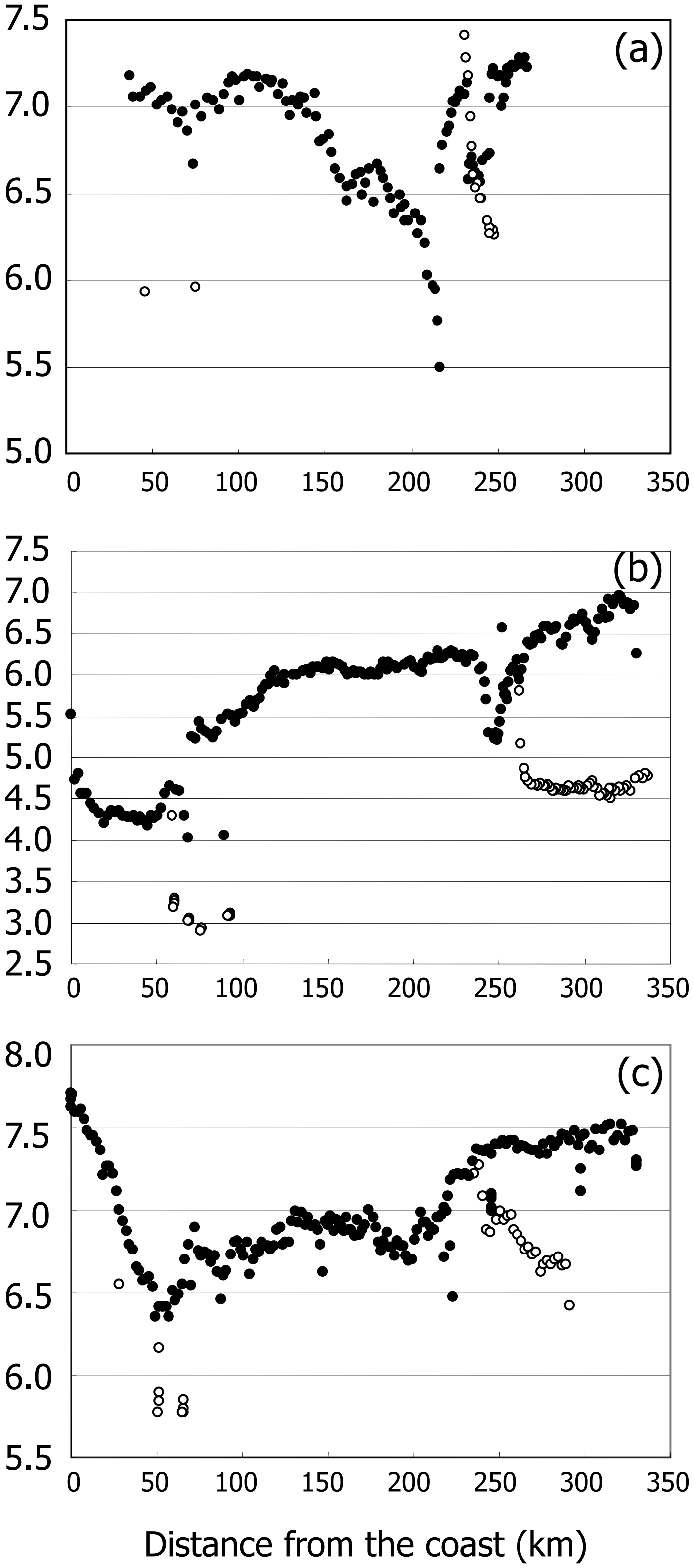

Fig. 3 Surface water pH of the Kahayan River in Central Kalimantan, Indonesia. (a) September 2003 (dry season), (b) March 2004 (rainy season), (c) September 2004 (rainy season). Closed circle: water in the main stream of the Kahayan river, Open circle: water in canals and tributaries.

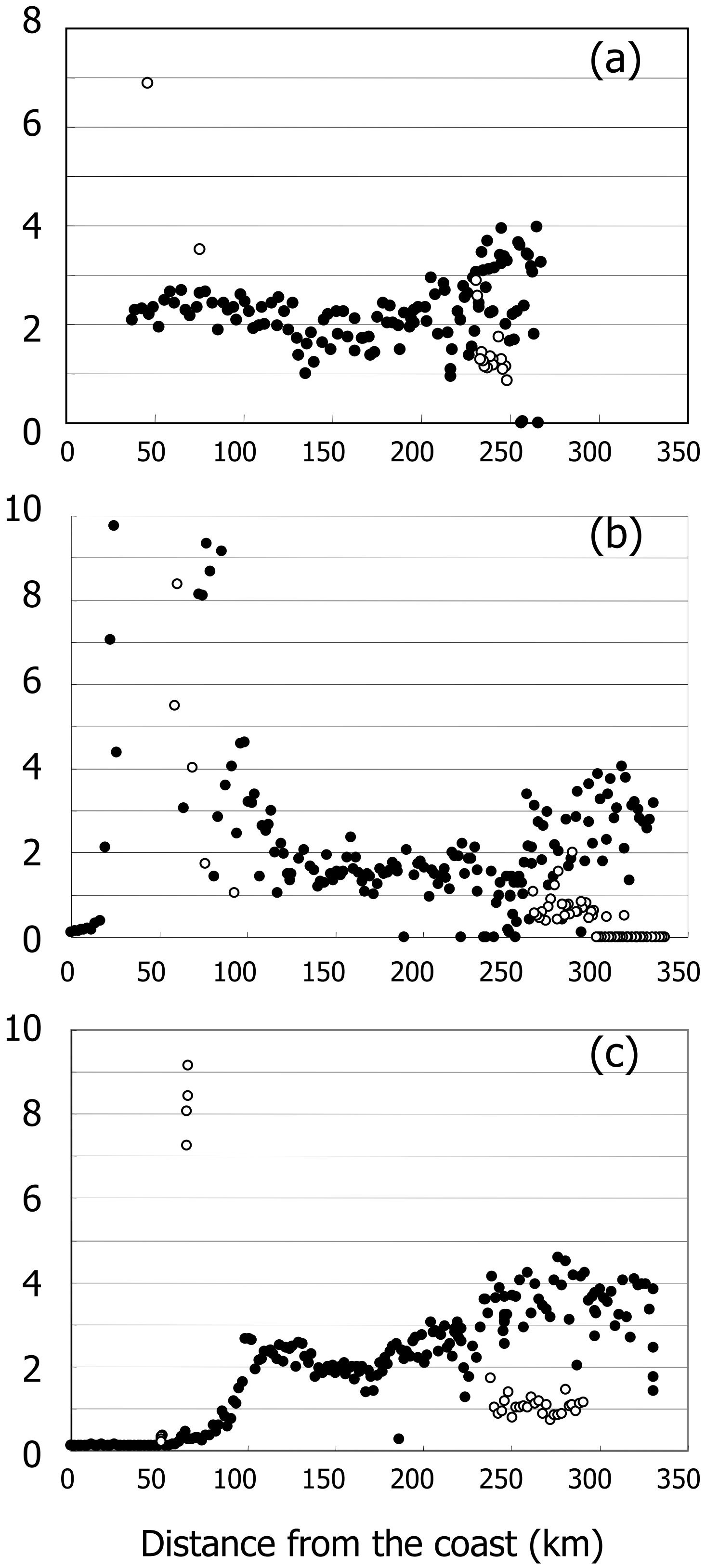

Fig. 4 Ratio of sulfate and chloride ions (weight ratio) of the surface water of the Kahayan River in Central Kalimantan, Indonesia. (a) September 2003 (dry season), (b) March 2004 (rainy season), (c) September 2004 (rainy season). Closed circle: water in the main stream of the Kahayan river, Open circle: water in canals and tributaries.

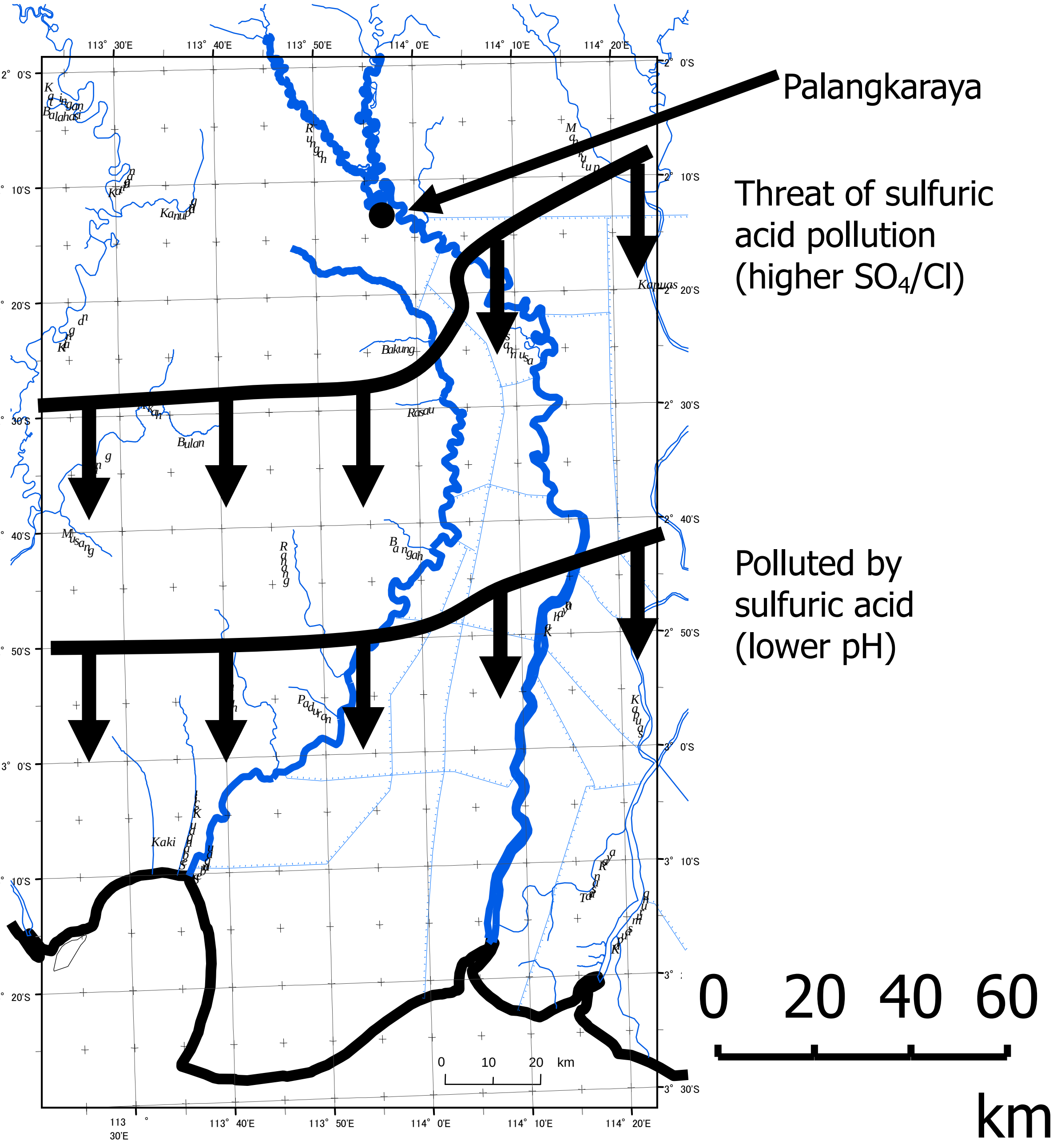

Fig. 5 Map showing the area of sulfuric acid pollution in the limnological system in Central Kalimantan, Indonesia. The area of actually polluted by sulfuric acid is the area of river water with lower pH, and the area of the threat of sulfuric acid pollution is the area of river water with higher SO_4/Cl ratio.

Energy Balance of a Tropical Peat Swamp Forest in Central Kalimantan, Indonesia

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Abstract

Tropical peat swamp forests grow over tropical peatlands, which are widely distributed in flat lowlands in Southeast Asia. Recently, however, deforestation and drainage are in progress on a large scale because of a growing demand for timber and farmland. In addition, the El Niño drought and its consequent fires are accelerating the forest devastation. The forest devastation alters energy balance and will influence regional climate. Thus we have measured eddy energy fluxes above a tropical peat swamp forest left in a devastated peatland in Central Kalimantan, Indonesia since November 2001. Both in the rainy and dry seasons, latent heat flux (lE) considerably exceeded sensible heat flux (H). Net radiation (R_n) was mainly used by evapotranspiration (ET). The El Niño event occurred in 2002, and the consequent drought made large-scale peatland fires in Central Kalimantan. The fires emitted smoke and decreased net radiation from mid-August through October. H and lE changed in parallel with R_n during the fires, whereas Bowen ratio (H / lE) increased from the late dry season through the early rainy season (October to December). Cumulative ET reached about 90% of cumulative

precipitation (P) at mid-October 2002, although the percentage decreased to 66% at the end of 2002. Annual ET and P were 1252 and 1856 mm in 2002, respectively.

Introduction

Tropical peat swamp forests grow over tropical peatlands, which are widely distributed in flat lowlands in Southeast Asia. Recently, however, deforestation and drainage are in progress on a large scale because of a growing demand for timber and farmland . In addition, the El Niño drought and its consequent fires are accelerating the forest devastation. The forest devastation alters energy balance and will influence regional climate, whereas there were no field data on the energy balance of tropical peat swamp forests. Thus we have measured eddy energy fluxes and micrometeorology above a tropical peat swamp forest left in a devastated peatland in Central Kalimantan, Indonesia since November 2001.

Materials and Methods

Study site

The study site is a tropical peat swamp forest remaining in Area B of the Mega Rice Project near Palangkaraya, Central Kalimantan, Indonesia (Riely & Muhamad 2002). The forest is located between the Sebangau *River* and a channel running from the north to south. Water table in the forest was zonally reduced near the channel. A tower of 50 m height was constructed about 300 m inside from the northeast corner of the forest (2º 20’ 41.6” S, 114º 2’ 11.3” E). Dominant tree species of the forest are *Combretocarpus rotundatus, Cratoxylum arborescens, Buchanania sessifolia* and *Tetrameristra glabra* (Tuah et al. 2000) and rich shrubs grow in the trunk space. The height of the forest canopy is about 26 m, and plant area index (PAI) measured at 1.5 m height with a plant canopy analyzer (LAI2000, Licor) was 4.5 m^2 m^{-2} in late June 2002. Predominant wind direction is the south (SE-SW). Fetch is longer than 1 km for the southern wind. During the dry season of 2002, between mid-August and late October, peatland fires occurred in large areas around Palangkaraya because of the El Niño drought. However, the forest did not burn.

Measurement of eddy energy fluxes

Sensible heat (H), water vapor (latent heat (lE)) and CO_2 fluxes have been measured at 41.7 m with a sonic anemometer-thermometer (CSAT3, CSI) and an open-path CO_2 analyzer (LI7500, Licor) facing the south since November 2001. Sensor signals were recorded with a data logger (8421, HIOKI) at 10 Hz. Half-hourly mean fluxes were calculated from the data according to the following procedures: 1) removal of noise spikes, 2) planar fit rotation (Wilczak et al. 2001), 3) covariance calculation using block average, 4) WPL correction (Webb et al. 1980). Data during rain and north winds were eliminated to maintain data quality. In addition, a friction velocity (u*) threshold of 0.15 m s^{-1} was applied. These gaps were filled using a look-up table (Falge & al 2001).

Measurement of micrometeorology

Micrometeorology has been measured since July 2001 on the tower. Net radiation (R_n) was measured at 40.6 m with a radiometer (CNR-1, Kipp&Zonen). Precipitation (P) was measured at 41 m with a tipping-bucket rain gauge (TE525, CSI). Air temperature and relative humidity were measured at 41.7 and 2 m with platinum resistance thermometers and capacitive hygrometers (HMP45, Vaisala). Sensor signals were measured every 30 seconds, and half-hourly means were recorded with a data logger (CR10X, CSI).

Results and Discussion

In Kalimantan, the rainy season is in summer and the dry season is in winter of the Southern Hemisphere. Semiannual precipitation from January through April and November through December 2002 (the rainy season) was 1529 mm, which accounted for 82 % of the annual sum (1856 mm) for 2002 (Fig. 1a). Daily mean vapor pressure deficit (VPD) was larger in the dry season than the rainy season (Fig. 1b). However, daily mean air temperature showed no seasonal pattern, which ranged between 25 and 28˚C with the annual mean of 26.7˚C (Fig. 1c). Wind direction changed seasonally in accordance with the Asian monsoon, from the north in summer to the south in winter.

Eddy energy fluxes (H + lE) accounted for 83% of R_n during the daytime on a half-hourly mean basis, judging from the slope of the linear regression between them, which had an intercept of -6 W m^{-2}. Wilson & al. 2002 reported that the slope increased by 3% and 7% by considering soil heat flux and heat storage change, respectively, on the average from 26 forest sites in FLUXNET. Therefore, although soil heat flux and heat storage change were not measured, the energy balance closure was estimated to be 90% at least in this forest site. The ratio of the annual sum of H + lE to that of R_n was 0.90 in 2002 (Fig. 3b).

In spite of the dry season, R_n began to decrease at mid-August 2002 (Fig. 2a). This decrease is due to the shading by the smoke emitted from large-scale peatland fires enlarged by the El Niño drought . H and lE varied almost in parallel with R_n (Figs. 2a). H ranged between 2 and 3 MJ m^{-2} d^{-1} before the fires, whereas it decreased below 2 MJ m^{-2} d^{-1} during

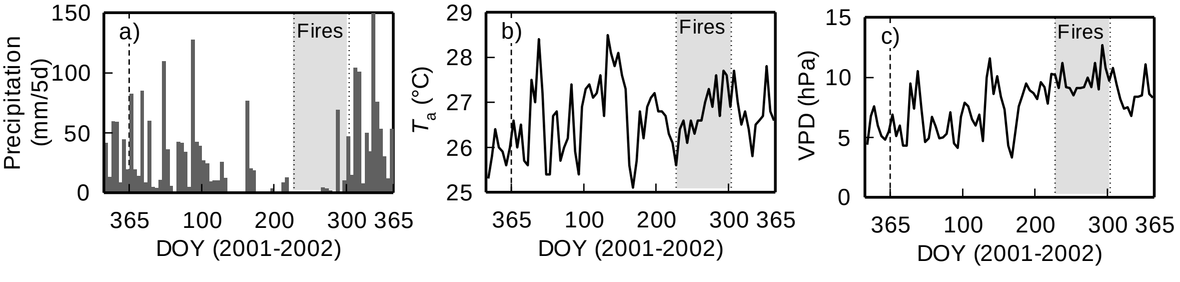

Fig.1 Seasonal variations in 5-d means of (a) precipitation, (b) air temperature (T_a) and (c) vapor pressure deficit (VPD) measured above canopy from 29 Nov. 2001 to 31 Dec. 2002. The fire period is shaded.

the fires and exceeded 3 MJ m^{-2} d^{-1} after the fires. lE varied between 6 and 12 MJ m^{-2} d^{-1} before and after the fires, which are equivalent to 2.5–5.0 mm d^{-1} of evapotranspiration (ET), whereas it dropped to a minimum of 4 MJ m^{-2} d^{-1} in late September during the fires. Bowen ration (H / lE) decreased gradually from January through July in the range of 0.20–0.35 (Fig. 2b). Although Bowen ratio dropped to a minimum of 0.15 in late September, it increased up to 0.45 in the late fire period and was between 0.35 and 0.45 after the fires. The decreasing pattern of Bowen ratio from the rainy season through the early dry season was due to increasing ET caused by VPD increase. On the other hand, the Bowen ratio increase from the late dry season through the early rainy season (October to December) was due to decreased ET, which was probably caused by ecophysiological constraint under water stress in the dry season; the constraint may have continued until the end of December.

Cumulative ET reached about 90% of cumulative P at mid-October, whereas it was 66% at the end of 2002 (Fig. 3a). Annual ET and P in 2002 were 1252 and 1856 mm, respectively. Annual mean daily ET was 3.4±1.0 (SD) mm d^{-1} in the El Niño year, which is compatible with 3.51 mm d^{-1} for an old-growth tropical forest in eastern Amazon (da Rocha H. R. et al. 2004).

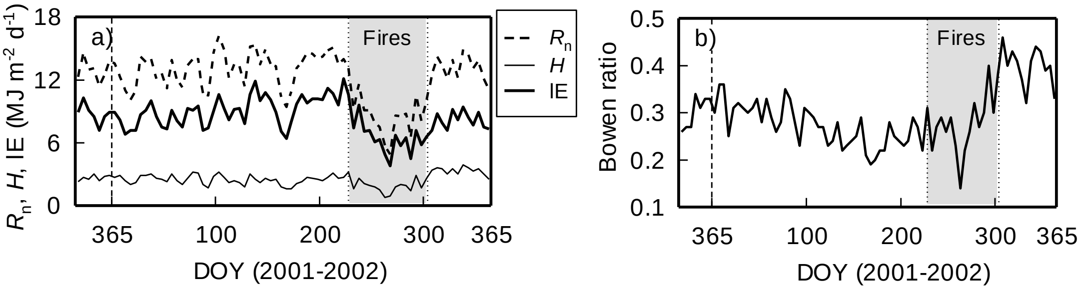

Fig.2 Seasonal variations in 5-d means of (a) net radiation (R_n), sensible heat flux (H) and latent heat flux (lE), and (b) Bowen ratio (H / lE) from 29 Nov. 2001 to 31 Dec. 2002. The fire period is shaded.

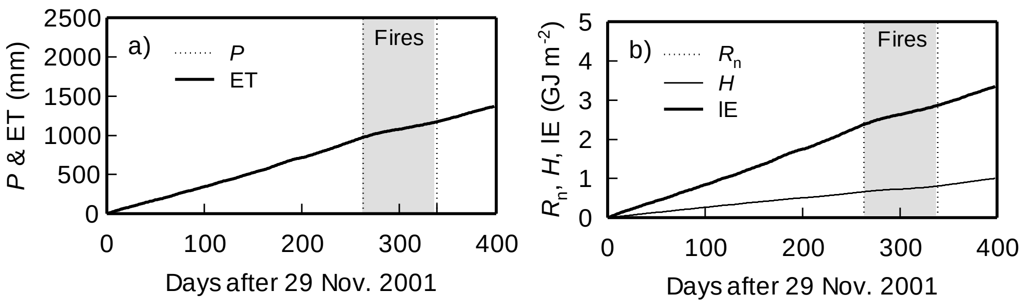

Fig.3 Cumulative (a) precipitation (P) and evapotranspiration (ET), and (b) net radiation (R_n), sensible heat flux (H) and latent heat flux (lE) from 29 Nov. 2001 to 31 Dec. 2002. The fire period is shaded.

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Land cover change and vegetation recovery in Central Kalimantan detected by satellite data

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Abstract

This study evaluated the land cover change and the impact of fires that occurred in 1997 and 2002 over the tropical peat swamp forest area in Central Kalimantan, Indonesia. We employed Multitemporal Principal Component Analysis (MPCA) methods for processing Landsat TM/ETM+ satellite images. MPCA seemed to be reliable because they merge spectral data corresponding to TM-1996 (pre-fire in 1997), ETM-2000 (post-fire 1997 and pre-fire 2002), and ETM-2003 (post-fire in 2002), which is crucial for detecting vegetation recovery. Furthermore, SPOT-VEGETATION 10-day Maximum Value Composite (MVC) data were used and compared with NDVI calculated by radiation values from tower-mounted instruments. The results prove the relationship and analyses using Landsat TM/ETM+, SPOT-VEGETATION data and ground-based NDVI to be effective for identifying land cover changes in the study area that is affected by forest fires. They can be applied over large areas at different time-scales.

Key words: Ground-based NDVI, Landsat TM/ETM+, NDVI and SPOT–VEGETATION.

1. Introduction

In 1997, a drought began in Southeast Asia. It was related directly to its contemporary El Niño-Southern Oscillation (ENSO) event (Wooster and Strub, 2002; Schimel and Baker, 2002). Similar problems caused by ENSO event occurred in 2002, when fires burned forests from July to October 2002. Forest fires are an important cause of environmental alteration and land degradation or conversion through human activities. In 1995, the Indonesian government initiated a large-scale land-use conversion project to develop one million hectares of wetland for rice and transmigration settlements: the so-called Mega Rice Project (MRP) in Central Kalimantan, Indonesia (Boehm and Siegert, 2001; Boehm *et al.*, 2002; Tetuko *et al.*, 2003). Page *et al.* (2002) estimated that 0.19–0.23 gigatons (Gt) of carbon were released to the atmosphere through peat combustion, with a further 0.05 Gt released from burning of its overlying vegetation in the Kalimantan Island. Using quick look imagery from the SPOT satellite, the total area of forest cleared or damaged directly by the fires has been estimated at 30,600 km^2. In East Kalimantan, 5.2 ± 0.3 million hectares, including 2.6 million hectares of forest, was burned with varying degrees of damage (Siegert and Hoffmann, 2000; Siegert, *et al*., 2001).

Therefore, this study was intended to evaluate the land cover changing and vegetation recovery especially by the impact of fire events in a devastated peatland in Central Kalimantan in 1997 and 2002 using Landsat TM/ETM+ and SPOT-VEGETATION data from the study area site.

2. Methods

2.1 Site description

The study area is located in a tropical peat swamp forest area around Palangka Raya, the capital city of Central Kalimantan Province (**Fig. 1**). Ground surveys and field investigations were carried out in the study area in July and December 2004. They were combined with data from an aerial survey using a helicopter to comprise an area of 75 km × 72 km, or approximately 540,000 ha.

The principal tree species of the upper canopy are *Gonystylus bancanus* (ramin=local name), *Shorea* spp. (meranti), *Cratoxylum glaucum* (gerongang), *Combretocarpus rotundatus* (tumeh), *Calophyllum* spp. (bintangor), and *Dactylocladus stenostachys* (mentibu). Mammal sightings in this area in 1993 and 1994 confirmed the presence of orangutans (*Pongo pygmaeus*) at an apparently high density (Page *et al*. 1997) in addition to several other endangered or threatened mammals, including agile gibbon (*Hylobates agilis*), maroon langur (*Presbytis rubicunda*), sun-bear (*Helarctos malayanus*), leopard cat (*Felis bengalensis*), and marbled cat (*F. marmorata*).

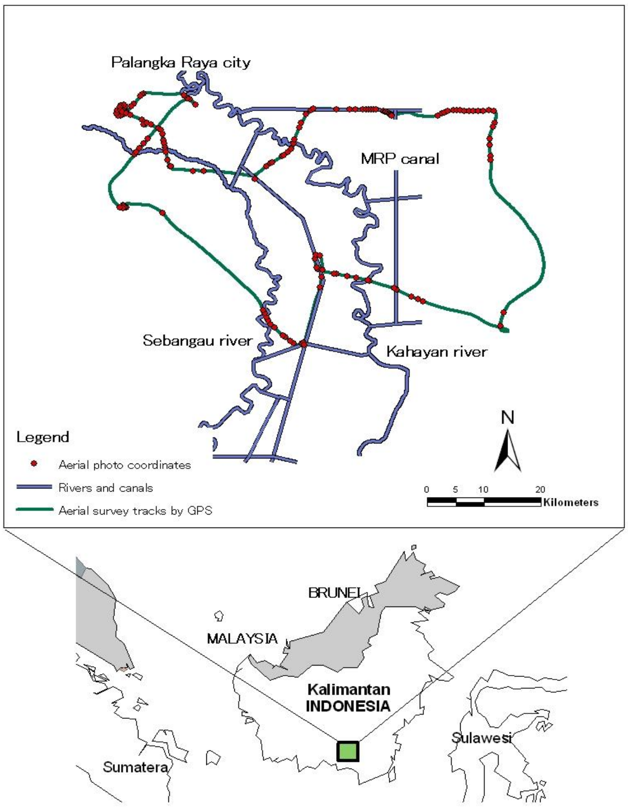


Fig. 1. Map of the study area in Central Kalimantan Province, Indonesia.
The area is approximately 540,000 ha. The aerial survey by helicopter was conducted in July 2004. The green line shows the aerial survey tracks measured by GPS.

2.2 Data and Methods

For multitemporal analysis, a series of three images was obtained from Landsat TM/ETM+ (Path-118/Row-062), acquired on 10 May 1996, 16 July 2000 and 14 January 2003.

We employed three multitemporal images corresponding to: pre-fire-event 1997 (TM 10 May 1996); post-fire-event 1997 and pre-fire-event 2002 (ETM 16 July 2000); and post-fire event 2002 (ETM 14 January 2003) using Multitemporal Principal Component Analysis (MPCA) methods. The MPCA method provides a systematic means of compressing multi-spectral image data with the aim of reducing redundancy in the different bands. The PCA offers some advantages: (1) most of the variance in a multi-spectral data set is compressed into one or two PC images; (2) noise may be relegated to less-correlated PC images; and (3) spectral differences between materials may be more apparent in PC images than in individual bands (Garcia-Haro *et al.*, 2001). Within this frame, PCA was applied in combination with field survey data, which permitted estimation of point samples of new recovery/degradation (Maldonado *et al*., 2002). PCA is a common technique that can be applied in the interpretation of a large number of reflectance spectra because it can identify the components responsible for the spectral variability, as expressed by the eigenvectors (Smith *et al*., 1985; Galvao and Vitorello, 1995).

Table 1. SPOT4-VEGETATION sensor geometric and radiometric characteristics

Geometrical characteristics	
Orbital altitude	822 km
Period of resolution	101.46 min
Field of view	±50°
Swath width	2250 km
Ground resolution	1.15 km
Pixel size	1 km

Spectral bands	
B0 (blue)	0.43– 0.47 µm
B2 (red)	0.61– 0.68 µm
B3 (near infra-red, NIR)	0.78– 0.89 µm
B4 (short-wave infra-red, SWIR)	1.58– 1.75 µm
B4 (short-wave infra-red, SWIR)	1.58– 1.75 µm

Note: There is no B1 channel onboard VGT in order to keep the same notation from SPOT1 to SPOT5.

SPOT-VEGETATION 10-day Maximum Value Composite (MVC) data from April 1998 to March 2003 (5 years) were obtained to detect the impact of land cover and vegetation recovery that were attributable to the forest fire events in 1997 and 2002.

The sun-synchronous SPOT4 satellite was launched in March 1998 with, onboard, the wide field of view imaging radiometer VEGETATION (VGT), which was specially designed to monitor land surface parameters. VGT is a linear-array push-broom system with 1,728 detectors for each of the four channels providing a swath width of about 2,250 km. The spectral bands of the four channels are given in **Table 1**. In-flight radiometric calibration of each of the four sensors is based on different methods: Onboard calibration lamp is selected as reference for monitoring changes in the cameras sensitivity over time. Calibration over Rayleigh scattering, sun glint, clouds or deserts are the complementary calibration methods. The estimated calibration accuracy is around 5% for absolute calibration, better than 2% for multi-temporal calibration and less than 3% for inter-band calibration (Henry & Meygret, 2001). The ground resolution is 1.15 km independent of the viewing incidence angle. In ground processing, all pixels are re-sampled onto a regular grid (1 km x 1 km) in a polar stereographic projection. The VGT “level P” products that we used provide reflectance values at the top of the atmosphere after geometric and radiometric corrections.

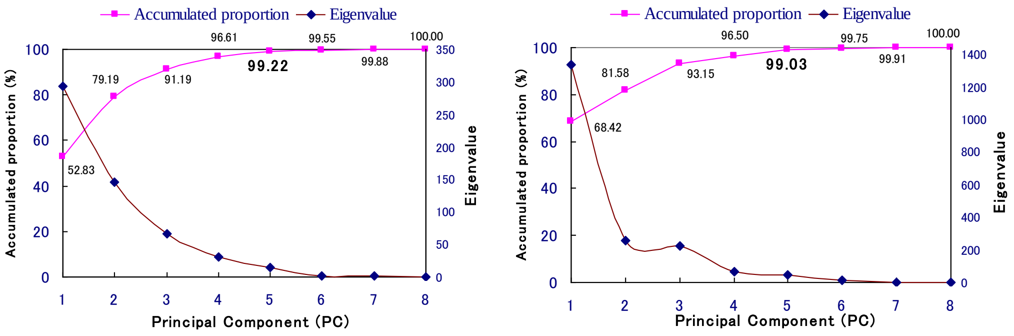
An analysis was carried out using ground-based NDVI values (Harada *et al.*, 2004) calculated from downward and upward (reflected) radiation measured at the top of the tower using the method of Huemmrich *et al*. (1999). The tower of 50 m height was constructed and located in a tropical peat swamp forest in Central Kalimantan.

3. Results and Discussion

In MPCA method, we took four bands (TM/ETM 2, 3, 4, and 5) of each date (eight bands) for calculating principal components ($PC_{1996–2000}$ and $PC_{2000–2003}$). These four bands contain most of the spectral information in vegetation-related studies (Huemmrich *et al*. 1999), including two visible and a near infra-red bands (TM/ETM 2, 3, and 4), and a middle infra-red (TM/ETM 5).

Five primary Principal Components (PCs) account for most spectral variance of $PC_{1996–2000}$, and $PC_{2000–2003}$ were 99.2% and 99.0% from the original data (**Fig. 2**). The remaining component (PC6, PC7, and PC8) were quite sensitive to noise along with variation of vegetation coverage. Furthermore, eigenvector characteristics of three additional principal components (PC6, PC7, and PC8) gave little more information than the first five PCs because they have eigenvalue variabilities less than 1% and did not show a useful specific form in further land cover change detection (Garcia-Haro *et al.*, 2001; Singh and Harrison, 1985).

As shown in **Table 2**, PC-1 image represented the brightness component and gave the preliminary visual information about change of land cover between two observation dates. The eigenvector of PC-1 showed all positive values and containing more than 50% of accumulative variance (Segah *et al*., 2005). PC-2 was the greenness/vegetation component, characterized by algebraic sign on red and near infrared band. PC-2 image expresses the changed of areas also with white appearance, especially stability in the greenness value. PC-3 showed the difference of brightness between two images, characterized by opposite sign of eigenvectors. The fourth axis (PC4), constituting the axis of temporal change, presents a great variation between both dates. Visual observations confirmed that PC4 was higher in the burnt areas.



(a) Bands 2,3,4,5 of TM-1996 & ETM-2000 (b) Bands 2,3,4,5 of ETM-2000 & ETM-2003

Fig. 2. The accumulated proportion and eigenvalue of PC's for 1996–2000 and 2000–2003.

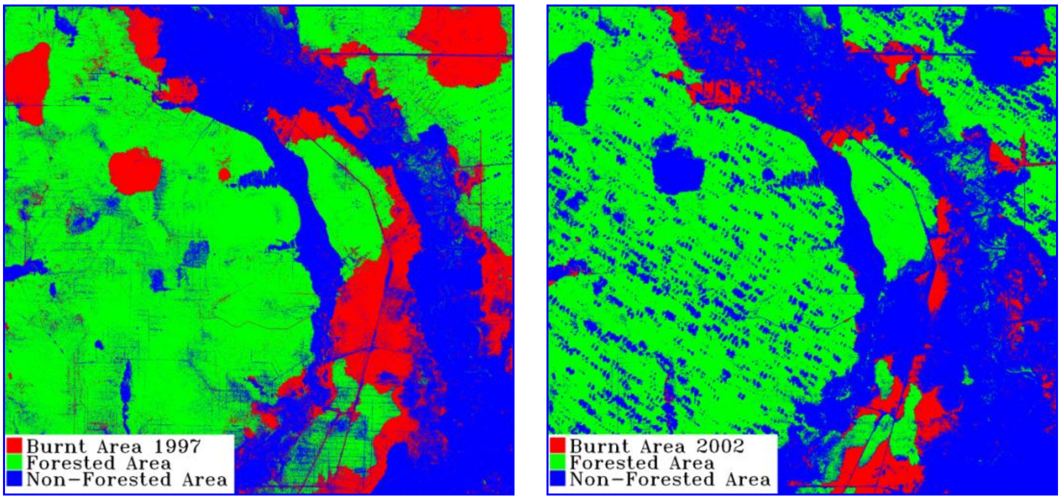


Fig. 3. Detected areas burned by fires in 1997 (left) and 2002 (right) with maximum likelihood classification using PCs.

To map the burnt areas and isolate noise, we found that the burnt areas of 1997 and 2002 were 89,086 ha (16.5%) and 31,859 ha (5.9%), respectively, from 540,000 ha of the study area that was classified using maximum likelihood classification, as shown in **Fig. 3**. Change enhancement offered in the PCs allows the creation of thematic map for detecting land cover change (Segah, *et al.*, 2003). Three areas were classified (burnt, forested, and non-forested) for each PC4 of $PC_{1996–2000}$ and $PC_{2000–2003}$. These results show that transformation of PCAs will increase the computation capability from classification by the declining dimension from original data.

Table 2. Eigenvector Characteristics of each Principal Components
(Landsat-TM 10 May 1996 and Landsat-ETM 16 July 2000)

PC's	Accumulative variance (%)	TM2 10_May_96	TM3 10_May_1996	TM4 10_May_1996	TM5 10_May_1996	ETM2 16_Jul_2000	ETM3 16_Jul_2000	ETM4 16_Jul_2000	ETM5 16_Jul_2000
PC-1	52.83	0.0778	0.0964	0.3466	0.4674	0.2013	0.1838	0.3795	0.6540
PC-2	79.19	-0.0012	-0.0612	0.6961	0.1343	-0.1745	-0.3463	0.3203	-0.4906
PC-3	91.19	-0.1439	-0.2404	-0.0789	-0.6656	0.0738	-0.0887	0.6485	0.1960
PC-4	96.61	0.0785	0.1809	-0.5943	0.4377	0.0364	-0.1048	0.5429	-0.3307
PC-5	99.22	-0.1095	-0.1894	-0.1762	0.1731	-0.4622	-0.7040	-0.1069	0.4129
PC-6	99.55	-0.4669	-0.7737	-0.0551	0.3144	0.1630	0.2020	-0.0306	-0.1151
PC-7	99.88	0.0560	0.0029	0.0064	-0.0106	0.8251	-0.5385	-0.1604	-0.0125
PC-8	100.00	0.8567	-0.5118	-0.0423	0.0000	-0.0337	0.0328	0.0053	-0.0060

SPOT-VEGETATION is a satellite sensor that is designed specifically to address the requirements of land cover mapping at about 1-km spatial resolution. Using SPOT-VEGETATION 10-day MVC data, we determined a change rate of 5 years NDVI from April 1998 to March 2003 by the difference of two SPOT-VEGETATION difference images of $NDVI_{April98}$ and $NDVI_{March03}$. The high-value $NDVI_{March03–April98}$ were detected as burnt areas. This value shows that the NDVI increases because of vegetation recovery after the forest fire event.

Results of this SPOT-VEGETATION 10-day MVC image analysis demonstrate the potential of multi-temporal vegetation images for identifying and mapping of burnt areas in the study area, especially the seasonal dynamics of vegetation spectral indices which can be used to discern vegetation recovery at different times and scales.

Fig. 4 shows the relation between SPOT-VEGETATION 10-day MVC and the 10-day mean NDVI value measured at the field micrometeorological tower in 2002. These figures elucidate the longevity and intensity of the 2002 drought, especially during July–October 2002. There is a high correlation of fires with the annual rainfall regime. Wooster and Strub (2002) also found a high correlation of fires in the Kalimantan Island in 1997 with the annual rainfall regime: the occurrence of forest fires was higher during the dry season of May–October 1997. In 2002 however, the dry season period in Kalimantan was markedly drier than normal: rain was absent at some locations for many weeks, as that in 1997.

Takahashi (2002) reported that, from the 10-year record of the ground water level in a peat swamp forest in Central Kalimantan, the levels of drought in 1997 and 2002 were categorized as markedly dry years. The big forest fires have occurred in the study area of peatland in Central Kalimantan between July and October 2002. The result was massive fire damage to the forest by fire, as detected in this study by Landsat TM/ETM+ and SPOT-VEGETATION satellite data. Anomalous 1997 and 2002 meteorological conditions were related directly to the ongoing ENSO event, which was reportedly the most intense of that century (Wooster and Strub, 2002).

In general, we found that the type of method implemented markedly affected the quantitative and qualitative estimates of land cover change by forest fires. Available ground information from a field survey indicated that the combination of human activities (land clearing, illegal logging, etc.) and forest fire induced the land cover change.

The result for burnt areas obtained by MPCA method was mutually consistent if compared with SPOT-VEGETATION simple difference images. MPCA method of Land sat-TM/ETM+ seemed to be reliable because they merge spectral data corresponding to TM-1996 (pre-fire in 1997), ETM-2000 (post-fire 1997 event/pre-fire 2002 event), and ETM-2002 (post-fire in 2002), which is crucial for detection of vegetation recovery. In addition, they produces a more direct interpretation linked with the vegetation damage and recovery processes after forest fires in the study area, especially in ex MRP area. Tani *et al*. (2005) reported that the burnt areas expanded inside large forest and also along MRP canals, which is a feature of damaged by fire of 1997 and also in 2002.

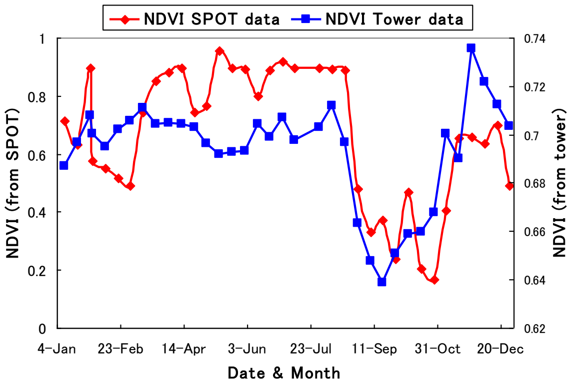


Fig. 4. Relationship between SPOT-VEGETATION and ground based NDVI in 2002.

Our results emphasize that SPOT-Vegetation 10-day MVC data were useful for regional burnt area mapping. Unlike AVHRR, SPOT-vegetation sensors have no thermal channels. Therefore, they cannot be used confidently to locate ‘active’ fires. Excellent SPOT-vegetation 10-day MVC geometric and radiometric characteristics make it attractive for mapping burnt areas (so-called “*fire scars*”). Furthermore, Eastwood, *et al*. (1998), demonstrated the strong potential of SPOT-VEGETATION 10-day MVC data for this application prior to its launch.

Nevertheless, using SPOT-VEGETATION for global description of fire effects is insufficient for accurate assessment of damaged ecosystems and probable carbon emissions. Higher resolution remote sensing data are necessary, especially for identification and delineation of each ecosystem and for evaluation of the level of degradation in each of them. The results proved that the analyses using Landsat TM/ETM+ and SPOT-VEGETATION 10-day MVC together with ground-based NDVI from a micrometeorological tower were effective for identifying land cover changes in the study area that was affected by forest fires in 1997 and 2002. Ground-based NDVI values were obtained daily for vegetation monitoring of the tropical peat swamp forest in Central Kalimantan. Using these values, we obtained a more detailed description of seasonal changes in NDVI for specific locations.

Analyses using multitemporal and multispectral satellite data and field measurement by ground-based NDVI instruments would be applicable to large areas at different time-scales. Monitoring changes in fire frequency are therefore vital for forest management and predicting climate change impacts. An important lesson of the 1997 and 2002 fire events is that sustainable management of peatlands and the prevention of forest fires must be emphasized, for instance, through better water management and restoration of degraded peatland areas.

4. Conclusion

The forest canopy change can be detected from multispectral satellite data using a variety of analysis methods. Consistent results indicate that the burnt areas of 1997 and 2002 were 89,086 ha (16.5%) and 31,859 ha (5.9%), respectively, using MPCA method within the study area of 540,000 ha. This study used MPCA method of Landsat-TM/ETM+ satellite image data, and SPOT-VEGETATION 10-day MVC data to compare the NDVI value of radiation sensor data of ground-based NDVI from a micrometeorological tower. These analyses are proved to be effective in identifying and mapping changes in land cover by forest fires in 1997 and 2002. Analyses using multitemporal and multispectral satellite data and field measurement by ground-based NDVI of micrometeorological instruments further allow for automated change indication and are applicable to large areas on different time-scales.

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3. Collaborative study

(3)

Hydrology and peatland technology in Central Kalimantan

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Time Change of Electric Conductivity of Water in the Sebangau River due to the Tidal Motion

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Introduction

It was found that a tidal wave propagates to Kya station 180km upstream far from the river mouth in the Sebangau River on the survey of water levels at the several gauging stations in the last year$^{1)}$. This means a volume of sea water penetrates into the river channel two times every day. Indeed, Haraguchi et.als.$^{2)}$ describes “The Cl^-/Na^+ ratio downstream from 89 km point was higher than that in the stream above 89 km point, and so the effect of the sea water appeared from the river mouth to the 89 km point from the river mouth.” How far and by what mechanisms the sea water does come up or retreat with a tidal wave in the channel of Sebangau River? To answer these problems would be very important from view points of water quality and environmental effects to the peatland area behind river banks.

In order to know time change of sea water movement following to a tidal wave, survey of salt water concentration in the river channel was planed to be carried out at the same five gauging stations as measurements of water level change were conducted in the last year. This annual report describes the results.

Method of the Survey

As the same way in the last year, temporal gauging stations were located in Paduran, Bangah, Selawati, Bakung and Kya to observe simultaneous water level change, vertical distribution of current velocity, cross sectional shape of the channel and salinity concentrations. The distances of the locations from the river mouth are about 50 km, 80 km, 100 km, 140 km and 180 km, respectively.

Measurements were conducted by two teams A and B which were from 4 and 5 persons, respectively, with following the schedule as shown in Table 1. Thus, simultaneous observation could be realized regarding to every neighboring two stations. Water level was measured every 30 minutes with visual method by using staff gauges. Current velocity was measured every 50 cm depth from the water surface at the center of each cross section by using an electric magnetic velocity meter for the team B. Salinity concentration was also measured every 50 cm depth from the water surface at the center of each cross section by using a salinometer for team B. However, as the instrument gauged zero for salinity to be too little, electric conductivity was measured instead of salinity. Electric conductivity would be corresponding to the thin salinity.

Table 1 Schedule and allotment for the survey

Gauging Station	Date and Time	Team	Items of the Measurements
Kya Bakung	10:00 - 22:00 19, September, 2004	A B	water level change, current velocity (B), electric conductivity (B)
Selawati Bangah	10:00 - 22:00 21, September, 2004	A B	water level change, current velocity (B), electric conductivity (B)
Paduran	10:00 - 22:00 23, September, 2004	A, B	water level change, current velocity, electric conductivity

Results of Measurements

Change of water level:

Figs.1 – 5 show the time changes of water level measured at every gauging stations. Notice the scale of vertical axes is different in each figure. It is known from the figures that a small rising tide and a larger ebb tide occurred within the surveying time. Although low water and high water appear at the same hour in a day at each station, it is only apparent. A tidal wave is propagated with about 8 hours from Paduran to Kya according to the investigation in last year. Therefore, high water at the Paduran station which formed to move the high water at the Kya station at near 15:00 on 19th in September in Fig.1 might occur at near 7:00 on the same day. As a high water emerges at Paduran at near 14:00 on 23rd in September as seen in Fig.5, the delay time of appearance of high water becomes 420 minutes per 4 days i.e. 105 minutes per day. This is confirmed from the data of Bakung station in

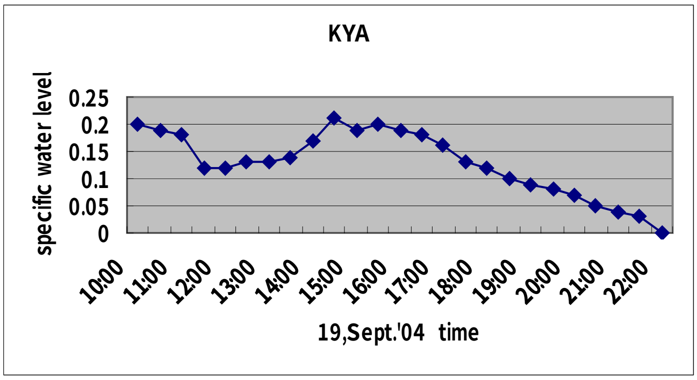

Fig.1 Time change of water level at Kya station

Fig.2 and Selawati station in Fig.3. Since sea water might penetrate to the river channel in period of rising tide, the survey in this time was not suitable to investigate the behavior of sea water. However, rising stage clearly appears from 12:00 to 15:00 at Bakung and Paduran stations, thus the time change of salinity concentration (readings of electric conductivity) will be remarkable in this time range at these stations.

Current velocity:

Figs.6-8 depict time changes of vertical velocity distributions of the current at the center of channel at Bakung, Bangah and Paduran stations, respectively. Vertical axis in the figures is taken for water depth, horizontal axis toward the right side direction is for velocity in m/s and horizontal axis toward left side direction is for hours of observations. While in the rising stages of water level, the flow tends to stagnate or to go upstream so the velocities take smaller values, in the ebb stages the flow runs with a higher velocity. To be noteworthy, in the ebb stage current becomes faster near the bottom, so the velocity distribution indicates an exponential curve increasing with water depth. The property will result in rapid retreat of the salinity water.

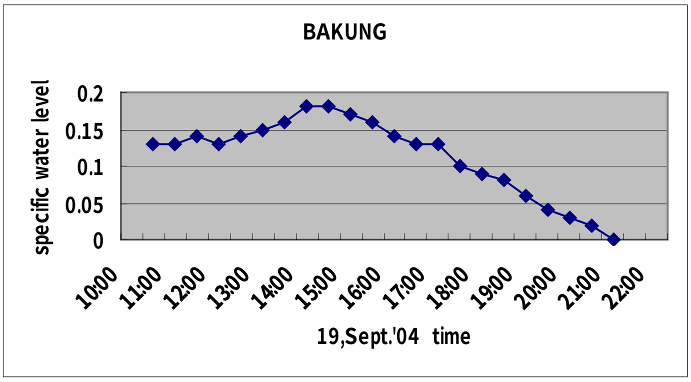

Fig.2 **Time change of water level at Bakung station**

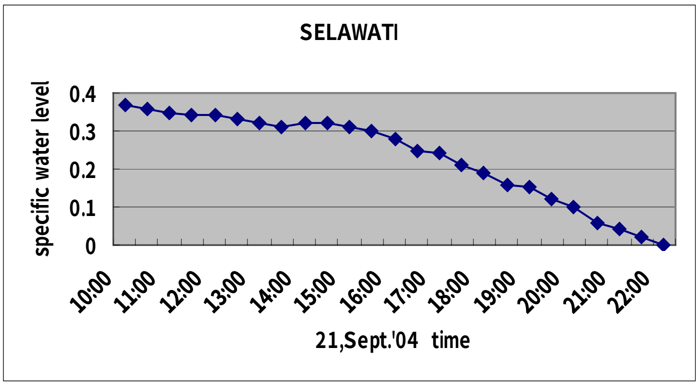

Fig.3 **Time change of water level at Selawati station**

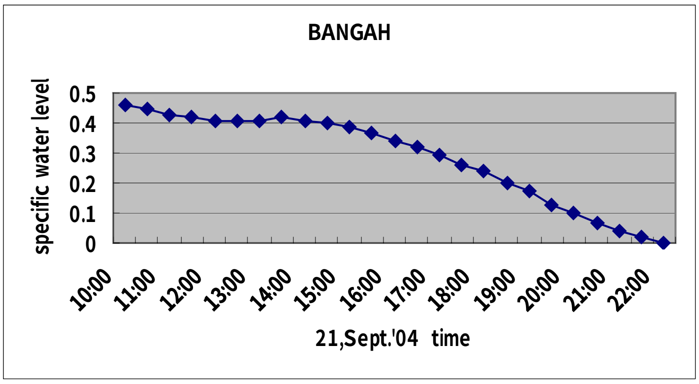

Fig.4 **Time change of water level at Bangah station**

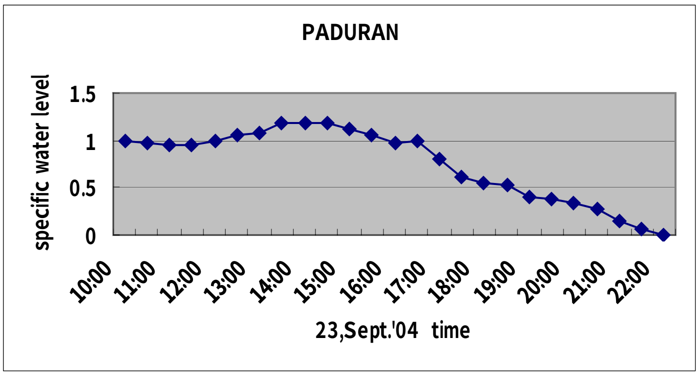

Fig.5 **Time change of water level at Paduran station**

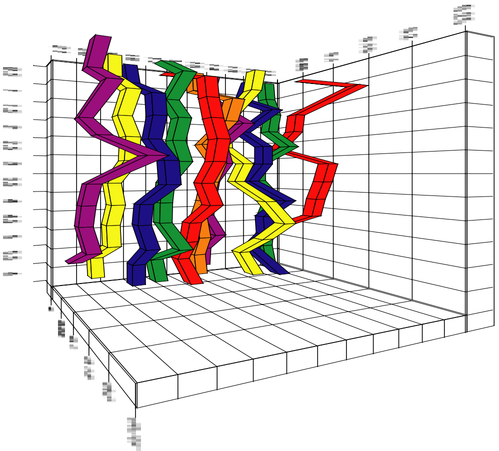

Fig.6 Time change of current velocity distribution at Bakung St. on 19, Sept. 2004

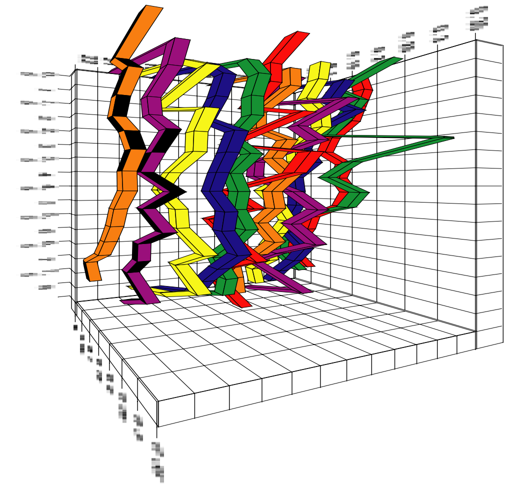

Fig.7 Time change of current velocity distribution at Bangah St. on 21, Sept. 2004

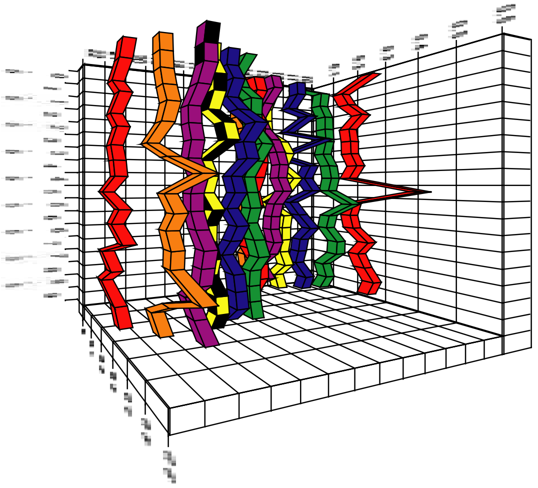

Fig.8 Time change of current velocity distribution at Paduran St. on 23, Sept. 2004

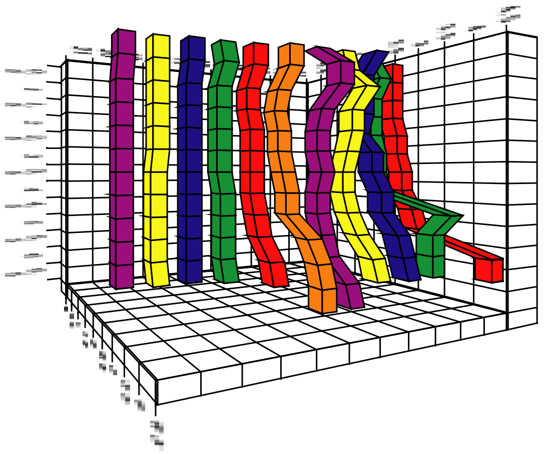

Fig.9 Time change of electric conductivity distribution at Bakung St. on 19, Sept. 2004

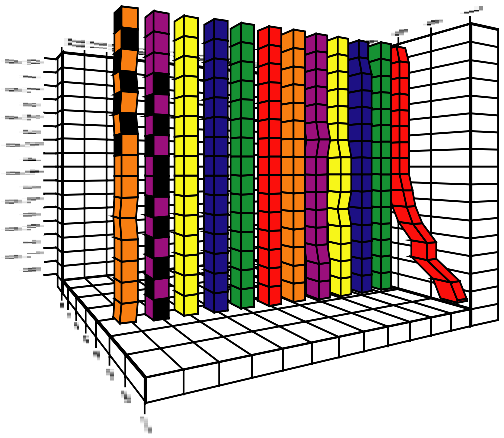

Fig.10 Time change of electric conductivity distribution at Bangah St. on 21, Sept. 2004

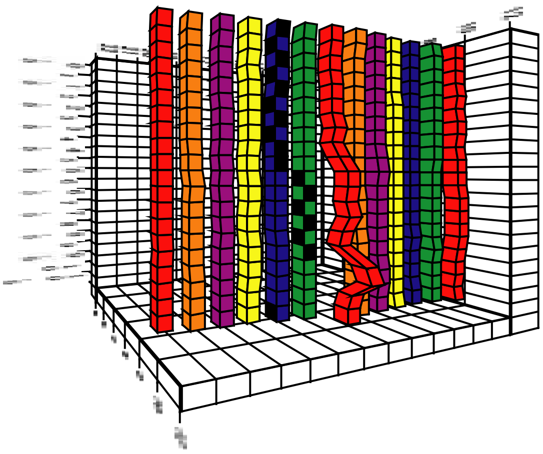

Fig.11 Time change of electric conductivity distribution at Paduran St. on 23, Sept. 2004

Electric conductivity:

Figs.9-11 show time changes of vertical distributions on the observed electric conductivities at the center of channel at Bakung, Bngah and Paduran stations, respectively. Vertical axis in the figures means water depth, horizontal axis toward right side direction corresponds to value of electric conductivity indicated in mS/cm and horizontal axis toward left side direction corresponds to hours of observations.

Observed values of conductivity were so low, that they could not be counted as salinity. However, the lower the stations are located, the larger average conductivity values become as known from the figures. In the rising stage of water level, the conductivity show comparably larger value, but in the ebb stage, the conductivity seems to gradually decrease. Furthermore, vertical distribution of the conductivity for the rising stage shows the exponential curve increasing with water depth. Hence the obtained electric conductivity will reflect the effect of sea water penetration.

Figs.12-14 are time changes of depth averaged conductivity values at each station. The variation curve at Bakung station, well agrees with that of water level change in Fig.2. The curve at Bangah station in Fig.13 has no peak at the corresponding time of the high water in Fig.4, though both curves show a close tendency. Delay of peak from the high water appears in the curve in Fig.14 at Paduran station, where the water level change ranges over 1meter or more as seen in Fig.5.

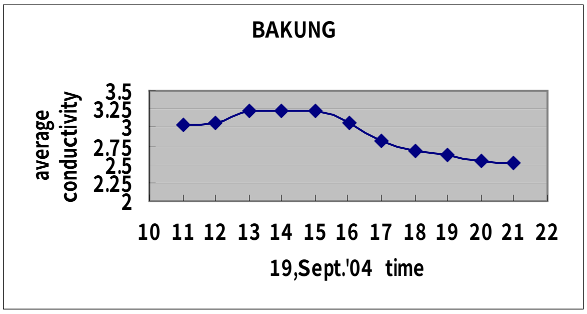

Fig.12 Time change of depth averaged electric conductivity at Bakung St. on 19, Sept. 2004

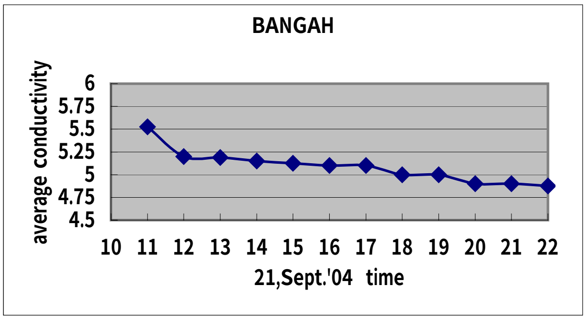

Fig.13 Time change of depth averaged electric conductivity at Bangah St. on 21, Sept. 2004

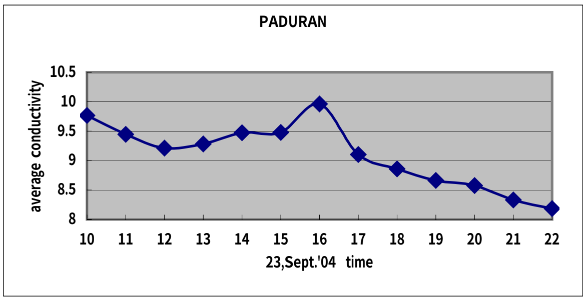

Fig.14 Time change of depth averaged electric conductivity at Paduran St. on 23, Sept. 2004

Summary and Remarks

Survey for sea water penetration to the Sebangau River due to a tidal wave propagation was performed between 19 and 23 in September, 2004. Simultaneous measurements with respect to water level, current velocity and electric conductivity were carried out at five gauging stations of the river and obtained the following results.

1. Electric conductivity of the river water, which could indicate thin salinity concentration, increases together with the rising of water level due to a tidal wave and decreases with the ebb.
2. Vertical distribution of the conductivity for the rising stage shows the exponential curve as increasing with water depth.
3. At Paduran station where the water level changed over 1 meter, wave motion of the salinity concentration propagates with time lag from the tidal wave motion.

   The facts of 2 and 3 suggest that the bottom current near the Paduran station has a feature of density current.
4. Current velocity decreases together with the rising of water level due to a tidal wave and increases with the ebb.
5. Vertical distribution of the current velocity for the ebb stage shows the exponential curve as increasing with water depth.
6. It was difficult to discriminate differences of the feature of tidal motion between the upstream reach from Bakung station and the lower reach from Bangah station without the difference of the values of electric conductivity, though there is the boundary between these two stations that Haraguchi et als. pointed out as effect of the sea water appeared.

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2) Haraguchi, A., S.H. Limin and U. Darungy: Water Chemistry of Sebangau River and Kahayan River in Central Kalimantan , Indonesia, Environmental Conservation and Land Use Management of Wetland Ecosystem in Southeast Asia, Annual Report for April 2003 – March 2004, Core University Program between Hokkaido University, Japan and Research Center for Biology, LIPI, Indonesia, 42 -57, 2004

Deposition of wash load observed in Kahayan and Rungan rivers.2

by

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Introduction

There are many digging machine of gold dusts along K(Kahayan River) and R(Rungan River) located upstream from Bukituti(K) and Tangkiling(R), see Fig-1. Both river valleys are supplied with sediment from the mountains of central Kalimantan and very fine sand dug by the gold mining work from the valley is put into the river flows. The fine sand, the diameter less than 70 μ m, is called “wash load”. Although it is said that wash load dose not deposit in flowing water, we observed it’s deposition in K and R1).

Fig-1

For each river reach shown in fig.2, we considered four deposition-mechanism as following:

① Deposition around the point:According to the analysis of the water samples it seemed to occurr in the dry season and not in the wet season.

②Electric coagulation: It is suggested because we observed both in dry and wet seasons.

③Effect of salt wedge; Because of the sudden decrease of the concentration of ss near Pilang , where the salt wedge could come up. We denote Kd for the lower reach of K from Palangkaraya.

④Critical concentration: In the sediment yield area upstream from Bukituti we observed very high concentration more than 500 ppm in the wet season, then they decreased downstream to near 200ppm. This suggests the existence of a certain critical concentration.

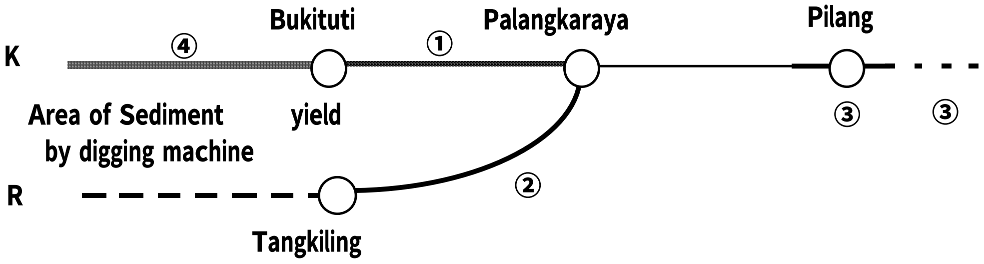


Fig.2

This time we mainly investigated on the mechanism ①, because of the large effect on geometrical change of rivers.　The state of the point bars in K and R are as following.

Ｋ：　Palangkaraya－ Bukituti→fully developed. .
　　　Palangkaraya－ Pilang→Strong meandering but poor bars.
　　　The lower reach from Pilang → Week meandering with no bar.
R：　Tangkiling－ Palangkaraya → braided with no bar.
　　　The upper reach from Tangkiling → Point bars.

Methods

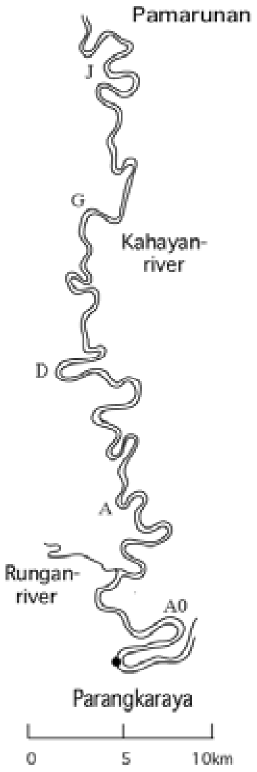


Fig-3.1

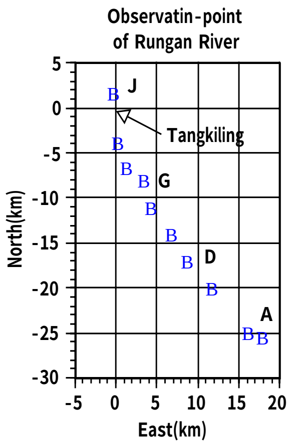
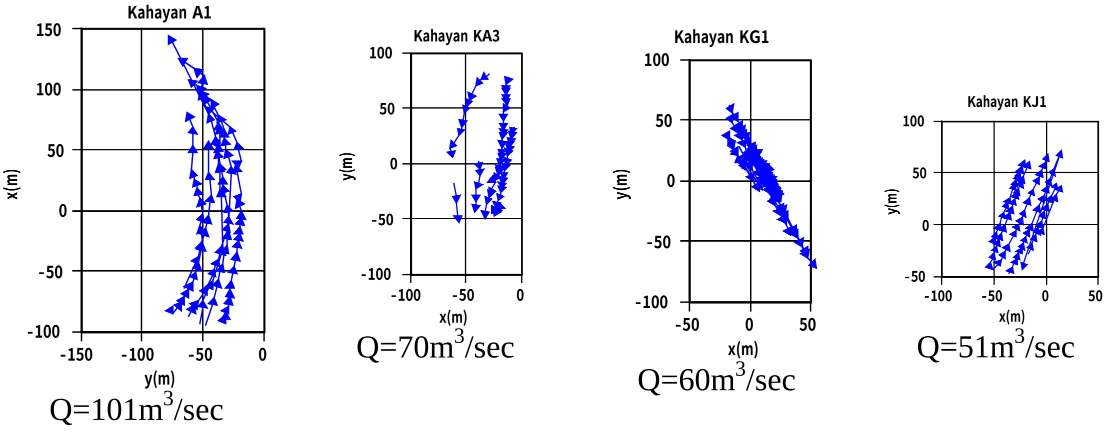


Fig-3.2

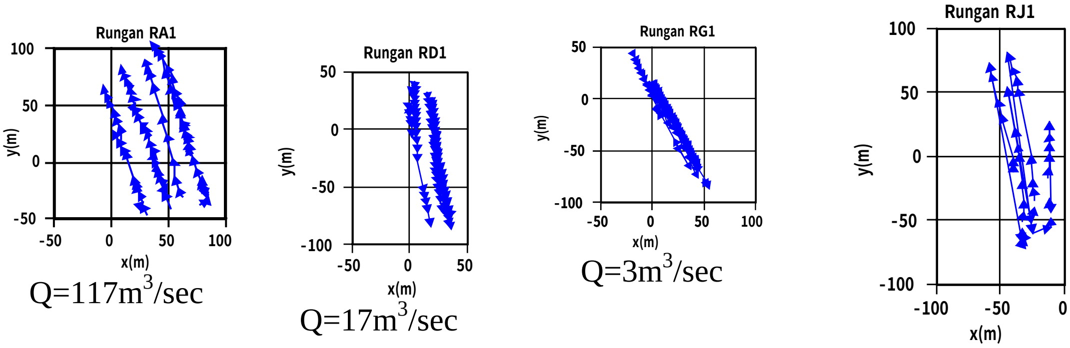
The sediment accumulation survey were done for both K and R at at the points A,D,G,J denoted in Fig.3 . We measured the water discharges at the same points to see their flow structure. Because of bend flows the traces of the boat were intricate as seen on Fig.4 and we got very scattered values.　J points for both K and R were chosen because they have rather uniform traces. Partly we took account of the values observed by the time and they are assigned to be 50 m^3/sec for K and 40m^3/sec for R.

The water near the surface was picked up to infiltrate the 8 μm mesh size filter, and concentration in weight is used. Plane view of point bars were surveyed using a portable GPS instrument. Sediment layers were measured by a shear stress meter. Inserting it into the ground indicated the existence of thick soft layer and thin hard layer alternatively. For the time being we regard the soft layer between the two hard layers as accumulated depth within a year.



Q=101m^3/sec　Q=70m^3/sec　Q=60m^3/sec　Q=51m^3/sec

Fig-4.1



Q=117m^3/sec Q=17m^3/sec Q=3m^3/sec Q=36m^3/sec

Fig-4.2

Concentration of ss

Fig-5 shows the change of the concentration along the river reach. $G_c = -dC/dx$ (ppm/km) , the gradient of the lines which approximated the data are shown on the table 1 with those observed by this time. They have similar values for the upper 3 data in dry season. On the table Q_d , the deposition rate per 1km 1 year is calculated by

$$Q_d = 32 G_c Q (ton/km \cdot year).$$

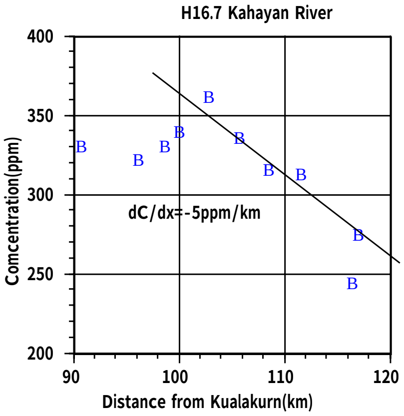


Fig-5.1

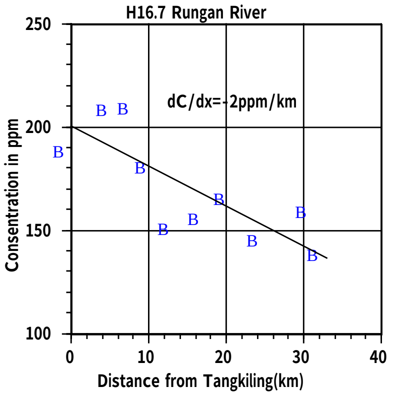


Fig-5.2

Table– 1

	Kahayan river				Rungan river			
	G_c ppm/ km	Q m^3/ sec	Q_d ton/ km-year	C_d ppm	G_c ppm/ km	Q m^3/ sec	Q_d ton/ km-year	C_d ppm
2002.9	5	30	5000	200		50		100
2003.9	7	80	18000	200	2	25	1600	60
2004.7	5	50	8000	260	2	40	2500	140
2003.3	0	400	0	150	0.9	130	3700	60
2004.1	0	400	0	150	0.6	200	3800	25

Fig-6 is Q vs. $C = C_d$ just upstream from their junction and shows the origin of ss is a point source.

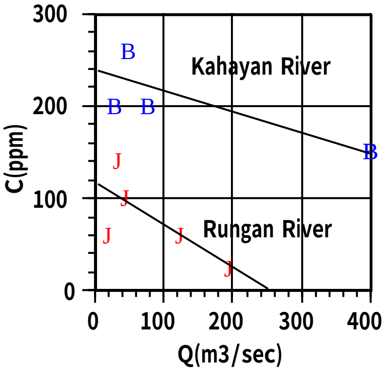


Fig-6

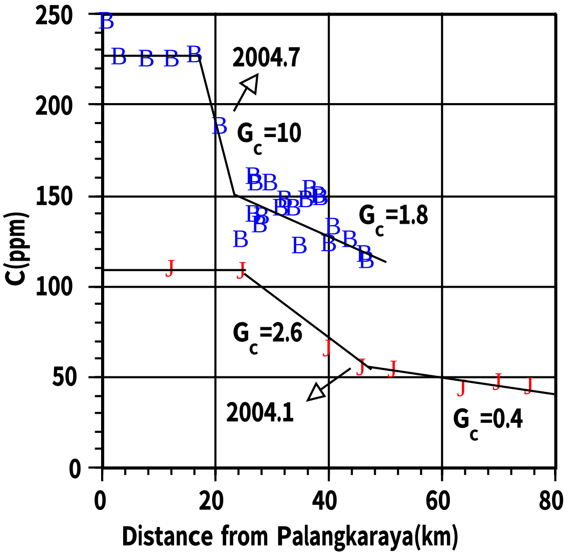


Fig.7

Fig.7 shows the variation of C of Kd with that of 2004.1. They decrease rapidly from s_1 and gradually from s_2 and s_3 denotes the end point of the observation, see Table 2 . G_{c12} and G_{c23} are G_c for $s_1 \sim s_2$ and for $s_2 \sim s_3$, respectively. Salt wedge might come up by s_1. That of the dry season is 8km father upstream than that of the wet season. C_i at s_i are shown on Table 3. Although the values of C and G_c in the dry season are larger than those of the wet season, the decreasing rate for $s_1 \sim s_2$ showed nearly the same value 0.6. Q_D,total amount of the deposition between s_1 and s_3 per year are estimated provided that the same flow condition continue for a year by

$$Q_D = 32(C_1 - C_3)Q(ton/year)$$

and are shown on the Table. Simple averaged value for both seasons becomes 500,000ton/year. Since s_1 of the dry season shift to near s_2 of the wet season, the deposited in the dry season between s_1 and s_2 may be brought to the lower reach from s_1 in the wet season. If we assume that the total of Q_D deposited between s_1 and s_2 of the wet season, the averaged thickness of the deposition is estimated roughly as 4cm/year from the relation

$$Q_D = 2.65(s_2 - s_1) \cdot B \cdot D$$

where $B = 250m$, see Fig-8.

Table-2

	s_1 (km)	$s_2(km)$	$s_3(km)$	G_{c12}	G_{c23}
2004.7	18	24	48	10	1.8
2004.1	26	45	80	2.6	0.4

Table 3

	C_1	C_2	C_2/C_1	C_3	$C_1 - C_3$	$Q(m^3/s)$	Q_D (ton/y)
2004.7	225	150	0.67	115	110	50	173x10^3
2004.1	110	60	0.55	40	70	400	883

Geometrical aspect of Kd

Fig.8 shows Q、velocity u、depth d and width B in the order of observations. The increment is about 2.3km on the straight line from Palangkaraya (the lower half is about the half of the upper half). Fluctuation of B from 150m to 300m with the wave length λ from 10km to 15km leads $\lambda / B \approx 40$. Kinoshita2) observed a special bed deformation with a very long wave length named bed load swell. In Tone river from 40km to 80km, it was from 6 km to 7km. Since B= 400～500m, $\lambda / B \approx 14$. It is possible that we observed a similar phenomenon in Kd. The phase between d and B is nearly inverse. u and d are in phase at the upper reach, but out phase at the lower reach.

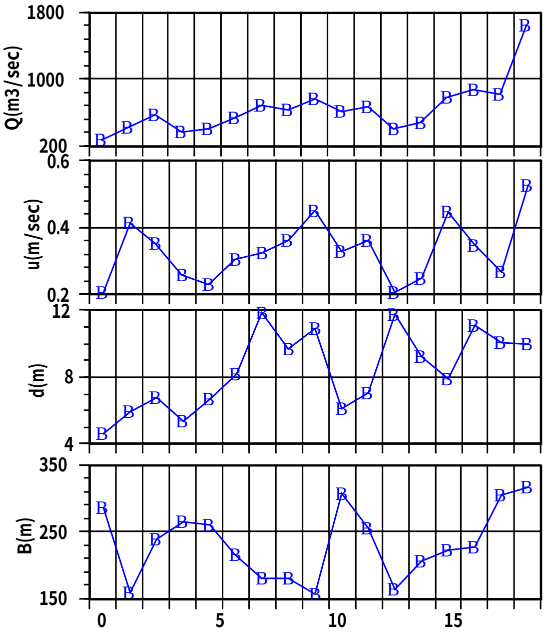


Fig.8

Sediment deposition survey

Fig-9 shows plane view of four point bars. Some wedge shaped cut are seen along each bank. Kahayan A0 has many longer cuts which looks like the back of a dinosaur. The longest one reaches more than 100m. It may be one of the big dunes which were observed across these point basr. Both Kahayan A and Rungan J have a tendency divided into 2 or 3 parts, probably because they were elongated by the long bend which are too long compared to the hydraulic length of sand bars　We explain the state of the deposition of silt around point bars using notations from A to F denoted on the plane of Kahayan D. There are rather much deposition on area A. It may be caused by the wake flow of woods at the upstream end of the bars. There is a small amount of deposition around the wedge type cut like E. Sometimes it scatter as a group of spots. Along A-B-C steps formed by a complex of deposition and erosion were observed. Fig.10 is a typical of the step. There is rather much deposition at small inner bend like F which is located in outer bank.

The largest deposition will occur over the area C-D. Typical scale is 200m×10m. Fig.11 shows the lateral distribution of deposition from the bank to the plant area. Since the depth of the first layer is nearly uniform, the deposition may occur in the wet season though we observed $G_c \sim 0$ .in the wet season. Following two reason may be considered.

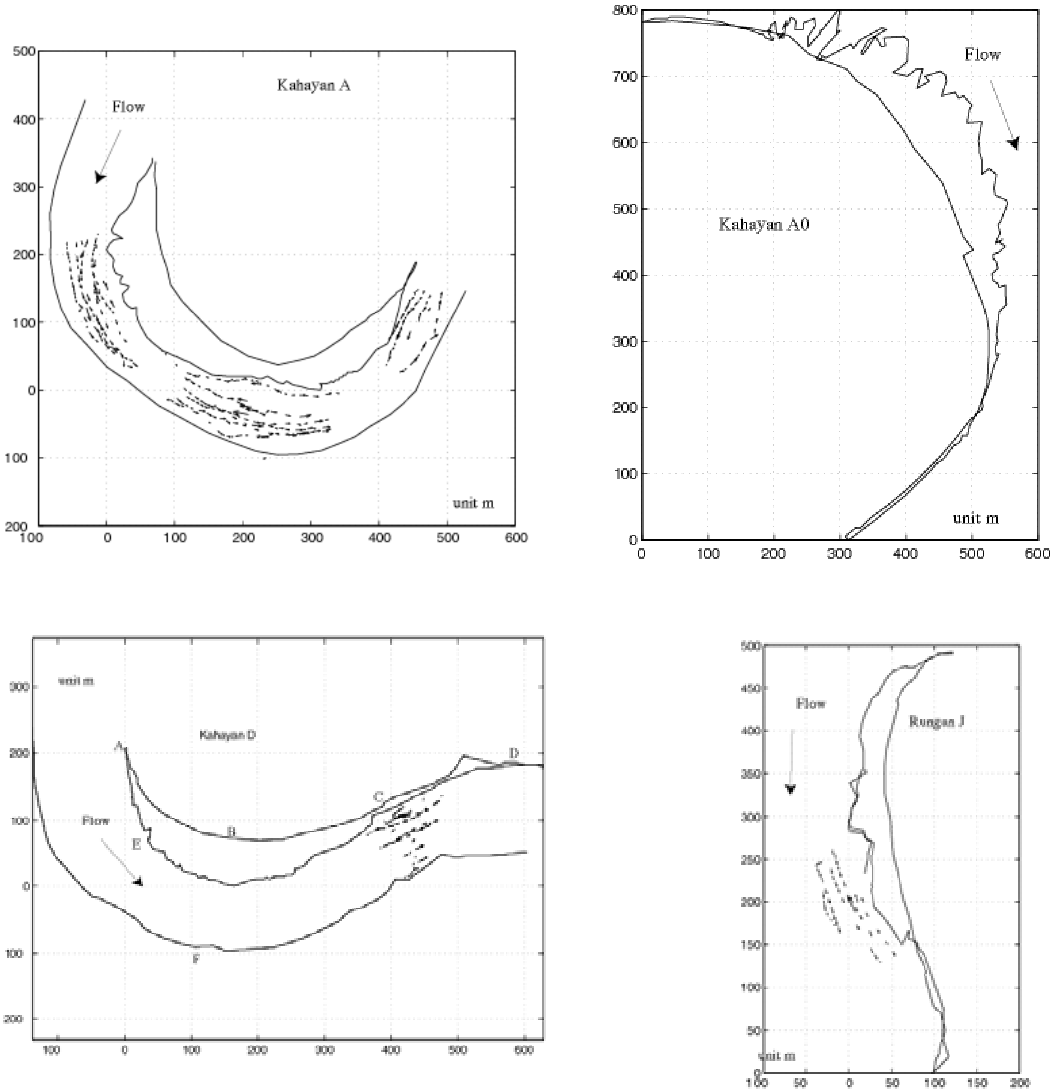


Fig.9

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① As Q increases, G_c decreases and it reached nearly zero in the wet season.
② In the wet season deposition and erosion are in balance.

Let's roughly estimate G_c in the wet season.

the deposition rate /year → 2.6 × width 10m × length 100m × depth 1m
3000ton/year

From Fig3.3 , the number of bend → 1bend/km

From these

$$Q_d = 32 G_c Q = 3000 ton/km \cdot year$$

we get $G_c \sim 0.2\,ppm/km$ assuming $Q = 400\,m^3/\sec$.
If we assume 2 months for the period of deposition in the wet season, it makes $G_c \sim 1\,ppm/km$. It is hard to assess such low value of G_c, because of rather large scatter of C for K. We think it is hard to explain ②. Therefore we consider the possibility of ①.

We denote the depth of the layers d_{p1}, d_{p2}. . . in the order from the top one. You can see $d_{p2} \approx d_{p3} \approx d_{p4} \cdots$, and d_{p1} is generally fairy larger than the lower one. Now we can list up the following reasons.

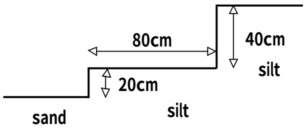

Fig-10

① In the wet season from the later 2003 to the earlier 2004, occasionally there are much deposition.
② Erosion will occur after the deposition.
③ Thin hard layer would be formed dividing the top layer.

Fig.12 shows the height of erosion from the water level along the bank of C→D of Kahayan A. This may show that the surface height of deposition become higher toward downstream. However we cannot reject the possibility that more erosion will occur toward upstream in some stage of the wet season, so we listed ② up. Till now we have observed though only two times that the hard layers were composed by leaves or iron, so we consider that the possibility of ③ is very low.

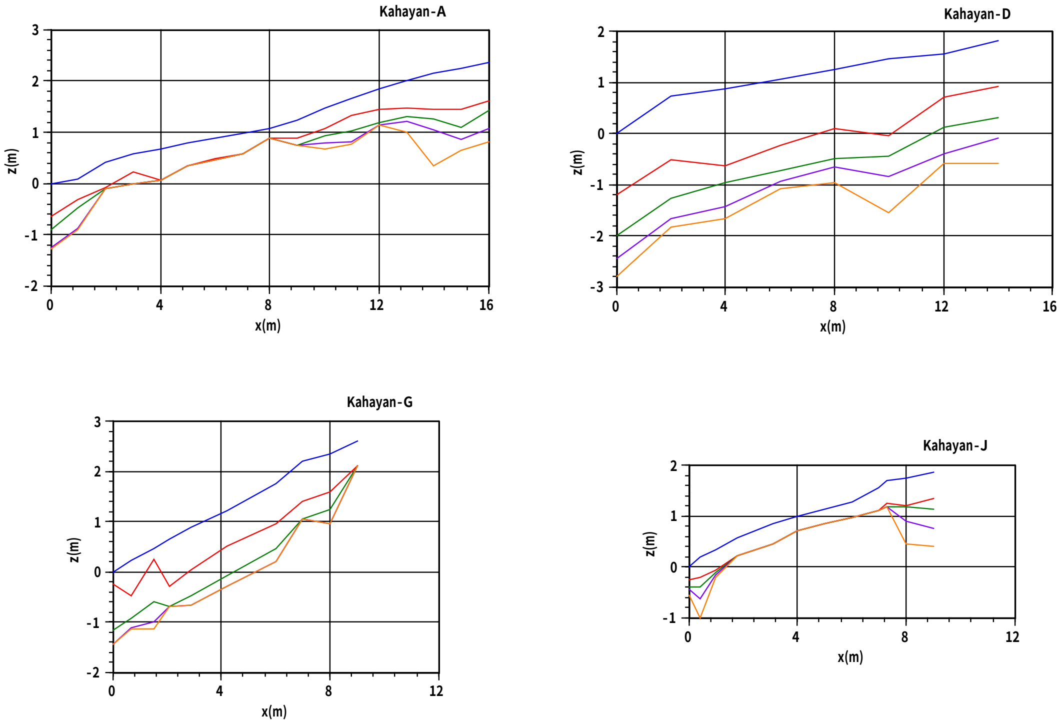

Fig.11.1

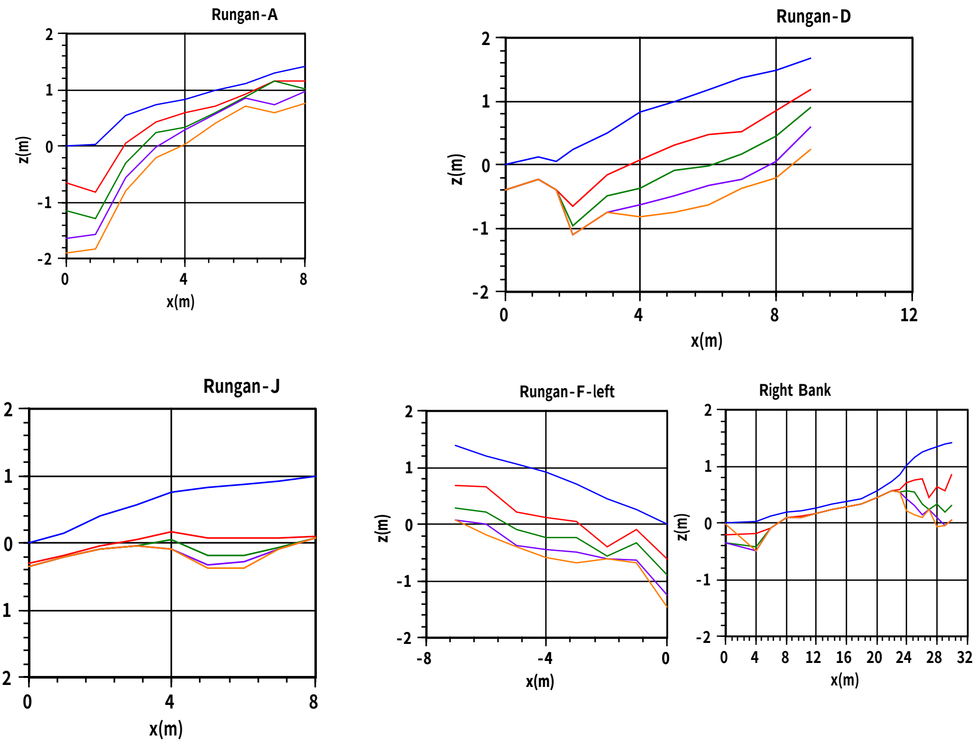

Fig.11.2

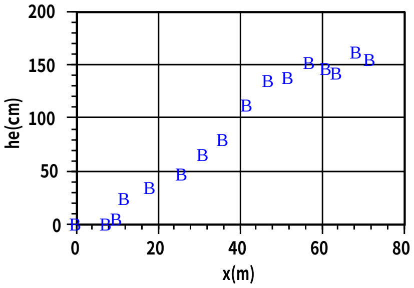

Fig.12

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Mercury contamination in river water and sediment in Central Kalimantan, Indonesia

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Introduction

Gold mining activities have recently increased in the catchment of the Kahayan River in Central Kalimantan. Water contamination with mercury due to the mining activities has been of concern to the residents along the Kahayan. Here the results of the survey on Hg contamination in river water and sediment in the Kahayan and the major branch, the Runga River, are reported with results of analysis of the Hg concentrations of intake water of the Kahayan and the treated water for drinking.

Methods

The survey from Tubangmiri to Palangkaraya in the Kahayan was carried out on 13-14 July, 2004 and from Mungkubaru to the confluence of the Kahayan in the Runga on 15-16 July, including the survey on the water in some branches of the rivers. Water samples were collected directly and sediment samples were taken by a bottom sampler. The number of gold mining machine was counted along the rivers. The water and sediment around the mining machine in upper Takaraspager which is located in the upstream of the Runga were also taken. The intake water of Kahayan and the treated water for drinking were sampled at the purification plant in Palangkaraya on 17 July.

Results and discussion

Table 1 shows that the result of the survey including pH, electric conductivity (EC) and total Hg concentration in water, and total Hg content in sediment of all studied sites. Figure 1 and Figure 2 show total Hg concentrations in water and total Hg contents in sediment in the Kahayan and the Runga, respectively. Higher Hg concentrations in branches than those in the main stream were observed in both the Kahayan and the Runga. Although total Hg were detected in almost of all water samples collected, the Hg concentrations were lower than 0.002 mg/l, which is the maximum tolerable concentration of the water standard in Indonesia.

Table 1. Sampling sites and their pH, EC, and total Hg concentration in water and sediment

River	Date Time	Sampling Site	GPS				Depth	Water Temp.	pH	EC	Total Hg in water	Total Hg in sediment
				deg.	min.	sec.	m	℃		μS/cm	μg/L	mg/kgDW
Kahayan	2004/7/13	Upper Tubangmiri	S	0	55	22.2	1.7	26.3	6.84	22.8	0.034	0.023
	15:27		E	113	33	5.6						
	2004/7/13	Upper Tanjunguntun	S	0	56	58.8	1.8	26.3	6.24	31.2	0.022	0.017
	16:27		E	113	36	43.2						
	2004/7/13	Upepr Tewah	S	1	1	46.1	1.5	26.1	5.99	25.0	0.034	-
	17:01		E	113	44	0.2						
	2004/7/13	Upper Kualakurun	S	1	5	7.6	4.0	26.0	5.93	24.9	0.038	0.014
	17:28		E	113	50	11.2						
	2004/7/14	Upper Hurungbunu	S	1	15	0.6	3.0	25.7	6.14	21.3	0.045	0.014
	8:39		E	113	54	2.8						
	2004/7/14	Upper Tumbangempas	S	1	22	53.9	3.6	25.6	5.40	17.2	0.061	0.004
	9:25		E	113	53	53.0						
	2004/7/14	Upper Sepangsimin	S	1	29	12.8	2.7	25.9	5.43	19.2	0.059	-
	9:53		E	113	54	26.3						
	2004/7/14	Upper Goha	S	1	38	20.6	6.6	26.5	5.94	21.8	0.065	0.067
	10:24		E	113	55	42.4						
	2004/7/14	Upper Lawang Uru	S	1	46	45.5	3.1	27.2	5.70	23.6	0.043	-
	11:27		E	113	55	11.5						
	2004/7/14	Upper Tahawa	S	1	52	16.7	5.2	27.2	5.49	21.4	0.039	0.088
	11:54		E	113	56	38.3						
	2004/7/14	Upper Sigi	S	2	1	26.6	3.4	27.4	5.49	20.4	0.032	-
	12:36		E	113	55	36.4						
	2004/7/14	Upper the confluence of Runga	S	2	7	45.9	2.6	27.5	5.61	21.1	0.032	0.003
	13:03		E	113	55	49.3						
	2004/7/14	Palangkaraya	S	2	11	45.8	5.3	27.5	5.48	18.1	0.030	0.060
	13:23		E	113	56	17.9						
Miri (branch of Kahayan)	2004/7/13	Between Tubangmiri and Tanjunguntung	S	0	54	33.6	1.5	26.0	7.10	40.1	0.026	0.024
	15:55		E	113	33	0.5						
Small river A (branch of Kahayan)	2004/7/14	Upper the confluence (Lower Tumbangtariak)	S	1	14	18.2	1.0	25.5	3.50	34.3	0.196	0.007
	8:29		E	113	52	58.7						
Small river B (branch of Kahayan)	2004/7/14	Upper the confluence (Near Pilangmunduk)	S	1	16	50.9	2.1	24.6	3.96	10.9	0.174	0.098
	8:54		E	113	54	25.2						
Runga	2004/7/15	Upper Mungkubaru	S	1	39	10.2	3.5	26.5	5.02	10.7	0.028	0.005
	10:30		E	113	41	29.7						
	2004/7/15	Upper Petukbarunai	S	1	43	55.0	4.3	26.7	4.43	10.8	0.030	-
	12:17		E	113	42	11.5						
	2004/7/15	Upper Petut Bukit	S	1	51	0.5	3.5	27.4	4.51	11.5	0.034	0.017
	12:47		E	113	43	52.4						
	2004/7/15	Upper Tangkiling	S	1	58	14.2	6.3	27.8	4.27	12.4	0.036	-
	13:18		E	113	45	45.5						
	2004/7/15	Upper Marang Balu	S	2	4	55.5	5.1	27.6	4.47	12.0	0.034	0.003
	14:17		E	113	50	20.9						
	2004/7/15	Mouth of Runga	S	2	9	47.3	5.5	27.8	4.50	12.2	0.016	0.115
	14:43		E	113	55	30.9						
Small river C (branch of Runga)	2004/7/15	(Upper)	S	1	41	51.3	1.7	26.6	3.39	48.5	0.073	0.200
	11:33		E	113	39	57.4						
	2004/7/15	Upper the confluence of Runga River	S	1	42	24.3	2.5	26.5	3.46	46.3	0.081	0.238
	12:01		E	113	40	49.3						
Small river D (branch of Runga)	2004/7/16	near a mining machine	S	1	41	36.2	-	-	-	-	-	0.003
	9:55		E	113	37	51.5						
	2004/7/16	A pond close by a mining machine	-				-	28.0	4.68	23.8	1.373	0.005
	10:00											
	2004/7/16	River water lower the mining site	S	1	41	35.3	1.0	27.7	4.01	49.2	0.117	0.006
	10:04		E	113	37	53.2						
	2004/7/16	Upper Takaraspager	S	1	41	30.9	0.8	27.2	3.97	49.9	0.079	0.181
	10:18		E	113	38	12.5						
A Water Plant for tap water	2004/7/17	Raw water (Kahayan river water)	S	2	12	21.8	-	27.7	6.25	18.6	0.051	-
	8:29		E	113	55	30.1						
	2004/7/17	Treated water in a reservor tank	-				-	27.4	5.56	74.3	*ND	-
	8:50											

*ND: Not Detected

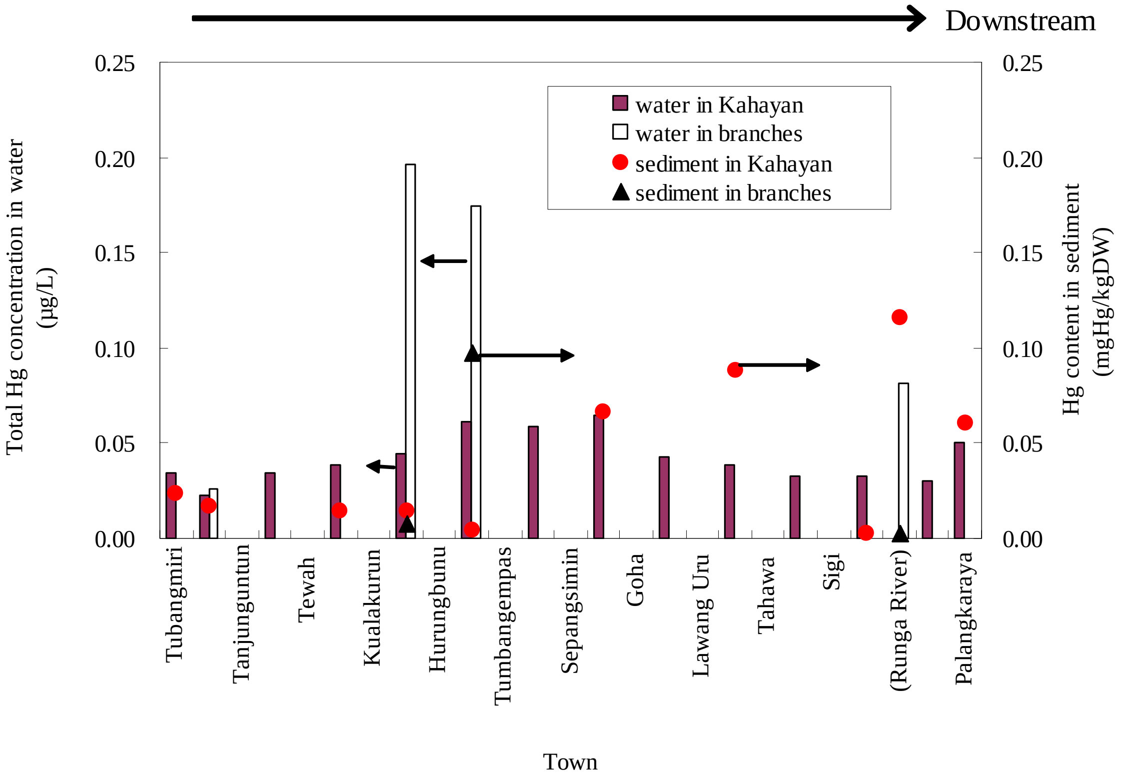

Fig.1. Hg in water and sediment in Kahayan River

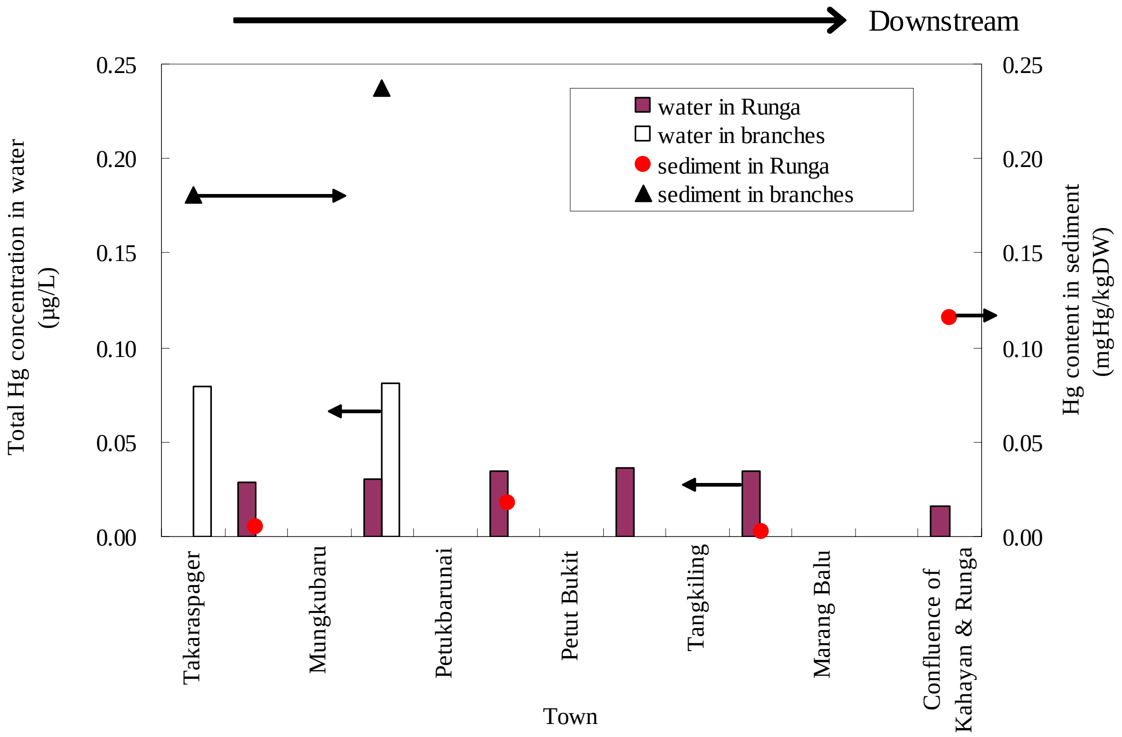

Fig.2. Hg in water and sediment in Runga River

The Hg concentration in the water near the mining activity was high while the Hg content in the sediment was relatively low. Mercury was undetected in the drinking water though the concentration in raw water was about 0.05μg/l. The Hg contents in sediment were up to 0.24 mg/kg in these studied sites, indicating that they were so far in a relatively low Hg contamination level comparing with the Hg contents in the sediment in the gold mining area in Jawa observed in 2002 by Yustiawati et al. (2003), which were up to almost 70mg/kg.

Figure 3 and 4 show the Hg concentrations in river water and the Hg contents in sediment with the cumulative number of gold mining machine in the Kahayan respectively, and Figure 5 and 6 show those in the Runga. There were some positive relationships between the Hg concentrations in water or the Hg contents in sediment and the number of the mining machine in the Kahayan, suggesting the Hg contaminations directly related to the gold mining activities in spite of low concentrations in river water at the present time. There were 1097 gold mining machines reported between Tewah and Palangkaraya in the Kahayan in Sep 2002 (2003), 932 machines observed in our survey in December 2003, and 999 machines in July 2004, which indicating the continuing gold mining activities in the Kahayan. It is important to continue the monitoring of the Hg concentration in water and the Hg contents in sediment in the river in the future.

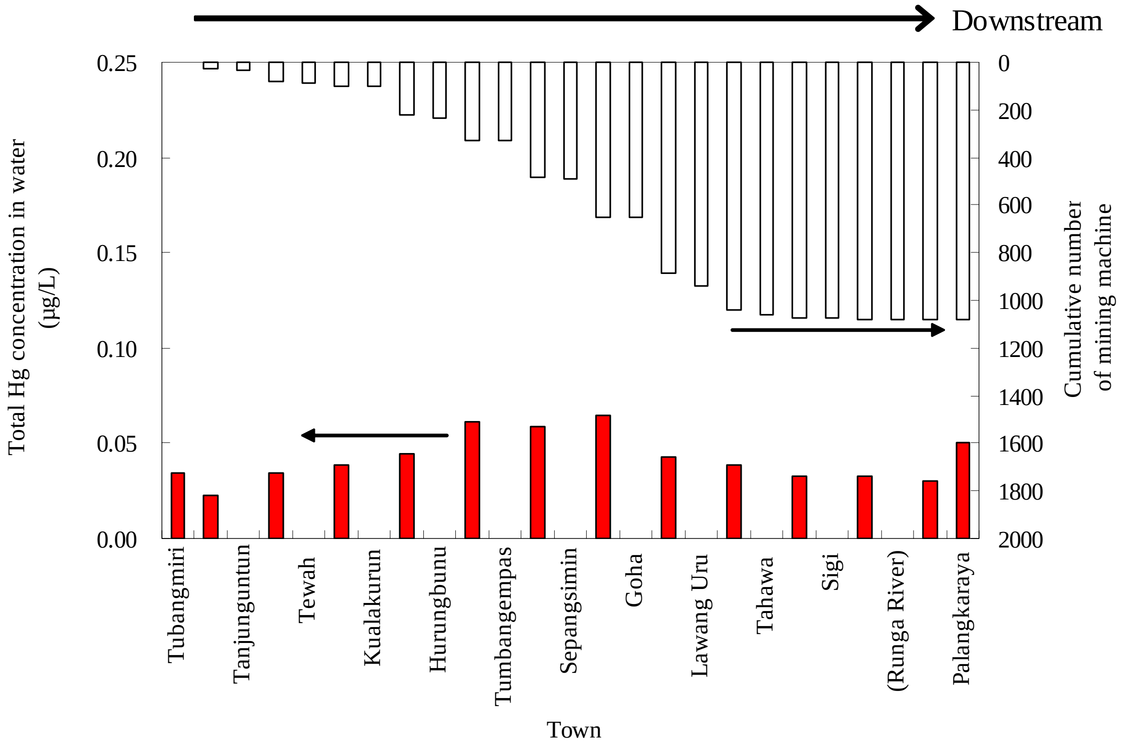

Fig.3. Hg concentration in water and cumulative number of minig machine in Kahayan River

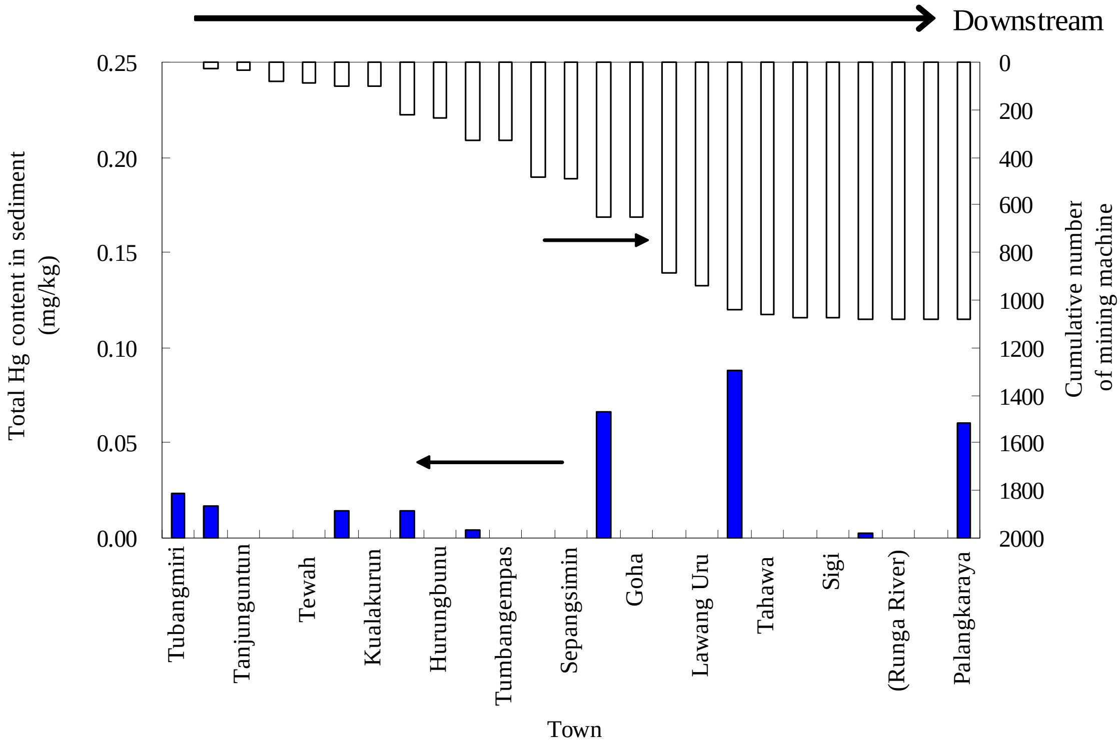

Fig.4. Hg content in sediment and cumulative number of minig machine in Kahayan River

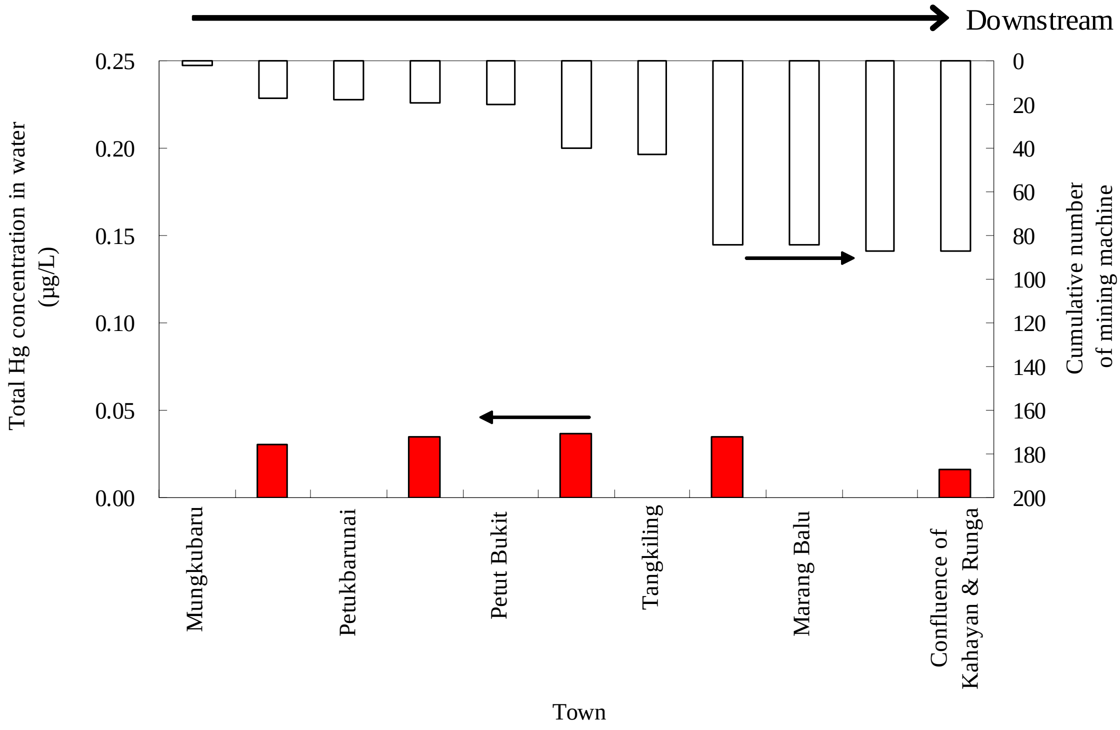

Fig.5. Hg concentration in water and cumulative number of minig machine in Runga river

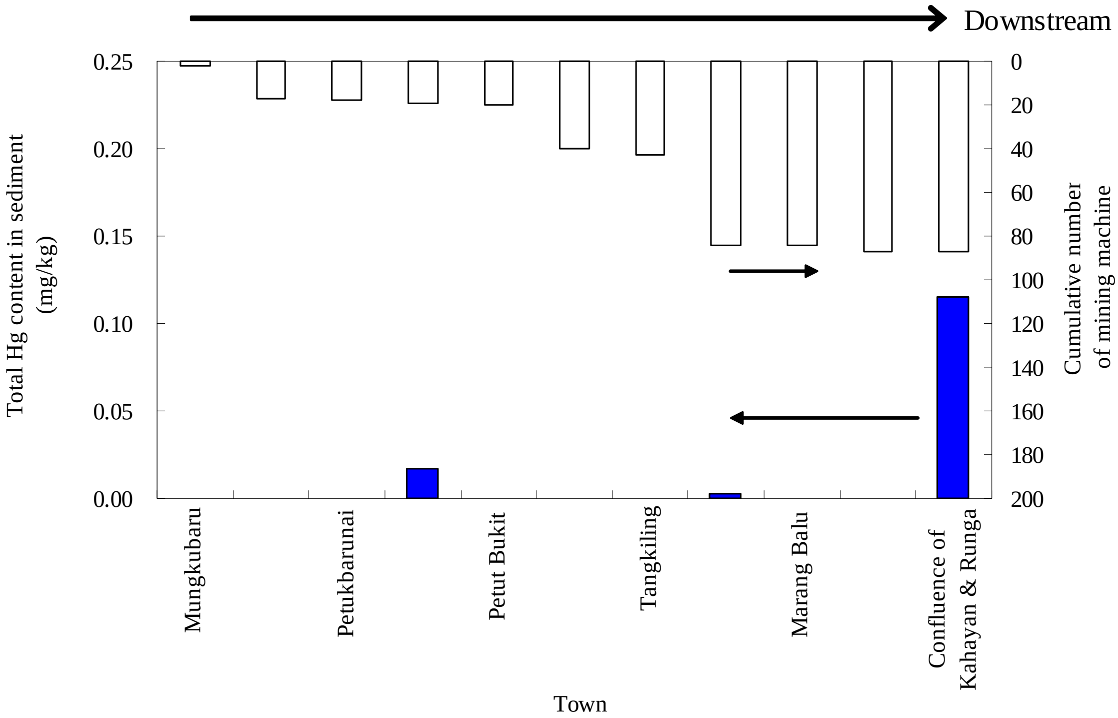

Fig.6. Hg content in sediment and cumulative number of minig machine in Runga river

Reference

Yustiawati, M. Suhaemi Syawal, Motoki Terashima, Tomoyuki Kimura and Shunitzu Tanaka (2003) Speciation analysis of mercury in river water and sediment in West-Jawa and Central Kalimantan, Indonesia: Environmental Conservation and Land Use Management of Wetland Ecosystem in Southeast Asia Annual Report for April 2002- March 2003, Hokkaido Univ.,pp210-218

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

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1. Introduction

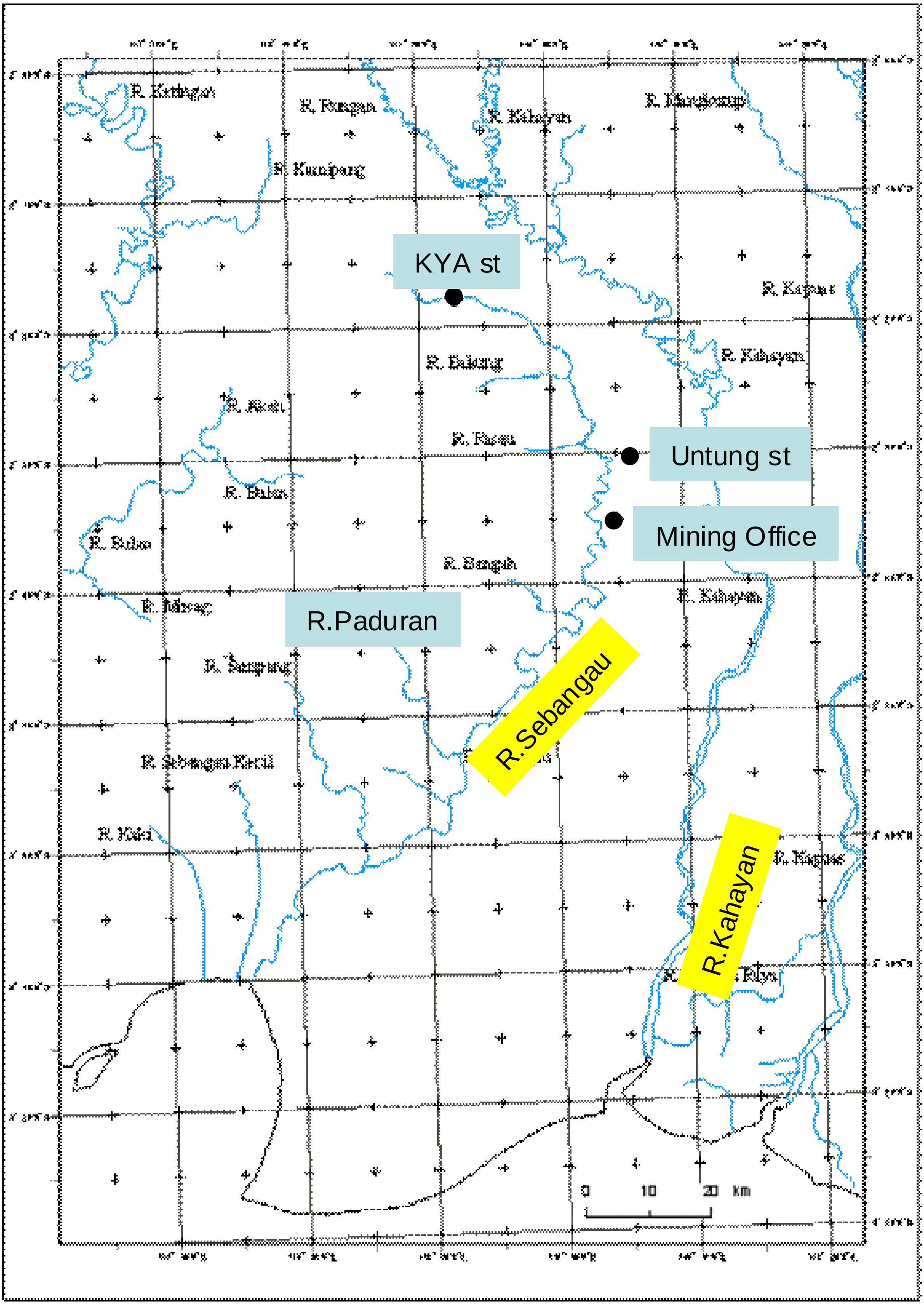
The purpose of this study is to research the influence of human activities to the natural wetland environment by determining characteristics and behavior of chemical components in the water of Sebangau and Kahayan river area. Also, the water quality is strongly related to agriculture, drinking supply and ecosystem, so it is important for the inhabitant to know the water condition.

Especially, it is considered that development of Parangka Raya area which is being urbanized recently effects water quality.

2. Study Site

In this year, study sites are mainly three areas. Each of them is in or near from Sebangau and Kahayan River, and is in a different degree of development. KYA points are along Sebangau river and in a natural condition, Untug points are along the branch of Sebangau river in Karangbangkirai which has influence by human activities. Paduran points are in natural area and the brunch of the downstream of Sebangau river (figure,1). For the research, we teamed up with the staff of Palangka Raya University and LIPI from September 13th to October 3th 2004. Also, they have kept the sampling regularly.

We are still working on analyzing chemical components in water and it is not complete yet. In this paper, the data which have been taken so far are presented(table,1).



Figute1. study area

Table 1-1 Results of chemical components

Study Area	Ta	Tw	pH	EC	TOC	DOC	POC	NO_3-N
unit	℃	℃	-	μS/cm	mg/L	mg/L	mg/L	mg/L
Kya station 12/30/03	-	-	3.8	63.0	28.7	26.1	2.6	N/D
1/30/04	-	-	3.8	64.2	28.5	28.1	0.4	N/D
2/30/04	-	-	3.7	70.8	30.0	29.3	0.7	N/D
9/27/04	32	28	4.2	31.7	-	15.3	-	N/D
Kya G3	-	-	3.9	63.6	-	24.5	-	N/D
Kya G4	-	-	4.6	23.8	-	12.9	-	N/D
Kya G5	-	-	4.3	38.3	-	15.0	-	N/D
K・K	30.4	30.5	4.3	27.6	14.2	13.9	0.3	N/D
Bangah	-	-	1.1	42.0	*	*	*	0.89
Untung A112/30/03	30.6	29	3.9	65.3	32.5	27.3	5.2	0.00
1/30/04	-	-	4.0	49.4	28.4	24.8	3.6	0.82
2/30/04	-	-	4.0	55.2	26.7	23.3	3.4	N/D
9/28/04	-	-	4.5	49.9	28.0	24.1	3.9	1.6
Untung B1 12/30/03	-	-	3.9	66.1	31.6	24.8	6.8	1.7
1/30/04	-	-	3.9	59.9	28.2	24.5	3.7	0.78
2/30/04	-	-	4.0	57.4	26.4	23.5	2.9	N/D
9/28/04	33.5	30.5	4.4	55.9	29.6	23.1	6.5	N/D
Untung C112/30/03	-	-	4.0	63.0	29.7	23.1	6.5	N/D
1/30/04	-	-	3.9	52.1	26.0	25.0	1.0	0.83
2/30/04	-	-	4.0	55.2	24.7	22.4	2.3	N/D
9/28/04	33.14	32	4.7	45.1	17.3	13.2	4.1	N/D
Salanpak	31.5	29.4	3.8	68.4	19.7	18.4	1.3	1.76
Mining Office	31.1	29.1	4.6	18.5	5.4	5.4	0.1	N/D
Mining Office Channel	30.1	31	3.6	94.6	46.5	28.7	17.8	N/D
Quartz Pond	31.1	30	4.0	46.3	30.5	20.4	10.1	N/D
Natural Paduran 1/30/04	-	-	3.8	68.2	*	*	*	N/D
9/27/04	28.2	29.1	3.9	99.6	29.3	25.0	4.3	N/D
Canal Paduran 3 1/30/04	-	-	3.3	359.0	16.7	6.3	10.4	N/D
9/27/04	28.7	30	4.6	60.6	24.6	17.6	7.0	0.75
Paduran3 GW	-	-	3.7	114.8	2.2	1.5	0.7	0.85
Paduran3 PM	-	-	8.3	760.0	7.8	6.9	0.9	N/D
Tumbang Tambirah	25.5	27.8	5.9	43.4	2.4	1.8	0.5	1.70
Harber	29.2	30	6.1	24.5	5.0	3.1	1.9	N/D
Mining Point 2	24.6	27.9	6.1	39.9	2.5	1.7	0.8	0.99
Untung House	-	-	4.8	16.9	3.4	3.2	0.2	N/D

＊: Not analyzed yet

Table 1-2 Results of chemical components

Study Area	Cl^-	SO_4^{2-}	4.3 Bx	SiO_2	Na^+	K^+	Ca^{2+}	Mg^{2+}
unit	mg/L	mg/L	meq/L	mg/L	mg/L	mg/L	mg/L	mg/L
Kya station 12/30/03	0.8	0.4	0.00	9.1	N/D	N/D	N/D	N/D
1/30/04	0.5	0.3	0.00	10.1	N/D	N/D	N/D	N/D
2/30/04	0.5	0.3	0.00	9.4	N/D	N/D	N/D	N/D
9/27/04	*	0.1	0.00	7.4	2.5	3.9	6.5	6.8
Kya G3	*	0.1	0.00	6.4	N/D	N/D	N/D	N/D
Kya G4	*	0.1	0.01	3.4	6.9	6.1	N/D	N/D
Kya G5	*	0.2	0.00	3.4	15.8	15.9	N/D	N/D
K･K	*	0.3	0.00	8.1	1.1	0.6	0.2	0.1
Bangah	2.2	1.5	0.00	7.1	2.8	0.7	0.6	0.4
Untung A112/30/03	2.6	1.4	0.00	8.4	2.0	0.8	1.9	0.5
1/30/04	1.4	0.7	0.00	7.7	1.7	0.6	1.2	0.4
2/30/04	1.7	0.8	0.00	7.4	1.4	0.5	1.3	0.3
9/28/04	5.6	3.2		8.1	5.1	N/D	2.6	0.4
Untung B1 12/30/03	2.8	2.3	0.00	7.7	1.6	0.5	1.7	0.3
1/30/04	2.8	2.0	0.00	8.1	1.9	0.7	1.9	0.4
2/30/04	1.1	1.0	0.00	6.4	0.8	0.3	1.1	0.3
9/28/04	1.9	1.4	0.02	6.7	1.5	0.8	1.6	0.4
Untung C112/30/03	5.5	2.8	0.00	6.7	5.0	0.5	3.0	0.4
1/30/04	2.7	1.9	0.00	17.0	1.8	0.6	2.0	0.4
2/30/04	1.3	1.1	0.00	7.1	1.0	0.5	1.4	0.3
9/28/04	2.2	1.2	0.04	4.7	1.5	0.4	1.3	0.4
Salanpak	5.7	2.4	0.00	5.4	4.9	0.8	2.0	0.3
Mining Office	0.8	4.9	0.04	1.8	0.2	0.5	1.2	0.6
Mining Office Channel	0.3	0.7	0.00	9.4	*	0.2	0.1	N/D
Quartz Pond	1.2	2.9	0.00	5.4	0.3	0.6	0.8	0.4
Natural Paduran 1/30/04	1.4	1.7	0.00	7.1	0.7	0.4	0.4	0.4
9/27/04	1.1	1.0	0.00	7.1	0.8	0.6	0.4	0.3
Canal Paduran 3 1/30/04	*	3.5	0.00	2.1	8.3	0.6	0.3	0.8
9/27/04	0.6	106.5	0.04	6.4	2.0	1.2	3.1	5.3
Paduran3 GW	*	5.1	0.00	0.8	18.2	1.3	0.9	1.9
Paduran3 PM	0.0	25.7	7.34	12.7	1.0	1.4	2.6	1.7
Tumbang Tambirah	0.3	2.3	0.24	19.0	2.2	0.3	2.6	1.1
Harber	0.3	1.9	0.57	11.7	2.7	0.8	4.5	1.8
Mining Point 2	0.5	1.8	0.98	18.7	1.4	0.7	2.2	0.7
Untung House	0.4	1.9	0.08	10.7	2.5	1.0	4.5	1.3

＊: Not analyzed yet

POSSIBILITY OF SPRING HYBRID FILTER SYSTEM APPLIED TO WATER TREATMENT IN KAHAYAN RIVER

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ABSTRACT

It is generally important to supply safety water to the people living in Paranka Raya. As a historical incident, the infectious disease in Japan had been extensively spreading and engendered a lot of death toll by the reason of low concept for public health on drinking water and wastewater. Therefore, we study the present conditions on the water purification process in water treatment plant and the wastewater treatment in Paranka Raya. Then it is conducted to consider the possibility regarding to reasonable purification technology for the water quality and to examine the removal characteristics of a high performance removal system.

The results are follows: Firstly, initial value of the coefficient of energy slope that is the comprehensive guideline which shows the porosity ratio and the energy slope of filtration layer, is almost constant and is nonexistent relation in the size of the suspended particle. Its initial value is almost constant. Secondly, filterability of the spring hybrid filter had three typical stages; constant stage for filtering quantity at the early period, gradual decreasing stage and logarithmical decreasing stage. Thirdly, it can be suggested that the hybrid system is one of the effective technology for the water quality improvement because of its high removal efficiency and simplicity, especially in the field such as filtration of raw water for water supply.

Key words: tropical peat forest, water quality, Central Kalimantan, spring hybrid filter system, water treatment, removal characteristics,

INTRODUCTION

The gradual decreasing of water environment improvement in rivers/lakes and marshes for the waterworks is lead into a social problem in recent years (Murakami, *et al.* 1996).

In this study, a high efficiency for the removal system using the hybridized spring filter is applied to water treatment, which include suspended solid and plankton. This filter system has been developed in our laboratory (Taki, *et al.* 1998a, 1998b and Kogai, *et al.* 1999) and which is hybridized with auxiliary material that covering on the spring filter as pre-coating layer.

OUTLINE ON PURIFICATION PLANT IN PALANGKA RAYAN

Research area

The geography of the Sebangau and the Kahayan catchments are shown in **Fig. 1.** Both of rivers, Sebangau River and Kahayan River flow southward through tropical peatland in the southern part of Central Kalimantan. The watershed of the Sebangau and Kahayan is covered with tall forest on deep peat. The forest contains commercially important timber species, including several that are specific to peatland, such as ramin (*Gonystylus bancanus*). The forest also supports a number of mammalian, avian and reptilian species. However some of the riparian forest near KYA Station and the neighboring area of Palanka Raya has been logged, legally and illegally, and burned, and then replaced by low vegetation predominantly of *Cyoeraceae* and *Pandanceae* (Shepherd, 1997).

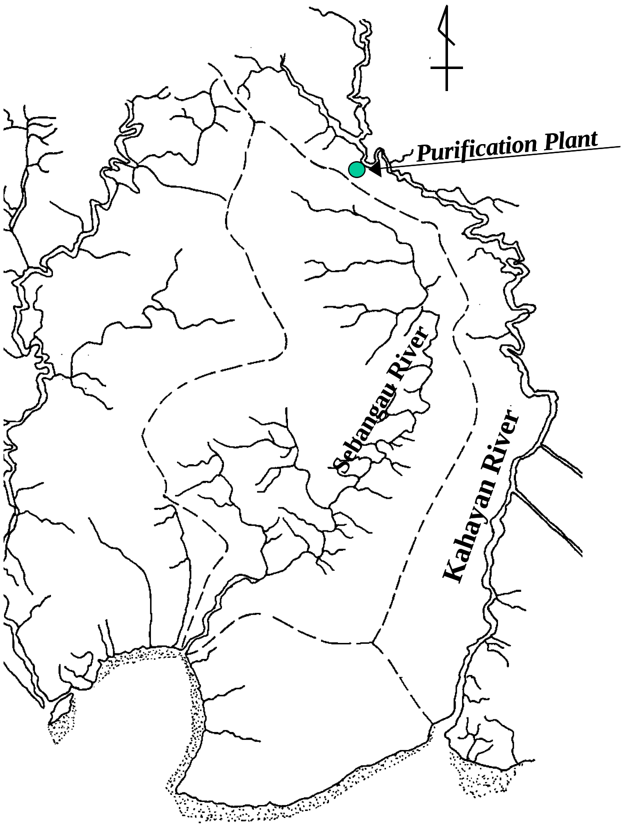

Fig. 1 Schematic on the catchments of Kahayan River and Rungan River.

Purification plant and wastewater treatment in Palangka Rayan:

Drinking water for the people in Palanka Raya are supplied by ground water utilized for private use and purified surface water of Kahayan River. Palanka Raya planted on a peatland which is formed by the active growth of tropical forests distributes widely, is located in the caught area between Kahayan River and Sebangau River. Here, these rivers can be classified as a big-size river and a mid-size river respectively, based on its width, length, depth, and discharge. The purification plant constructed in 1987 is located on the bank area and at downstream point from approximately 1.0 km of the confluence of Kahayan River and Rungan River, as shown in **Fig. 2**. The discharge of Rungan River has a range between 30 and 50 percent of the discharge of Kahayan River. Water quality of Rungan River is a low quality that will be contained high-suspended solid by some kind of dredging such as a gold mining. The turbid water is mixed into the water of Kahayan River as shown in **Fig. 3,** and then the water is pumped up to the plant located in downstream side.

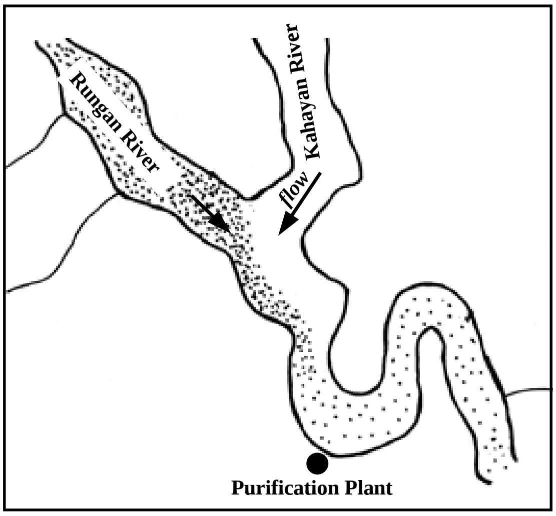

Fig. 2 Locative relationship between purification plant and Rungan River formed turbid stream.

Recently, some of the forest in the catchments of Kahayan River and Sebangau River has been converted to logging concession, agricultural use and settlement use. Changes in a catchments area influence water quality, and the natural environment of the Sebangau catchments is likely to change in the near future. Currently however, it is observed that the brown color of humic acid that flows into the river changes very little between rainy season and dry season, despite the dramatic difference between the flux of the two seasons.

Intake water, 200 litters per second for the plant is guided by 500 mm diameter steel pipe and 75 Kw/hr pump from the Kahayan River. The end point level of intake pipe is set at one meter below the water surface and at two meters upper the riverbed in the beginning of the plant constructed. However, the riverbed is eroded year by year, of which speed is about one meter in a year, and the depth is reached about 6 meters, now.

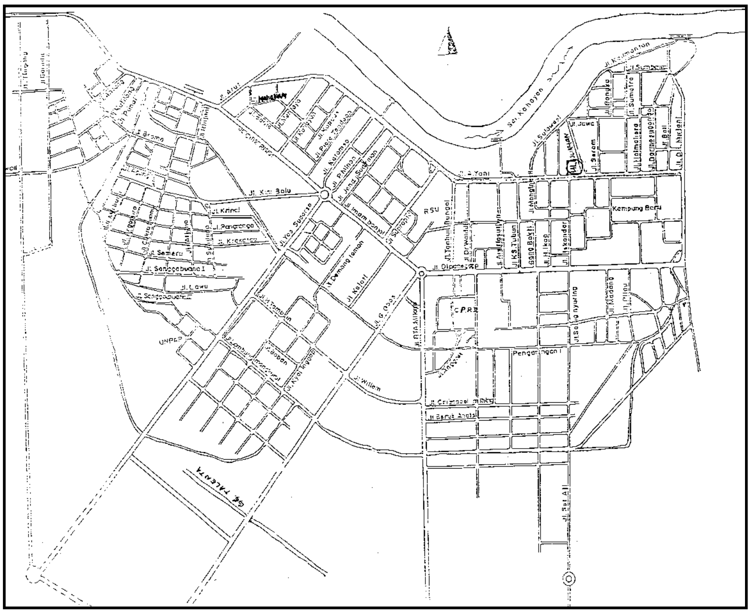

Fig. 3 Water supply district in Palanka Raya.

Utilization/quantity of surface water supplied with the plant (50 litters/person/day) is limited about 1/3 times of the groundwater, and its quantity is estimated about 13 m^3 in each month in a family. Toll system is utilized as 900Rp/m^3 (in a rage more than 10m^3), 1350 Rp/m^3 (in a rage from 11 to 20 m^3) and 5000Rp (basic charge).

According to the domestic sewage in Palanka Raya, it appears that many of them do not have the whole sewage system such as a sewer system, so their domestic water discharges into a channel/gutter directly, or discharges after a simple/defective facility for the wastewater treatment. It can be doubtable that these systems connote the explosive occurrence of infectious disease.

MATERIALS AND EXPERIMENTAL PROCEDURE

Apparatus and experimental procedure

The experimental apparatus as shown in **Fig. 4**, consists of metal spring (clearance between coils; 65 μm) for a filter frame, the auxiliary material layer and a pump. The spring filter is put on as a bar (outside diameter of spring filter; 15 mm, length; 100 mm) and hanged from the ceiling, which is installed inside the filtration tank.

Furthermore, the pressure gauges are attached forth and rear space of the spring filter for evaluation of filtration efficiency. Data i.e. filtration pressure, suspended solid and filtrated water quantity is automatically and continuously recorded in the personal computer.

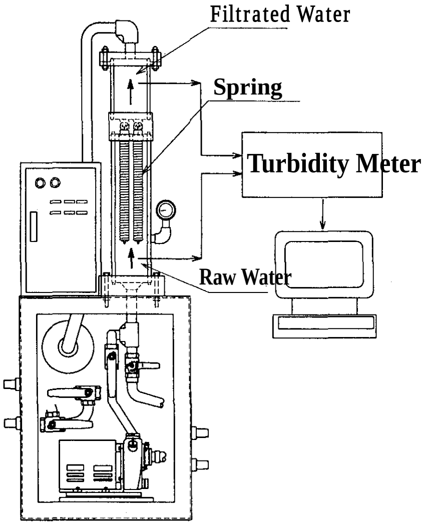

Fig.4 Schematic diagram on spring hybrid filter system.

The procedure of the experiment is conducted into two stages, pre-coating stage and filtration stage as follows:

Firstly, as in a stage of pre-coating layer, silica particles (mean grain size; 42.6 micron meters) are pumped up with water from the pre-coating tank. The concentration of silica particles is 1,000 ($mg \cdot l^{-1}$) in a tank. The first stage of the procedure is completed when the particles are stacked and covered on the surface of spring filter as a pre-coating layer which thickness is 8.4(mm). Schematic of the spring filter and the auxiliary material is shown in **Fig.5**. Here, the hybridized spring filter has a remarkable characteristic, that is, not only the particles of auxiliary material but also suspended substance (grain size is less than 5 micron meters) as river/lake water do not pass through the filter hole (clearance; 65 micron meters).

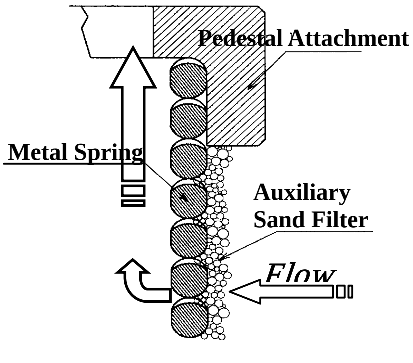

Fig.5 Detail diagram on the filter

Initial pressure in filtration tank is 0.1～0.2(MPa) and the mean initial filtration flux is 745 ($l \cdot min^{-1} \cdot m^{-2}$, minimum flux; 662 $l \cdot min^{-1} \cdot m^{-2}$, maximum flux; 828 $l \cdot min^{-1} \cdot m^{-2}$).

Secondly, as in filtration stage, river/lake water is induced into the filtration tank and filtered continuously. Along with the continuous filtration, surface of the filter becomes to be gradually choked by the suspended substances in the water. The flux, filtration pressures and the quality of suspended solid in filtrated water are measured continuously and automatically.

River/lake water for the experiment is selected in 3 kinds of water. Firstly, whetstone powder whose grain sizes are 5, 10, 20, 28 and 40micron meters, and whose specific gravity is 3.24. Secondly, natural lake water in which phytoplankton such as containing water-bloom and Fe^{++} ion. **Photo 1** shows an exposure of the experiment scene for lake water purification. Finally, industrial wastewater, i.e. soap industrial wastewater and food industrial wastewater.

The spring filter is restored smoothly onto the primary state with back washing and expansion of the spring toward longitudinal direction, if the filter surface is choked by suspended solid and then filtration efficiency decreases.

Photo1 Experiment scene for lake water purification.

Characteristics of Spring Hybrid Filter

In general, primary problems on filtration are efficiency and a continuously operating period. Then the characteristics of pre-coating layer made by an auxiliary material is described for efficiency and operating period as follows:

Quantity of filtered water that passes the pre-coating layer is estimated by eq. (1) as Darcy law,

$$Q = -\kappa A \frac{dh}{dl} \qquad (A = \pi D \cdot L) \qquad \text{------} \quad (1)$$

Here D and L in eq.(1) are the outside diameter and the length of spring filter. Energy slope of pre-coating layer made from silica is dh/dl and the coefficient of permeability of the layer is k. Now, Reynolds number (Re) is in the range of 0.48～0.59 and Re<1, so the value of coefficient of permeability is calculated by Fair-Hatch formula as eq. (2),

$$k = 0.039 \frac{g}{\nu} \lambda^4 d_s^2 \qquad \text{------} \quad (2)$$

Here g and ν mean the gravitational acceleration and the kinematic viscosity of water. d_s and λ mean the average grain size and the porosity ratio of the pre-coating layer. In a case of the loosely stacked pre-coating layer, the porosity ratio is 0.91. In the densely stacked layer in which each particle is in contact with 12 points, the ratio is 0.35. Now, it is considered that the energy slope in eq.(1) is related in the porosity ratio of the pre-coating layer, the filtration flux Q in eq.(1) is induced into eq.(3) by eq.(2).

$$Q = E_{\lambda} \frac{120DL}{\nu} d_0^2 \qquad \text{--} \ (3)$$

Here E_{λ} means the coefficient of energy slope including the porosity ratio and the energy slope in the pre-coating layer. d_0 is the diameter of equivalent sphere for silica grains. From eq.(3), it is recognized that the filtration flux has a increasing function of equivalent sphere diameter and a parameter of the coefficient of energy slope as shown in **Fig.6**, that is, the flux increase in proportion to the square of auxiliary particle diameter. The parameter range from 5 to 12 in **Fig.6** is best fitted in this experiment (i.e. grain size; 42.6 μm, flux; 662 to 828 $l \cdot min^{-1} \cdot m^{-2}$).

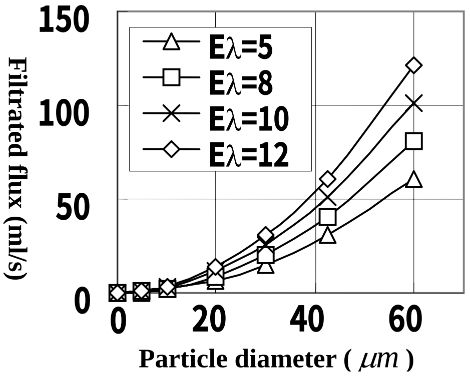

Fig.6 Relationship between filtration flux and particle diameter of auxiliary sand filter.

RESULTS AND DISCUSSIONS

Effect of particle size in raw water

The experimental result of the spring hybrid filter system in each case of particular size is shown in **Fig.7**. In case of raw water with small size if particular, it is observed that filtration flux was exponentially decreasing with the increasing of operating period. For example, in

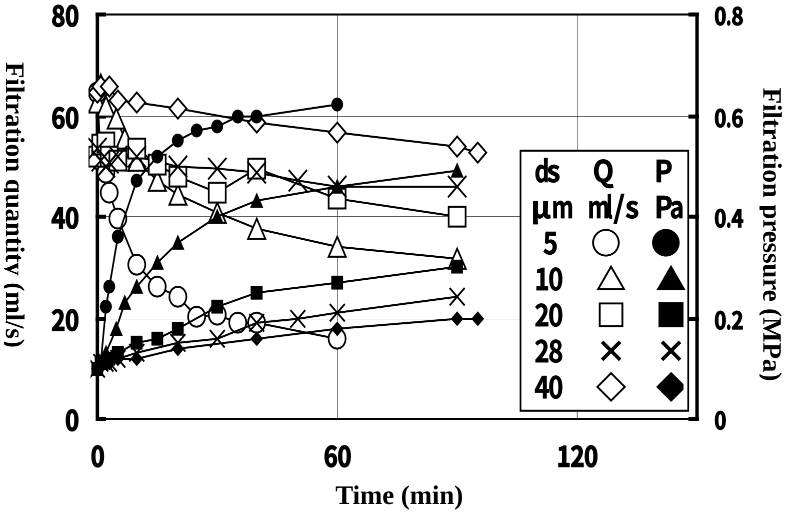

Fig.7 Filtration characteristics of spring hybrid filter in various sizes of particles.

case of fine grain size, 5 micron meters, the flux was rapidly decreased into 50% of initial condition at 10 minutes after of the beginning of second stage, and after 60 minutes, the flux was in 25% of it. Then, the tendency of flux decreasing became small in proportion to the grain size increasing, *e.g.* the result in coarse grain size, 40 micron meters, the reducing rate was 13% in 60 minutes of continuous operating period.

Therefore, it is able to consider that the reduction rate of the flux is in proportion to the size of suspended particles, which accumulated on the pre-coating layer surface. On the other hand, the phenomenon of filtration pressure was appeared an inverse proportional relationship from the flux, shown **Fig.7**.

Experimental result on the energy slope coefficient E_λ is shown in **Fig.8** with a parameter of suspended grain size. It can be seen from the figure that the energy slope coefficient at initial operating condition is almost constant of 12, independent of the grain size parameter. However, with the lapse time, one flat section and two kinds of the logarithmically decreasing section are clearly appeared in **Fig.8** as non-line, dotted line (B, F) and solid line (A, C, D, D', E). It is furthermore, observed that the non-line section and the dotted line section become longer as increasing the grain size parameter.

The dotted line section should be represented a gradually choking or maintained the porosity ratio for the relative size between the auxiliary material and suspended solid in wastewater. On the other hand, solid line section is represented by most of choking due to the suspended solids themselves. It can be therefore described that the timing of back washing for choked filter is at intersection of dotted line and solid line.

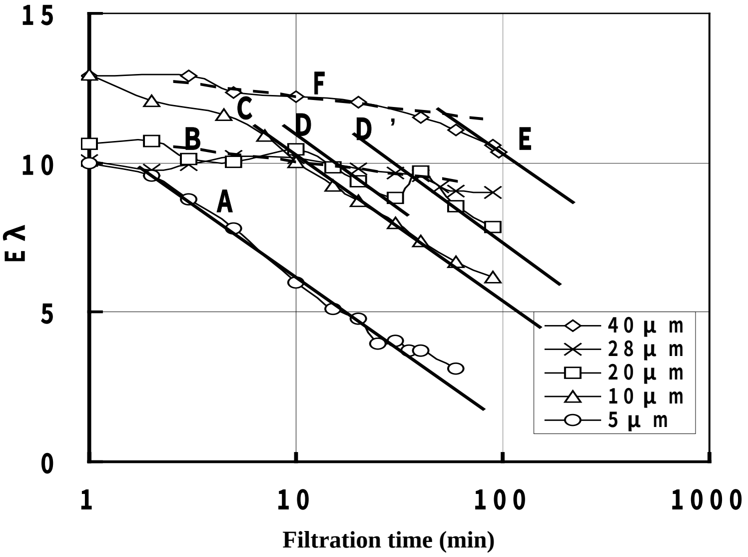

Fig.8 Relationship between the coefficient of energy slope and the filtration time.

Application to actual water treatment

The result of the batch experiment using actual lake water is shown in **Table 1**. The experiment is conducted with water bloom containing lake surface water, Fe^+ rich well water and the soap and food factory as the factory wastewater. In case of lake water, it is measured that the general bacterial number decreased from 2,640 cells・ml^{-1} to 426 cells・ml^{-1} and suspended degree changed from 1.5 degrees to 0.4 degrees. Consequently, the adaptation of the filter on the purification of lake/river water will be possible to apply the particle bacterial level.

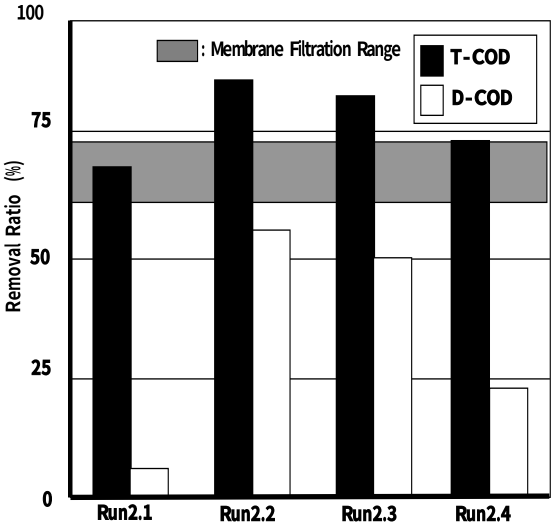

Fig.9 COD_{Mn} removal ratio on natural lake water.

The concentration of total Fe is decreased

Table 1 Removal characteristics of spring hybrid filter applied to each wastewater

	Lake surface water		Well water		Soap factory waste		Food factory waste	
	influent	effluent	influent	effluent	influent	effluent	influent	effluent
Bacteria (N/ml)	2640	426	1	0	-	-	-	-
Coliform bacteria	+	+	-	-	-	-	-	-
PH	8.4	8.5	6.2	6.3	5.4	7.1	6.7	6.7
Total Fe (mg/l)	-	-	1.3	0.02	2.4	0.26	1.18	0.42
COD_{Mn} (mg/l)	14.5	9.5	1.5	1.3	99.5	27.8	281	67.8
Suspended degree	1.5	0.4	6.5	0.1	-	-	-	-

Table 2 Applications on spring hybrid filter system

Application field	**Examples**
Human environment	**Water purification on lakes, rivers, marshes, domestic waste, etc.** **Water source protection, removal of effluent oil, etc.**
Welfare work	**Recycle and purification of bath water, washing water, medical supply, etc.**
Agriculture	**Purification of pond water, stockbreeding waste, etc.**
Large industry	**Heating and atomic generation industries, plant cooling water, etc.**
Machine process	**Recycle and purification of machine oil, washing water, etc.**
Others	**Recycle and purification of swimming pool water, car washing water, etc.**

from 1.30mg・l^{-1} to 0.02mg・l^{-1} in the case of well water. On the other hand, the COD_{Mn} removal is recognized in 70 to 75 percent of lake water including particle organic matters as shown in **Fig. 9**. Applications on spring hybrid filter are shown in **Table 2**.

CONCLUSIONS

Present conditions on the water purification process in water treatment plant and the wastewater treatment in Paranka Raya is studied in this paper. Then it is conducted to consider the possibility regarding to reasonable purification technology for the water quality and to examine the removal characteristics of a high performance removal system.

The results obtained by the various kinds of experiment are as follows:

1) Initial value of the coefficient of energy slope that is the comprehensive guideline which shows the porosity ratio and the energy slope of filtration layer, is almost constant and is nonexistent relation in the size of the suspended particle. Its initial value is almost constant.
2) Filterability of the spring hybrid filter had three typical stages; constant stage for filtering quantity at the early period, gradual decreasing stage and logarithmical decreasing stage.
3) The spring hybrid system is one of the effective technology for the water quality improvement because of its high removal efficiency and simplicity, especially in the field such as filtration of raw water for water supply.

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Combustion and thermal characteristics of peat fire in tropical peatland in Central Kalimantan, Indonesia

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ABSTRACT

Peat fire in a tropical peatland not only releases a large amount of carbon into the atmosphere but also causes significant damage to peatland ecology and the landscape. It is important to grasp peat fire and to establish more effective methods controlling peat fire. In this paper, the results of field and laboratory works aimed at elucidation of the combustion and thermal characteristics of peat fire are described. Field studies were carried out at 9 study plots in actual peat fire areas along the Trans Kalimantan Highway of Central Kalimantan in 2002. Laboratory analyses using a bomb calorimeter and TG-DTA were carried out to obtain low and high ignition temperatures and calorific values of various peat fire fuels. Results of field studies on weather conditions, temperatures in peat layers during fire, pattern of peat fire front, speed of peat fire spread, fuel composition, moisture content and fuel loss on fire are described in this paper. The present work clarified the nature of fire movements and the smoldering process in an actual peat fire in tropical peatland. Based on our results, the authors hope that a more effective method for controlling peat fire will be developed.

Key words: *tropical peat, peat fire, peatland fire, thermal characteristics and Central Kalimantan.*

INTRODUCTION

Tropical peatlands are important natural resources and have considerable effects on regional and global environments. Wetlands including peatland, provide a wide range of products and services that are important for direct and indirect human uses, the welfare of wildlife, and the maintenance of environmental quality (Maltby and Immirzi, 1996). Tropical peatlands are one of the largest near-surface reserves of terrestrial organic carbon, and their stability therefore has important implications for climate change (Page *et al.*, 2002). However, the stability of tropical peatlands has been threatened since the early 1980s by human activities such as forest conversion to farmland, transmigration settlement, excessive draining, and logging (Siegert *et al.*, 2001a). In coincident with El Niño makes them increases susceptibility to fire (Hardjowigeno., 1996; Barber *et al.*, 2000).

In Indonesia, peatland fires are mostly anthropogenic (Goldammer and Seibert 1990). Fires are used by local and immigrant farmers as part of small farmland activities such as land clearance (Siegert, 2001b) and to produce ash for fertilizer (Kanapathy, 1976). During droughts, the fires have same time spread out of control and become wildfires in peatland areas.

Fires in peatland not only burn the surface vegetation but also peat deposits up to 100 cm below the surface (Boemh *et al.*, 2001). However, peat fire have occurred only in extreme drought conditions or after the ground water level was lowered artificially (Wein, 1983; Takahashi *et al.*, 2001). Peat fires produce large amount of the smoke, deterioration in air quality with dense haze caused health problems (Page *et al.*, 2002), with gave seriously bad effect on social activities, human health (Liew *et al.*, 1998) and disturb peatland ecosystem as a whole. Peatland fires produce large emissions of particulate mater, CO and other gas compounds (Muraleedharan *et al.*, 2001, Page *et al.*, 2002) even though burns with low-intensity (Wein., 1983). Therefore, studies on peat fire mechanisms and peat fire processes are important in the context of peatland fire management.

After a large forest fire in Indonesia in 1997, many scientists studied fire damage to biomass resources, biodiversities, natural ecosystems, social activities, human welfare and the global environment (Nugroho *et al.*, 1997; Chandrasekharan., 1998; Barber *et al.*, 2000; Siegert., 2001; Saharjo *et al.*, 2003; Purwaningsih *et al.*, 2003), but there have been studies on the peat fire mechanisms and peat fire processes in tropical peatland.

Wein (1993) discussed peat fire behavior using a schematic cross section of combustion zone of surface peat layer with a preliminary model of energy, moisture and gas flux to and from the zone of combustion during burning. Hungerford *et al.* (1995) also showed a comprehensive complication of sustained smoldering and consumption process of peat soil in Alaska. The smoldering front begins to burn downward and laterally, resulting in the the creation of a bowl-shape depression. Miyanishi (2001) presented clearly the processes of smoldering combustion and pyrolysis in a shallow duff layer by numerical simulation model. The results of numerical simulation showed that both pyrolytic and oxidative degradation of duff occur down to a depth of about 1 cm and that only endothermic pyrolysis occurs below that depth due to depletion of oxygen.

From the results above were given an excellent overview of similar aspect related to peat fire processes in tropical peatland. In spite of the very different climatic, peat material and social economical conditions in which peat fires occur, there are some common physical factors that play a major role in determining the incidence and propagation of peat fires. These factors will be the main subject of this paper.

The aim of this study was to clarify the physical aspects of peat fire characteristics in tropical peatland of Central Kalimantan, including the weather in the dry season, peat combustion properties and characteristics of fuel materials in peatland.

STUDY SITES AND METHODS

Study sites

As shown in Fig 1, the study sites were located in a secondary peatland forest along the Trans Kalimantan Highway between Palangka Raya and Pulang Pisau and in a secondary peatland forest near Fire Climatology Station University of Palangka Raya in Central Kalimantan-Indonesia. The peatland was mixed farmland and wasteland in the fluvial plain of Kahayan and Sebangau Rivers.

Nine study plots along the highway were selected for field observations of wildfire in peatland

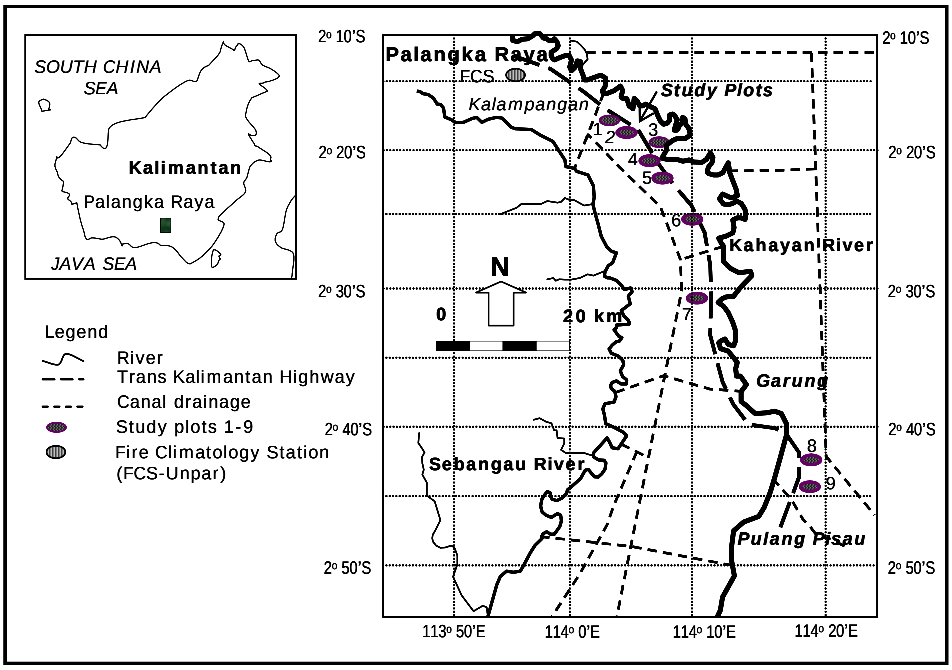

Fig.1 Geographical map of study area and location of study plots along Trans Kalimantan Highway, between Palangka Raya to Pulang Pisau.

during the dry season in 2002. The wildfires in each plot were caused independently. The distances between plots ranged from about 1 to 30 km. The depths of the peat layers at the nine plots were about 1-3 m (RePPProT, 1990). The principal types of vegetation in the study plots were cinnamon fern (*Osmunda cinnamomea*, pakis), vegetable fern (*Stenochlaena palustris*, kalakai) and bracken fern (*Pteridium*, Gleditsch hawuk) with heights ranging from 1 to 3 m.

The poor tree vegetation in the study plots was caused by commercial logging, road clear-cutting, conversion of forest to farmland and settlement since the 1980sas well as by frequent fires. Because of the poor tree vegetation, the study sites subjected to intense solar heating and more wind movement.

Climate observatory

A climate observatory has been established in an open area of 30 square meters in a wildfire experimental station located about 2 km west of the main campus of the University of Palangka Raya and about 20 km northwest of plot 1. Air temperature and humidity were measured at a height of 1.5 m in a weather shelter using a platinum electronic resistance sensor and a capacitive thin-film polymer sensor (HMP-5D, Visala). Rainfall was measured at a height of 1.2 m using a trapping bucket type of rain gauge (34-T, OTA Keiki). Wind speed and direction were measured at a height of 4 m using a wind vane (WS-05103, Young). Global radiation was measured at a height of 1.5 m using a thermocouple sensor (PCM-01, Prede). Soil temperatures were measured at depths of 0 cm (surface), 10 cm, 20 cm and 40 cm using platinum electronic resistance sensors, and climate parameters were recorded by using a data logger (Kadec, KONA System) at one-hour intervals. Ground water level was measured with a pressure sensor (Drug, DCM-100) in a well.

Peat combustion properties

Ignition temperature and calorific values of peat samples

Peat samples were taken from peat layers at depths of 0-20 cm, 20-40 cm and 40-60 cm in a secondary peat swamp forest near the climatology station of the University of Palangka Raya. Each peat sample was separated into fine and coarse peat materials by using a sieve of 2.0 mm in mesh size. Ignition temperature was determined in the laboratory by using a thermo-gravimetric differential thermal analyzer, TG-DTA JASCO A 6300. The heating rate used was $10^{o}C\ min^{-1}T$ from ambient temperature up to $500^{o}C$. The masses of samples used in this analysis were 0.20 to 0.35 grams because the heating rate of a sample cannot be kept constant if the mass of the sample is too much (Ichihara *et al*., 2000)

The peat calorific values were determined by a Bomb calorimeter, IKA C7000. The bomb capacity is 300 bars/210 ml with energy input up to 30,000 joules under ambient temperature ranging from 18 to $30^{o}C$. Peat samples were taken from three locations at depths of 0-5 cm and 5-10 cm from a secondary peat swamp forest near the fire climatology station, farmland near plot 1 and from a pristine forest about 7 km west from plot 4. The masses of samples were about 1.2 mg, oven-dried and powdered.

Fire temperature in the field

Chromel-alumel thermocouples of 0.5 mm in diameter with a stainless steel sheath and a 6-channel data logger (KADEC-US, KONA System Co. Ltd, Japan) were used to measure fire temperatures in the field above and below the ground surface. Thermocouple sensors were set at depths of 0, 5, 10, 15 and 20 cm in the peat layer 5 cm ahead of the fire front in study plot 2 and at depths of 0, 10, 20, 30 and 40 cm in the peat layer 5 cm ahead of the fire front in plot 3. The references soil temperatures a depth of 40 cm were measured at 4-5 m from the fire front. The data logger was buried at a depth of more than 30 cm to prevent damage caused by the high temperature of the fire.

Speed of peat fire spread

The speed of peat fire spread in peat soil was measured in three quadrates (each 3m by 3m) in study plots 3, 5 and 7. The quadrates were set up leeward of the fire front against the prevailing wind of these areas. Iron rods each of 75 cm in length and 6 mm in diameter were stuck with 50 cm intervals in quadrate for grid of fire observation. Typical fire front movement is shown in Fig. 4.

Since fire movement depends on both wind direction and peat properties, the fire front forms complex shapes. Distance between an initial point and several points on the fire front were measured at one-day intervals. In this paper, the mean value of several measured distances was defined as speed of peat fire spread. The distance of fire line movement was measured by using an iron ruler and observed one time a day during the fire season in September 2002. Measurements at overhanging areas were carefully done by using an iron stick and ruler.

Fuel materials in a secondary peat forest

Fuel properties

Fig. 2 shows the method to calculate amounts of grass, litter and peat before and after fires in study plot 5 following the methods of Bessie and Johnson (1995). Lines transects were established (1) near the burning site to calculate the amount of grass, litter and peat before burning and (2) in scar burn to calculate amount of grass, litter and peat after burning.

Ratios of dead and fresh plant at 1m^2 were weighted separately in the field and oven-dried at 80°C for 24 hours.

Fuel materials below the ground surface were measured at plots 3, 4 and 5. Three quadrates each of 1m^2 in area were set up in each plot. Materials in each quadrate were collected from layers at 0-15 cm, 15- 30 cm and 30-50 cm in depth and separated into four categories: wood/root debris, grass root, and fine and coarse peat matrix sieved at 2 mm in size. The wood debris, wood root and grass root were classified according to size and weighed before and after oven drying. The peat matrix was classified into two sizes using a sieve of 2 mm in mesh size after air-drying for 2-3 days.

Peat moisture was measured at plot 1 and plot 2 on August 8, 2002. Peat samples each of about 200 g were taken at six depths from the surface to 50 cm in depth at intervals of 10 cm, and stored in sample plastic bags. The samples were weighed before and after drying in an oven at 120°C for 24 hr.

Fuel loss by fire

Grass and litter in each the quadrate and peat to the depth of 50 cm were collected and weigh. All unburned materials from the original surface to a depth of 50 cm in each quadrate were collected and weighed after the fire. Biomass loss of surface fuels and peat loss caused by fire were

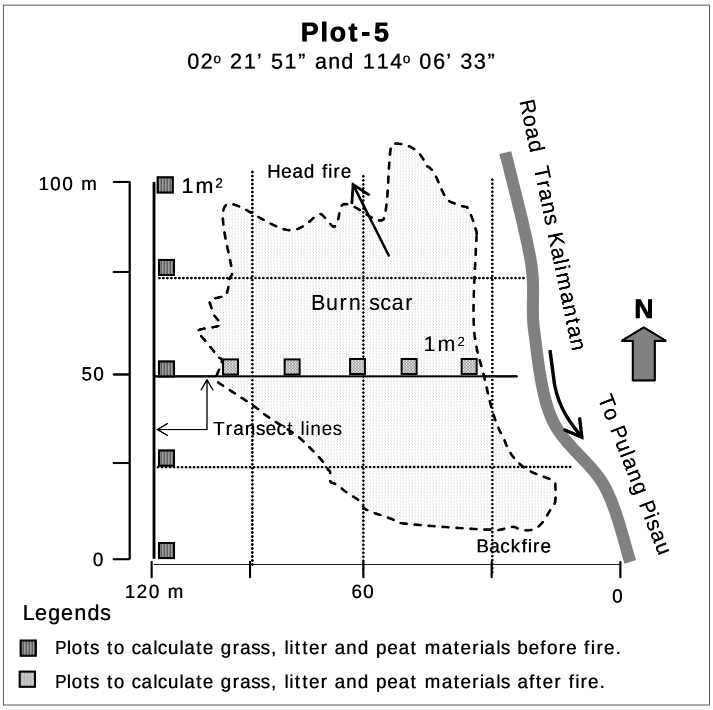

Fig. 2. Five, 1m^2 plots to calculate grasses, litter and peat before and after burning. This is an example of fuel measurements in plot 5.

calculated by Equation (1):

$$\overline{M}_{loss} = \overline{M}_{b\,dry} - \overline{M}_{a\,dry}\ (kg\ m^{-2})$$

where $\overline{M}_{loss}$ is mean mass loss caused by fire, $\overline{M}_{a\,dry}$ and $\overline{M}_{b\,dry}$ are the mean masses of material after and before fire in the five quadrates in study plots. A part of collected fuel materials was used for measurement moisture content in an oven at 120°C for 24 hr. Total dry weights of biomass in each quadrate before and after the fire were estimated using the measurement moisture of materials. But dry weight of surface materials used for $M_{a\ dry}$ without oven dry, because the materials were very dry by fire.

RESULTS AND DISCUSSION

Weather in the dry season

Fig. 3 shows mean monthly rainfall during a period of 23 years from 1981 to 2003 and monthly rainfall of 1997 and of 2002 in Palangka Raya, Central Kalimantan, Indonesia. The mean monthly rainfall ranged from 100 to 341 mm. The dry season in Central Kalimantan is normally two months per year, on July and August, with a mean monthly rainfall of about 100 mm. According to Mackinnon *et al.*, (1996) mean monthly rainfall was less than 100 mm is categorized as a ***dry month*** and mean monthly rainfall of more than 200 mm month^{-1} is categorized as a ***wet month***. Occasionally, there is an abnormally long dry season lasting for 4 to 5 months, usually due to the effect of El Niño, as well as the case in 1982, 1987, 1991, 1994, 1997 and 2002. This weather phenomenon was promoted larges tropical peatland area become suitable to fire.

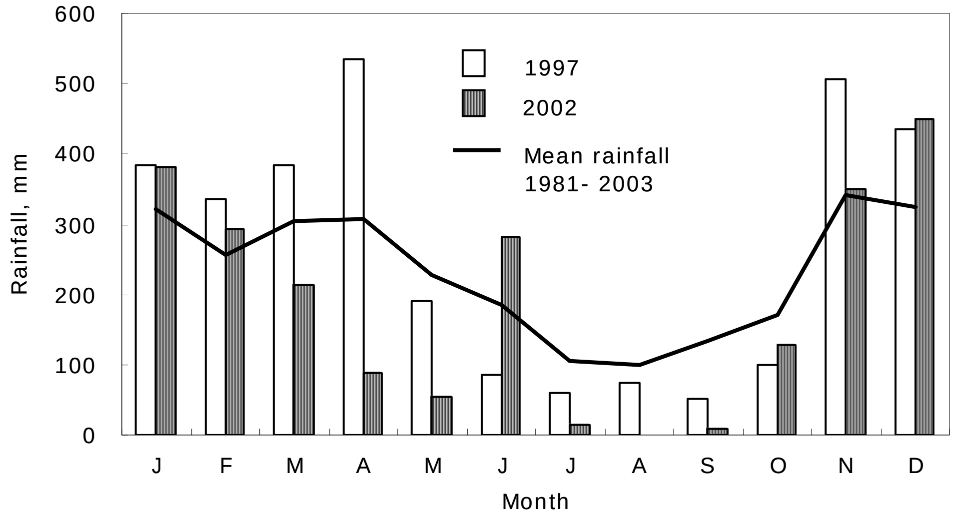

Fig. 3. Mean monthly rainfall from 1981 to 2003 in Palangka Raya, Central Kalimantan, and their comparison with the mean monthly rainfall of 1997 and 2002.

Fig. 4 shows the mean monthly air temperatures in Palangka Raya from 1981 to 2001. The mean monthly of air temperatures in 1997 were 2°C higher than those mean monthly of 23 years. The increase in air temperature in this area may have been caused by reduction in of forest canopy as a result of extensive logging, conversion of forest to agriculture land, and frequent forest fire. According to Takahashi and Yonatani, (1997) that removal of the forest canopy and peatland degradation alter the microclimate, producing a greater albedo effect and leading to increase in temperature and decrease in relative humidity.

Fig. 5 shows mean monthly the ground water levels (GWL) during the last 10 years in a pristine peat swamp forest in Central Kalimantan and the mean monthly ground water levels during El Niño years in 1997 and 2002. The lowest GWL were in November 1997 (97.6 cm below the surface) and in September 2002 (94.1 cm below the surface). As a result the peat soil was extremely dry and easy to ignite.

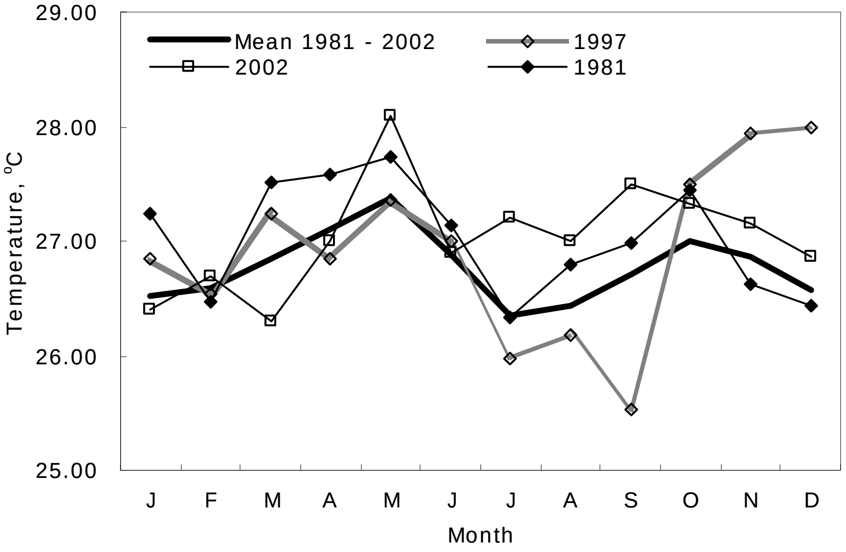

Fig. 4. Mean monthly air temperature from 1981 to 2001 in Palangka Raya of Central Kalimantan, and their comparison with mean air temperatures of 1981, 1997 and 2002.

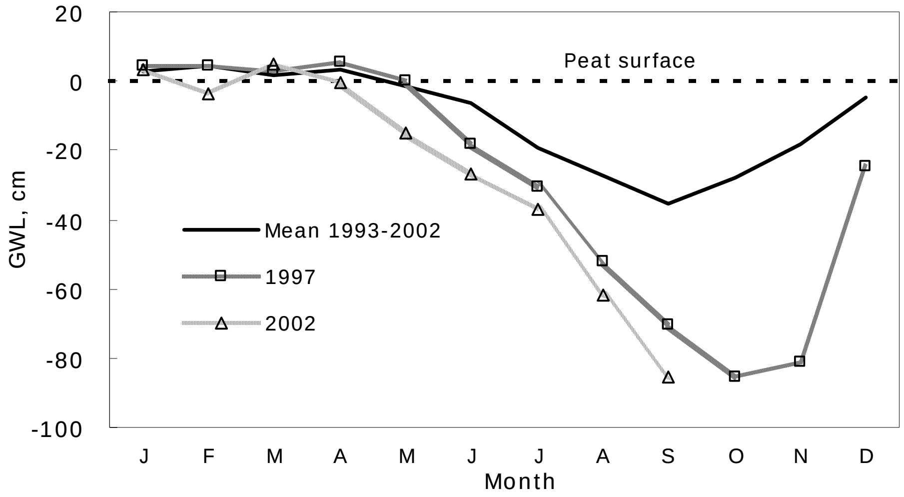

Fig. 5. Mean monthly ground water level in a pristine peat swamp forest from 1993 to 2002 in Palangka Raya, Central Kalimantan, and their comparison with the mean monthly of 1997 and 2002 (After Takahashi, 2003).

Ground water level was in fact a key factor determined fires in peatland area. Lowering of ground water level also affected moisture content of grass, litter and the surface peat itself and provides a suitable condition for sustaining fire. For example in 1997 more than 1.4 Mha of tropical peat swamp forest was burned in Central Kalimantan (Siegert *et al.*, 2001b).

The climatic conditions in 2002 during our study were as follows: rainfall in July and August was 2.0 and 0.0 mm month^{-1}, maximum daily air temperature was 36°C and minimum relative humidity was about 40% in July and 34% in August. Average 10 minutes daily wind speed ranged from 2.2 to 4.0 m s^{-1}.

Peat combustion and thermal properties

Ignition temperature

Fig. 6 shows a result of pyrolysis processes of peat samples obtained from depth of 40-60 cm from a secondary peat swamp forest measured by using a thermogravimetry and differential thermal analysis (TG-DTA) in the laboratory. Pyrolysis is defined as the chemical breakdown of solid fuel under the influence of heat and usually in an oxygen-deficient environment (Miyanishi, 2001). In this paper, ignition temperature defined as a transitional point from endothermic to exothermic processes (Frandsen, 1997).

There are two important curves of thermogravimetry (TG) and different thermal analysis (DTA). A TG curve shows weight loss of a peat sample during a pyrolysis process, in which found three major of weight losses: (1) water evaporation, W_d (2) combustion of volatile matters, W_v and (3) combustion of charcoal matter, C_c. A DTA curve shows the rate of heat release from a peat samples during the pyrolysis process. An endothermic reaction occurs in the pre-ignition process, while exothermic reaction occurs after the peat sample is going to burn. The DTA curve is important for determining (1) ignition temperature of volatile matters, T_v, (2) ignition temperature of char, T_c, and (3) carbon content, C_c, of a peat sample. Results of peat pyrolysis for both fine and coarse peat materials obtained from depths of 0-20 cm, 20-40 cm and 40-60 cm are shown in Table 1.

Ignition temperatures of peat volatile matter, T_v, of tropical peat both for fine and coarse materials ranged from 256 to 277°C. These values correspond to ignition temperatures of boreal peat of 210 to 270 °C described in an Ignition Handbook (Babraukas, 2003). T_v surface peat was lower than those of deeper peat layers. It has been reported that surface peat has a low moisture content, high carbon content, and low decomposition level (Yonebashi *et al.*, 1992). Ignition temperature of char, T_c of tropical peat both for fine and coarse materials ranged from 340 to 369°C. These values correspond to the reported ignition temperatures of lignin in the range from 280 to 500°C (Roberts, 1970).

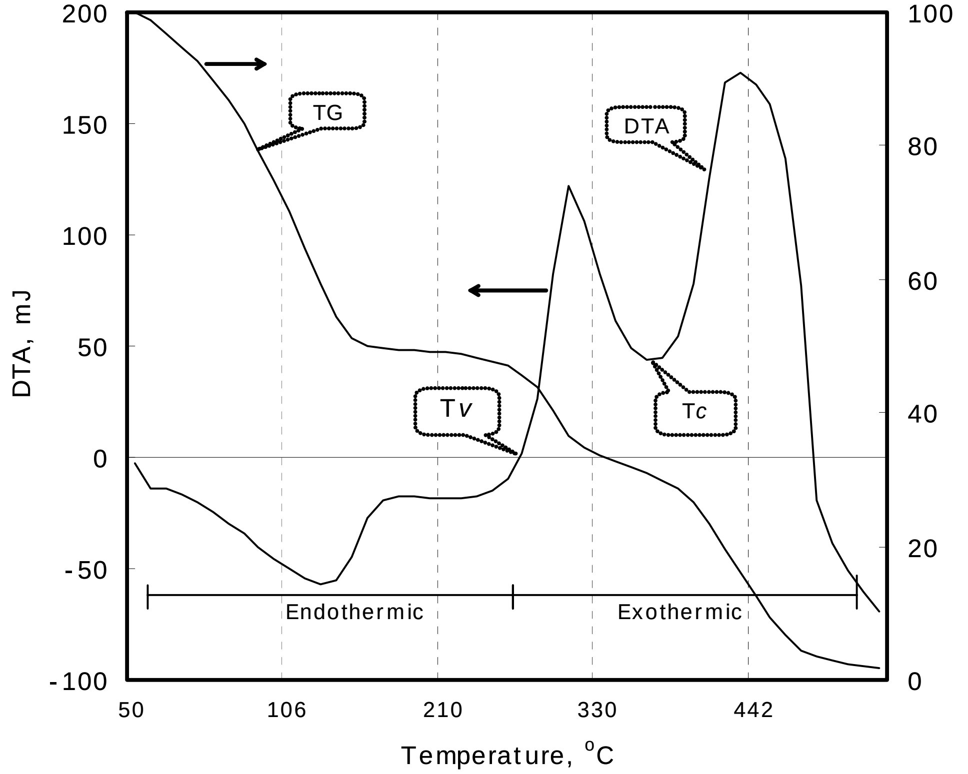

Fig. 6. TG-DTA curves of the peat material at 40-60 cm in depth from secondary peat swamp forest of Central Kalimantan.

After simultaneous analysis of TG and DTA curves, the pyrolysis processes of peat materials could be divided into the following three phases.

(1). ***First phase***. The first phase is an endothermic phase in which the soil moisture absorbed by the soil structure evaporates during heating processes up to 150°C. The weight losses of peat surface were 20-45% at the depth of 0-20 cm, about 54% at the depth of 20-60 cm and about 50-57% at the depth of 40-60 cm. In this phase, an endothermic peak appears on the DTA curve corresponding to the water rate on the peat soil.

(2). ***Second phase***. After the peat has been heated up to 260°C, the pyrolysis speed increases, hemicelluloses and celluloses decompose into gasses as CO_2, CO, CH_4, CH_3OH, CH_3COOH and laevoglucose as heat is gradually increased, and weight loss of volatile matter ranges from 10-47% on the TG curves. Moss of peat materials in this phase involves dehydration leading to the formation of carbonaceous char that could lead to glowing combustion. The initially peak of DTA curve and the weight loss amounts in this phase corresponds to hemicelluloses and cellulose on the peat soil. However, the coarse peat materials at a depth of 0-20 cm have only one peak on DTA curves. It has been reported that coarse peat materials at a depth of 0-20 cm contain much hemicelluloses and cellulose, and that they degraded at temperatures of 200-260°C for hemicelluloses and at temperatures of 240-350°C for celluloses (Roberts, 1970).

(3) ***Third phase***. In this phase, self-combustion occurs and appears at second peak of DTA curves and TG curve changes with the weight loss down rapidly. The second peak of DTA was higher than initially peak. This means that peat charcoal burn was violent than the volatile matter of peat soil. The violent of the peat charcoal burn is probably due to presence large of a large amount of lignin in the peat soil. It conversely with the wood phenomenon, the charcoal burn is not as violent as wood flame burn (Yunchu *et al.*, 2000).

The amount of weight loss in this phase corresponds to the amount of carbon content, C_c, in

Table 1. The temperatures and weight loss of peat from TG-DT Analysis. Legends: T_v is ignition temperature of volatile matter; T_c is ignition temperature of char, ΔW_d is weight loss at drying process, ΔW_v is weight loss of volatile matter, C_c is carbon content on peat soil.

Peat Depth (cm)	T_v (°C)	T_c (°C)	ΔW_d (%)	ΔW_v (%)	C_c (%)
……………………………………Fine peat material…………………………………………					
0 - 20	263	350	45.4	16.4	38.2
20 - 40	275	368	54.3	11.4	34.4
40 – 60	277	368	57.2	10.8	32.1
…………………………………Coarse peat material……………………………………					
0 - 20	256	340	20.7	47.6	31.7
20 - 40	268	369	54.1	11.6	34.3
40 – 60	260	363	50.0	13.4	36.7

Peat Depth (cm)	T_v (°C)	T_c (°C)	ΔW_d (%)	ΔW_v (%)	C_c (%)
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40 – 60	260	363	50.0	13.4	36.7

peat soil. The carbon content was calculated as the difference between residues at 340°C and 500°C, and these values are indicative of the true char values (Momoh *et al.*, 1996). Carbon yield from the surface peat ranged from 31 to 38% at a depth of 0-20 cm, and from 32 to 36% at deeper peat layers. These carbon values are lower than carbon content of Industrial Finland peat at H_{1-2} of 48-50% (Andriesse, 1988) and also lower than results analyzed by Neuzil (1997) of 57% for globally tropical peat, because only noted organic carbon on peat soil, while inorganic carbon included in weight loss of volatile matters. Based on the results of analysis shows in Table 1, the highest yields of carbon were found in surface peat probably due to the minor components of chemical factors and inorganic compounds present. The rate of heating, particle size, presence of moisture and inorganic contents increases also affected the yield of char (Miyanishi, 2001).

Calorific values

The calorific value is defined as the total heat generated by complete combustion of a unit mass of sample at a constant volume in an oxygen atmosphere of a bomb calorimeter (Núňes Reguria, 1997). The calorific values of peat samples obtained at depths of 0-5 cm and 5-10 cm from pristine forests, secondary forests, and farmland are listed in Table 2.

The calorific values of peat ranged from 19 to 23 kJ g^{-1}. These values are larger than those of boreal peat, ranging from 8.0 to 18.0 kJ g^{-1} (Tokyo Astronomical Observatory, 1998), and higher than those of typical trees (i.e., *Combretucarpus rotundatus,* 17.5 kJ g^{-1}) in a peat swamp forest. Tropical peat materials are usually formed from wood, whereas boreal peat is formed from sphagnum and grasses. Due to their higher calorific values, tropical peat materials are more flammable than are other fuels, especially when they are dry.

Table 2. Calorific values of peat sampled from threes locations at 0-5 cm and 5-10 cm in depth

Location	Depth (cm)	Material	Calorific value (kJ g^{-1})		Average (kJ g^{-1})	Moisture (%)
			1	2		
Pristine peat forest	0-5	Root & wood	21.21	21.10	21.15	49
		Peat Soil	20.50	20.61	20.56	32
	5-10	Root & wood	21.86	21.14	21.50	37
		Peat Soil	20.97	20.98	20.97	26
Secondary Peat forest	0-5	Root & wood	18.85	18.85	18.85	45
		Peat Soil	19.63	19.58	19.60	43
	5-10	Root & wood	18.34	18.38	18.36	67
		Peat Soil	19.53	19.45	19.49	31
Agriculture/ Bare peat	0-5	Peat Soil	23.07	23.89	23.48	19
	5-10	Peat Soil	19.92	21.27	20.59	23

Calorific values of peat materials at a depth of 0-5 cm were not different from those of peat materials at depth of 5-10 cm both pristine and secondary forests, but there was small difference between peat soil and root/wood.

In the secondary peat forest, calorific values of peat were slightly lower than other peat, because peat material in the secondary forest contents residues of former fires such as ashes, and unburned materials.

The calorific values of agriculture farmland at a depth of 0-5 cm depth were higher than those of the secondary and pristine forest. These high calorific values in farmland might have been caused by decomposition of surface peat and accumulation of char by burning of surface peat for fertilizer.

Temperatures in peat layers during a fire event

Some typical peat fire temperatures were observed at plot 3 during a fire event from August 21 to 26 in 2002 and are shown in Fig. 7. The peak temperature of 275°C appeared on August 22 with duration of peat fire has been kept a constant temperature at least for 4-5 hours (Fig. 7a). Fig 7c shows clearly that the peat fire started at 7 a.m. and moved away at 12 a.m. of 22 August, with duration of peat fire process was about 5 hours. The rapid temperature rise at 7 a.m. was due to heat from the peat fire front as a pre-heating process. The slow temperature rise at around 90°C was caused by evaporation of peat moisture. After this process, temperature rose rapidly again.

The second temperature peak on August 23 in fig (7a) was due to continuation of the surface peat fire mentioned above. Temperature of around 75°C in 10 cm depth in Fig. 7(c) may show smoldering combustion still continued in burned hole of peat fire. Temperature rise tendencies at depth of 20, 30 and 40 cm supported occurrence of smoldering. This smoldering combustion became very active during the daytime with strong solar radiation on August 23. The lower temperature of surface layer on August 23 was caused by exposed sensor on air after surface peat fire one day before. (Fig. 7c)

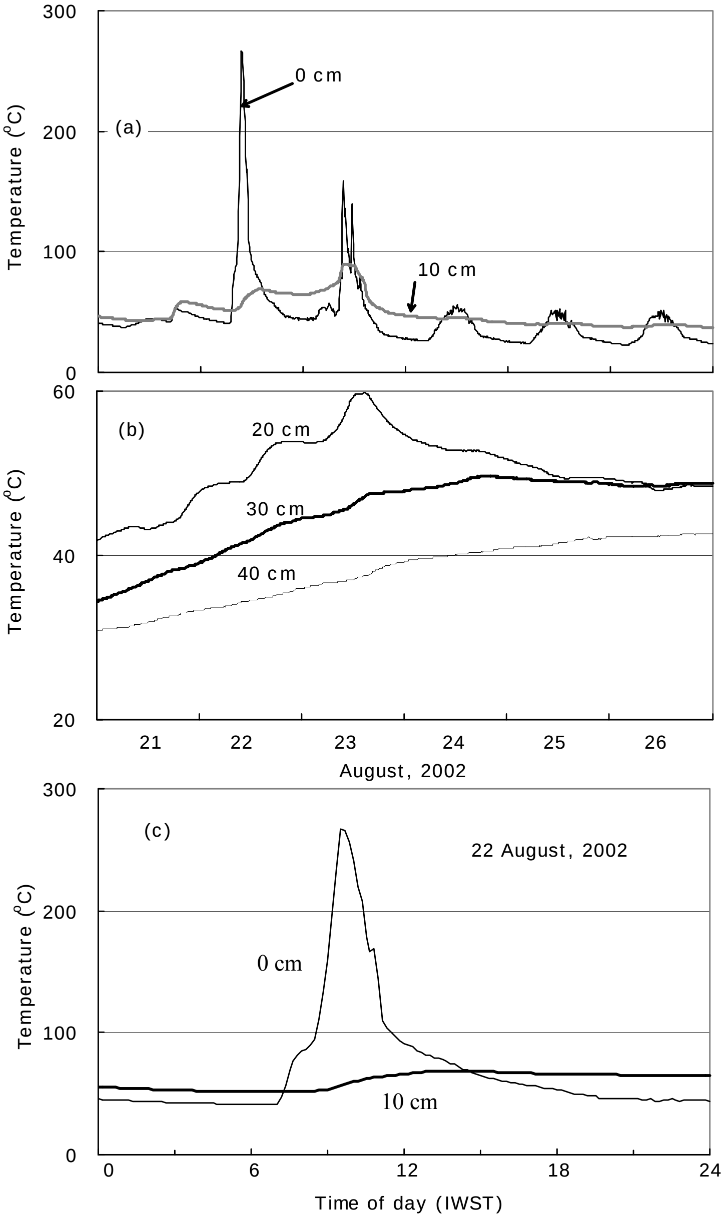

Fig. 7. The temperatures in peat layers during a fire event from August 21 to 26, 2002 in plot 3 of Kalampangan. (a) at ground surface and 10 cm deep from surface, (b) at 20, 30, 40 cm deep, (c) diurnal temperature changes of ground surface and 10 cm deep on the first day of fire event, August 22, 2002.

Fig. 8 shows the relationship between burning time and behavior of temperature penetration into deeper peat layers, as effects of dry woods burn. Initially, the surface temperature of the peat layer was raised slightly to 50°C after burning for five minutes, and it was no any effect into deeper peat layers. After thirty minutes, the surface peat temperature had increased to 400°C and temperature of peat at a depth of 5 cm also increased to 100°C. Increasing the fire temperature of surface peat correspond with fire growth in the fuel woods. After 40 minutes, the surface temperature had decreased to 350°C and peat layer at a depth of 5 cm had started to burn. From this case we noted: if the surface peat is heated to 200-400°C for 40 minutes, only the peat layer at a depth of 5 cm will burn, while at deeper peat layers have not burn.

The temperature penetrated from a surface fire or surface peat fire into deeper peat layers is governed by many factors such as temperature level, duration of burning, peat moisture content, and quality of the peat matrix. According to Babrauskas (2003), if the peat layer is heated for more than two hours, the ignition temperature drops to 150-160°C.

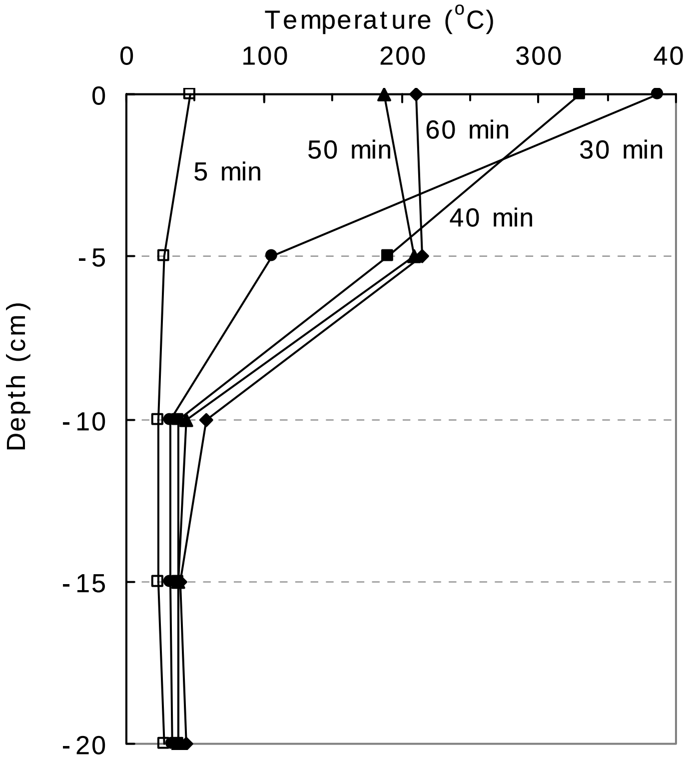

Fig.8. Dry wood burning and pattern of temperature penetrated into deeper peat layers on August 6, 2002 in Kalampangan.

Characteristics of the peat fire front

Pattern of peat fire front

Peat fires include surface peat fire and deep peat fire. A surface peat fire is a peat fire that burns at a depth of 0-20 cm with the main fuel materials being grass roots, humus and small woody fragments. A deep peat fire is a peat fire that burn at a depth of 20-50 cm with the main fuel materials being of large woody fragments and peat matrix. In this paper, "***surface fire",*** which defined as fire on the surface caused by surface fuels, is distinguished from ***"surface peat fire"***.

Fig. 9 shows results of field observations of peat fire development in tropical peat of Central Kalimantan. Initially, the surface fires occurred in surface peat, starting from the slashed area and then spreading out of control to bush vegetation or to secondary peat forest between the village and forest areas. Activities of the villagers in this area such as land clearing by the use of fire were the main source of surface fires. The fact in the field that from 20 point of surface fires event were observed during this study, most of surface fire was ignited from slashed area. An interesting phenomenon that even though fires was high intensity in a slashed area, but peat fires were not occurred in there, most of them we found at the surrounding or in adjacent of un-slashed area about 20-30 m ahead of the slashed area. The reason for this might be that the speed of fire spread in slashed area was faster than that in the un-slashed area, in which the duration of burning was very short and expanding fires into deeper peat layer required not only high intensity of surface fire, but also duration for its fire applied.

The surface fire ignited surface peat through cracks or woody material, or assembles of litter in small cavity, that extends into the peat soil (Fig. 9a). Spots on the surface of peat that had in which has been ignited by surface fires were clearly visible after surface fire passed of 1-2 hours later. These spots will extend into the peat soil if the fuel materials can maintain a fire temperature for at least 1-2 hours, otherwise these sports gradually extinguish. The location in which an ignition point occurred appears not so leafy but sheltered from straight wind blow.

After surface peat had been ignited a smoldering front took place and started to burn downward and laterally into the surface peat at a depth of 0-20 cm (Fig. 9b) and then extended into peat at a depth of 20-50 cm (Fig. 9c).

The process of peat fire and peat consumption is not well understood. However some characteristics of surface peat fires (at a depth of 0-20 cm) can be explained as follows:

(1) A surface peat fire occurs at shallow peat or peaty soil or in karangas peat. According to Shimada (2001), the depth of peat soil at floodplain and marginal peat of Central Kalimantan is 50 to 70 cm. Since the mean peat thickness is small, surface peat fires do not frequently penetrate into the deeper peat layer up to 50 cm in depth. Moreover soil materials at deeper layer such as sand, granites and mineral soils are noncombustible. This phenomenon was found in our study sites 8 and 9 where the bottom of peat layer was mineral soil. According to Frandsen (1997) an inorganic content of 81.5% is the limit for peat soil ignition.

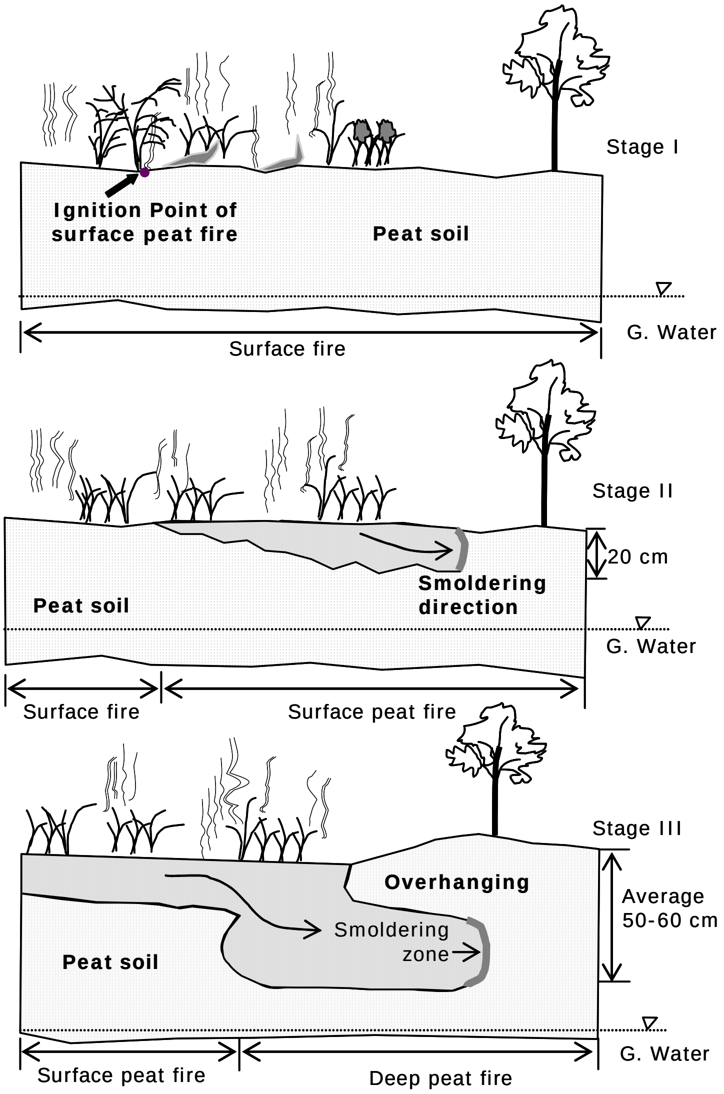

Fig. 9. Peat fire development in a tropical peatland of Central Kalimantan. Stage I: a spot of peat surface is ignited during the surface fire event. Stage II: is surface peat fire burning at < 20 cm depth and stage III is deep peat fire burning at >20 cm depth.

(2) A surface peat fire also occurs widely in an area with deep peat soil, before the fire encounters a suitable condition to burn downward into a deeper peat layer. Ground water level, moisture content, and fuels arrangement appear to be the main factors preventing a smoldering front from burning a deeper layer of peat soil.

(3) A surface peat fire moves quickly in zigzag lines with several fire fronts to find favorable conditions and burn into a deeper peat layer. The width of the fire front is about 10-50 cm (Fig. 11). The functions of surface peat fires are ignition of deep peat fires and serving as kindling charcoal for other fires.

Deep peat fires (burning at a depth of 20-50 cm) were ignited by surface peat fire fronts. A deep peat fire is the ultimate stage of the peat fire process. This fire spread into the peat dome, hummock, and areas surrounding tree roots. It also burned the peat stockpiles on both sides of the

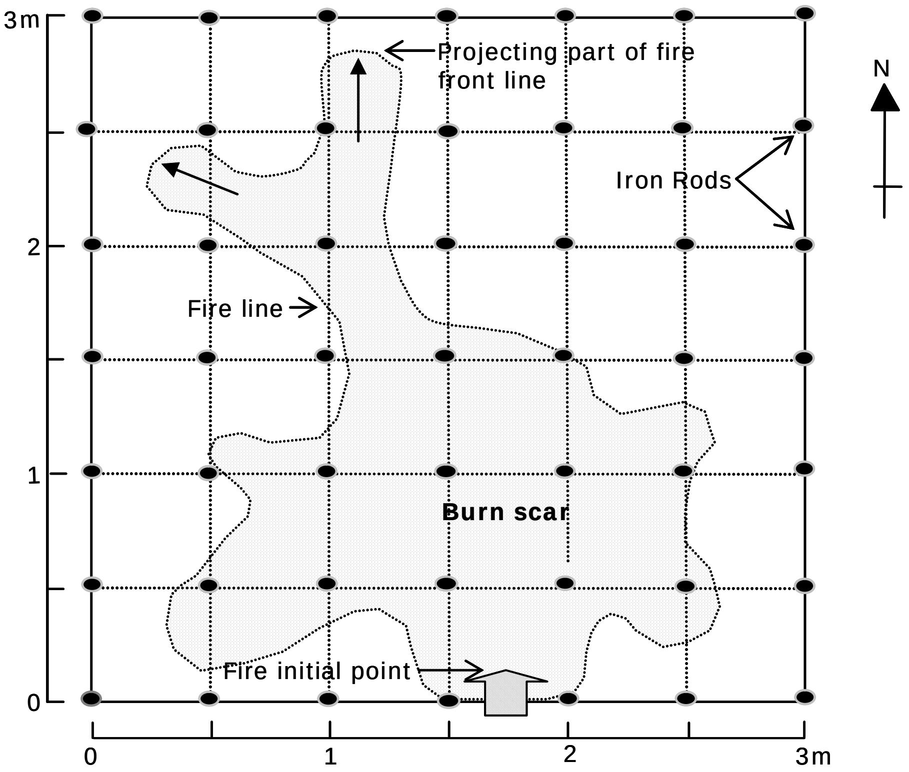

Fig. 10. A typical horizontal distribution of burned surface peat layer with several projection parts of the fire front line at Plot-2 on August 10, 2002.

highway or the canal. The deep peat fire was hazardous, giving rise to black smoke and releasing pollutants into the atmosphere. Once the deep peat fire had been ignited, it was difficult to extinguish even under heavy rainfall. Cristjakov *et al.* (1983) reported that the concentration of bitumen per unit weight of peat soil increased after the peat had drie and that particles of dry peat responded to water with resin, and even if the rain water penetrated into the peat through cracks, it was not absorbed by peat materials.

Deep peat fires frequently occur in the tropical peatland of Central Kalimantan. They are mainly caused by (1) lowering of the water table, (2) decrease in soil moisture, and (3) available of fuel wood in the peat matrix. Physically, the deeper peat layers (20-50 cm) contain much wood debris. The wood debris appear in a chaotic arrangement and form many chinks or gaps (See woody materials in peat soil in table 5). Moreover the bulk density of peat soil at a deeper layer (40-80 cm) was less than that of surface peat. This fact is in agreement with tropical peat characteristics in Malaysia, where the bulk density of a deeper peat layer is 0.09 – 0.10 g ml^{-1} while that of surface peat soil is 0.11 – 0.13 g ml^{-1} (Okazaki *et al*., 2001). High wood content and low bulk density of deeper peat layers enables oxygen to be supplied to the deeper peat layers, when smoldering combustion occurs.

The peat fires processes in a tropical peatland are not essentially different from the processes of peat fires in a boreal forest, in which the smoldering progresses are dominant at the lateral spread (Hungerford *et al.,* 1996). Horizontally fire often burns peat soil below the surface leaving unburned material overhanging (50-100 cm) that will cave in under a person’s weight. Although the unburned overhanging collapses, the lateral spread of fire continues and some of them go to the surface and promote a new surface peat fire. The lateral spread of deep peat fire is stopped when the ground water level rises, at the end of the dry season.

Speed of peat fire spread

Table 3 shows the speed of spread of the fire front measured at depths of 0-20 cm and 20-50 cm at study plots 3, 5, and 7. The average speed of fire spread at surface peat fire (at a depth of 0-20 cm) was 3.83 cm hr^{-1} or about 92 cm day^{-1}. Maximum speed of spread of surface peat fire was 6.49 cm hr^{-1} or 155 cm day^{-1} and minimum speed was 1.73 cm hr^{-1} or 42 cm day^{-1}. The average speed of fire spread in deep peat (at a depth of 20-50 cm) was 1.29 cm hr^{-1} or about 29 cm day^{-1}. Maximum speed of deep peat fire was 2.50 cm hr^{-1} or 60 cm day^{-1} and minimum speed was 0.50 cm hr^{-1} 12 cm day^{-1}. The speed of spread of deep peat fire is a half to one third slower than the speed of fire spread in surface peat .

These speeds of fire spread in the tropical peatland are not greatly different to those reported for different types of peat and different regions. In a Russian peat fire, the speed of fire spread in stockpiled peak was reported to be 0.5-10 cm hr^{-1} (Chistjakov *at al.*, 1983). The speed of fire spread in Australian peat is 4.2 cm hr^{-1}, and that in Canadian peat is 3-12 cm hr^{-1} (Wein, 1983). Unfortunately, they are not measured the speed of peat fire speed following depth. The speed of fire spread has been shown to have a linear relationship with wind speed (Fernandes, 2001), but the relationships of speed of fire spread in a tropical peatland with soil moisture and wind speed are still not clear.

Table 3. Speed of fire speed in tropical peatland, with standard deviation (SD), and numbers of fire samples (N).

Peat Fire type	Average (cm h^{-1})	Maximum (cm h^{-1})	Minimum (cm h^{-1})	SD (cm h^{-1})	N
Surface peat fire (burning at 0-20 cm)	3.83	6.49	1.73	1.41	20
Deep peat fire (burning at 20-50 cm)	1.29	2.5	0.5	0.64	20

Fuel materials in the secondary peat forest

Fuel composition

Table 4 shows the amounts of fuel materials above ground in the 9 study plots. The amounts of surface fuels ranged from 15.4 to 39.6 tons ha^{-1} and the dry weight ratios of dead materials in the study plots were about 34-62%.

The fuel materials in peat layers in plots 3, 4 and 5 from the surface to depths of 15 cm, 15-30 cm, and 30-50 cm were classified into four components: (1) fine peat materials (2) coarse peat materials, (3) wood/root debris, and (4) grass roots Fig. 11. The precentage of wood/root debris in the deeper peat layer was 19%, which is much larger than that in other layers, while the percentage of grass roots in the surface layer was 20%, which is larger than that in other layers.

Both grass roots in the surface layer and woody peat in deeper layers are very flammable when they are dry and are the main materials for fire propagation into deeper peat layers. On the other hand, wood/root debris might cause the formation of many chinks and gaps in the peat soil through which fresh air can be supplied to the fire front.

Wood debris in each layer of each quadrate was counted and sorted according to diameter as shown in Table 5. There was no wood debris larger than 4 cm in diameter in the surface peat layer. Larger wood debris, 4.0-6.9 cm in diameter, was found in the peat layer at a depth of 15-30 cm , and much larger wood debris, 8.0-8.9 cm in diameter, was found in the layer at 30-50 cm in depth. This tendency is similar to that tropical in peatlands in Bacho Thailand and Mukah Malaysia, in which woody peat of larger sizes were found in deeper peat layers (Okazaki *et al.*, 1994).

Table 4. Characteristics of fuel vegetation in study plots

Items	Study plot								
	1	2	3	4	5	6	7	8	9
Vegetation type	……………………….Bush……………………………								
Maximum Vegetation height including trees (m)	5	6	5	5	2	4	5	5	8
Ratio of dead plants (%)	34	40	59	53	39	62	45	47	52
Surface fuels (t ha^{-1})	34.2	39.6	20.1	34.4	23.9	20.5	20.5	15.4	19.6

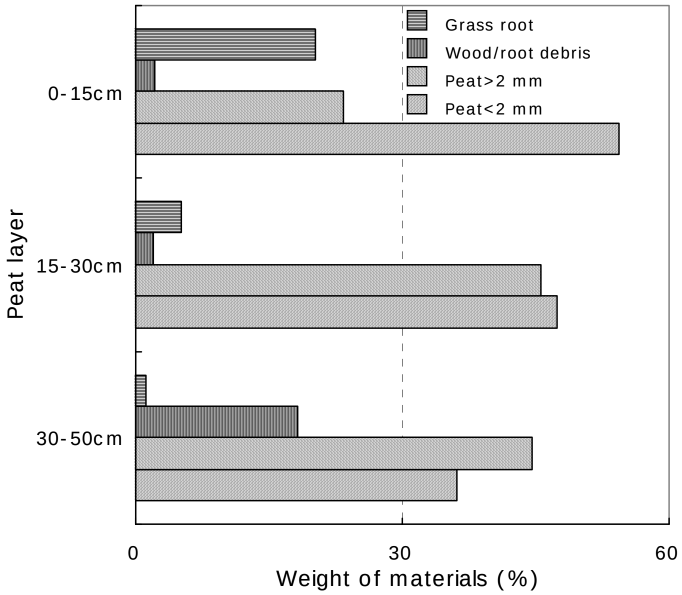

Fig.11. The composition of fuel materials in peat layers from surface to 50 cm in depth in a one meter square quadrate.

Peat moisture content

Fig. 12 shows vertical profiles of peat moisture in various peat layers in study plots 1 and 2 measured on August 8, 2002, where the moisture content of peat soil was increased with depth of peat. In both plots, the moistures of surface peat were about 100% in gravimetric moisture content. The peat moisture increased to about 120% at a depth of 10 cm , and was almost constant up to a depth of 40 cm . After 40 cm, water content increased sharply to about 220%.

According to Frandsen (1987), peat soil is ignited at a moisture content below 110%. He also noted that the surface of a peat swamp forest can be ignited at a moisture content less than 130%. The low moisture content of the peat surface in both study plots means that surface peat in these plots were dry enough and possible to burn since middle of August.

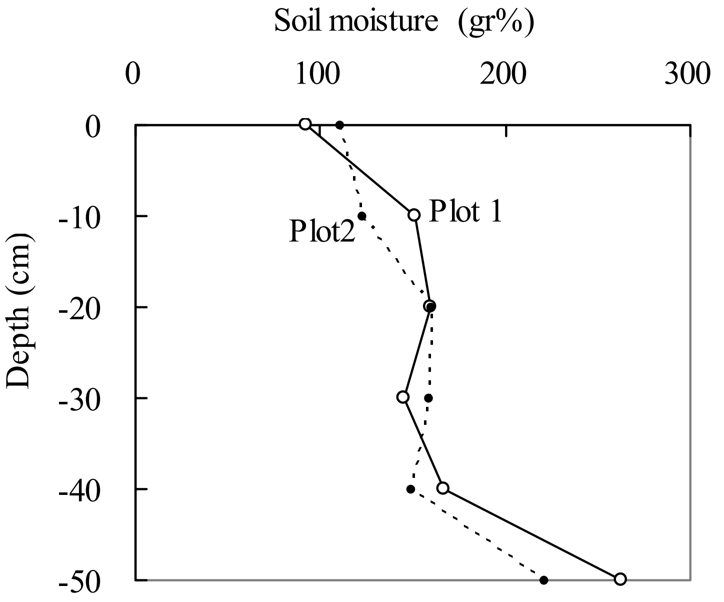

Fig.12. The peat moisture content at study plot 1 and plot 2 sampled on August 8, 2002.

Fuel loss by fire

Table 6 shows mean values of biomass and peat in the five quadrates before fires and weight loss after fires in the nine study plots. Mean peat weight was about 34 kg m^{-2} and mean peat weight loss was about 8.3 kg m^{-2}, about 24% of the peat weight before fire. The mean weight of grasses before burning was 3.3 kg m^{-2}, and loss by fire was 1.6 kg m^{-2}, about 48% of the grass before fire. The mean weight of litter before burning was 2.2 kg m^{-2}, and loss by fire was 1.1 kg m^{-2}, or about 50% of the litter before fire. These results indicate that about 50% of grass and litter was burned during fires, where as only 24% of peat was burned. The reason for the low percentage of peat loss was mainly due to comparison of 50 cm peat weight and burned weight. However 24% means that the average depth of burnt peat was about 12 cm or surface peat fire.

The amounts of fuel materials loss by fire in the study plots are larger than those in our previous study (artificial fire) on slash and burn of a secondary peat forest near a fire climatology station (Usup *et al*, 2002). At the time the surface fuel was losses on fire was about 36% and peat soil was not burn at all. This is because the surface fuel in the present study was sufficiently dry and more suitable for surface fire propagation. On the other hand, there was abundant wood debris on the peat surface, which remained on the ground without burning in a fire that occurred in 1997. The small amount of rainfall from May to September in 2002 made the fuels on the peatland very dry, thus providing good fuels for combustion in this area.

The loss of surface fuel materials in a fire event depends on the fuel types, moisture content, and fuel bed. According to Pyne *et al.* (1996), loss of surface fuel materials in a fire event never reaches 100%; it ranges from 50 to 95% in all wildfire events. Loss was only about 27.4% in a forest subjected to slashing and burning for conversion into pasture land (Fernside, 1993), and loss was about 90% of trunks and large branches above ground (Seiler and Crutzen, 1980) and about 42-57% in a slashed area of a primary tropical forest in the Brazilian Amazon (Kauffman et al., 1995). Loss was estimated to be about 25.1% in Manuas region (Carvalho *et al.*, 1995).

According to Van Wagner (1972), duff consumption by fire in *Pinus resinosa, Pinus strobes* and *Pinus banksiana* of boreal forest was predicted about 7.55 kg m^{-2} as the maximum limitation amount of duff that could be consumed by fire. The Standard Duff Moisture Code Layer in the Canadian Fire Weather Behavior System is 7 cm in depth and 5 kg m^{-2} in weight, assuming a duff bulk density of 0.071 g m^{-3} (Miyanishi, 2001).

Table 6. The mean of fuel materials at $1m^2$ such as grasses, litter and peat in each study plots, before and after fire.

Plot	Total fuel at $1m^2$ (kg m^{-2})			Total (kg m^{-2})	Fuel loss at $1m^2$ (kg m^{-2})			Total (kg m^{-2})
	Grass	Litter	peat		Grass	Litter	peat	
1	2.70	2.02	34.86	39.58	1.62	1.21	5.26	8.10
2	3.44	2.54	34.48	40.46	1.74	1.30	6.98	10.02
3	3.34	2.32	32.80	38.46	1.33	0.93	6.60	8.86
4	3.16	2.70	32.38	38.24	1.89	1.31	8.48	11.68
5	2.82	2.10	34.40	39.32	1.28	0.94	10.30	12.52
6	3.92	2.34	34.58	40.84	1.57	0.93	10.08	12.59
7	3.16	1.84	35.50	40.50	1.72	1.03	10.70	13.45
8	2.78	2.04	36.70	41.52	1.27	0.93	9.20	11.40
9	4.12	2.14	34.10	40.36	1.70	0.89	6.80	9.39
Mean	3.27	2.23	34.42	39.92	1.57	1.05	8.27	10.89
%	8.19	5.58	86.23	100.00	14.42	9.66	75.92	100.00

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C-14 DATES ON PEATLAND DEVELOPMENT AND HISTORY OF PEATLAND FIRE AROUND PALANGKARAYA, CENTRAL KALIMANTAN, INDONESIA

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Abstract

The development and fire history of peatlands in Central Kalimantan were examined on the basis of peat stratigraphy and radiocarbon dates. During the period from pre Holocene to ca. 10,000 cal. yr BP, alluviation occurred extensively in Central Kalimantan. This alluviation and associated river migration promoted development of vast waterlogged environments which allowed peat accumulation. The main period of peat accumulation from ca. 10,000 to 7000 cal. yr BP, occurred at the relatively high rate of 0.07-0.1cm/yr. The accumulation rate of peat slowed down to 0.008 cm/yr from ca. 7000 to 4000 cal. yr BP, which might have related to drier climatic conditions. Within the last ca. 4000 years, the peat accumulation pattern was complex: peat accumulation appears to have largely ceased with only patchy accumulation in some places. Numerous charcoal layers in the thick peat provide evidence that fire has occurred every 100-350 years in the peatlands since its initial development, 10,000 yrs ago. This implies that the tropical peatlands may not be completely fire resistant. The severity of fire is low, as indicated by the spotted distribution of charcoal layers. Burning might have been anthropogenic in origin because the high water table may have inhibited natural fire, and because people have lived in Kalimantan since 35,000 yr BP.

Keywords: Central Kalimantan, charcoal, C-14 dates, fire history, peatland development.

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1. Introduction

Central Kalimantan is well known as a region of Indonesia where tropical peatlands are widely developed. There were, however, only a few reports on these peatlands until about 10 years ago. After this time, serious degradation of the peatland ecosystems due to recurring fire attracted many scientists to conduct studies focusing on the present condition of the ecosystems particularly in relation to fire. In spite of these studies, there are few examples of peatland development (e.g. Siefferman et al., 1988; Page et al., 1999) and there are almost no studies of peatland fire, particularly from an historical perspective. Information of these subjects is important for a better understanding of processes of peat formation particularly in relation to climatic and environmental changes. Moreover, it is also important to evaluate the present peatland condition i.e. whether it is accumulating or degrading. This report presents the development chronology and fire history of peatlands around Palangkaraya, Central Kalimantan.

2. The Study Site and Methods

Seventeen cores were taken by hand using a half cylinder type Eijkelkamp peat sampler (cf. Neuzil, 1997) for stratigraphic examination and radiocarbon dating from 3 sites: Setia Alam, Kalampangan and Gerung (Fig. 1). A series of 13 cores was taken along a NE-SW transect from the Sebangau River toward interior forest of Setia Alam (Fig. 2). Three cores were taken from Kalampangan (Fig. 3) and 1 core from Gerung (Fig. 4). An additional section which shows evidence of an erosional boundary between peatlands and alluvium was examined at Gerung (Fig. 4). A total of 45 samples were taken for AMS C-14 dating. These samples were from charcoal in the cores except for those taken from KA-3 and the Gerung section and the lowest sample from KM 4 which were wood fragments. AMS radiocarbon dating was undertaken by BETA Inc. Co. and the Japan Nuclear Center (JNC).

3. Results

3.1 Stratigraphy and structure of peatlands

Figures 2, 3 and 4 show the stratigraphy and the structure of peatlands from

Setia Alam, Kalampangan and Gerung respectively.

It is evident in the cross-section of peatland from Setia Alam (Fig. 2) that the basement of peat is alluvium consisting of stiff clay and silt sediments. The upper-most alluvial sediments are organic rich and gradually change to peat upward. The peat thickness varies from several cm to about 2 m in the flood plain area and it is from about 3 m to more than 5 m in the interior forest. Wood and root fragments were abundant in the peat. Charcoal layers were intercalated in many horizons. There are 3 layers in KM 1, 1 layer in KM 2, 6 layers in KM 3 and 11 layers in KM 4. Peat horizons which contain rich charcoal fragments were also identified at the top of KM 0.5 and KM 4. Litter overlaid the peat in most cores obtained from Setia Alam. Thin clay and silt layers were also found in the tops of cores RL 1, RL 5, RL 6 and RL 7 which are located in the present flood plain of the Sebangau River.

The cross-section of peatland from Setia Alam shows that the surface of the alluvial-basement undulates gently and tends to be higher toward the interior forest. The ground surface of the peatland appears to follow this relief and hence shows a domed-morphology. A relatively steep slope is present at the margin of the present flood plain of the Sebangau River.

Alluvial-sand (kerangas sand) outcropped at the bottom-most part of KA 3 from Kalampangan (Fig. 3). This sand was overlain by about 2.5 m of peat. Rip-up clasts of kerangas sand were contained in the peat. Charcoal layers and fragments were also found in peat horizons of this core. Charcoal layers are numerous in the peat horizons of KA 1 and KA 2. There are 7 charcoal layers in KA 1 between 100 and 220 cm depth and 15 layers in KA 2. Wood-charcoal fragments are present in some charcoal layers of KA 1 and KA 2.

A thin peat horizon overlies alluvial sediment in GR 1 of the Gerung site. Two woody-charcoal layers were identified in the peat horizon. A litter layer was present at the surface. Conversely, a former peatland outcropped along the small irrigation channel whose alluvial-sediment unconformably cuts into the marginal part of the peatland and then overlies it (Fig. 4). Peat rip-up clasts were found in the alluvium horizon.

3.2 Radiocarbon dates

The radiocarbon ages from Setia Alam, Kalampangan and Gerung are presented in Tables 1, 2 and 3 respectively. Calibration of conventional age yr BP into calendar age yr BP was undertaken using CALIB 4.3 (Stuiver and Reimer, 2000), and the 2σ range are given, for each date.

3.2.1 Setia Alam

The lowermost horizon of peat and organic rich sediment in Setia Alam shows a C-14 age of 10502 ± 267 cal. yr BP in KM 3 and 10351 ± 206 cal. yr BP in KM 4. The charcoal fragments in the uppermost horizon of alluvium in RL 1 provide a C-14 age of 9645 ± 227 cal. yr BP. Ages older than 4000 cal. yr BP were obtained from peat below 1 m depth in KM 1, KM 2, KM 3 and KM 4. Young peat ages (less than 200 yr BP) were found at depths less than 1 m as indicated in KM 1, KM 2 and KM 3. The dates on this horizon vary from modern at depths of about 20 cm to 160 ± 160 cal. yr BP at about 100 cm. There is no sample with dates between 200 and 4000 cal. yr BP. In KM 1, the charcoal layer at 12 cm depth is from a modern fire, while that at 124 cm depth was derived from a fire that occurred at 8276 ± 128 cal. yr BP. In KM 3, the age of the charcoal layer at 20 cm depth is 77 ± 77 cal. yr BP, while that at 8077 ± 141 cal. yr BP. In KM 4, the age of the charcoal layer at 20 cm is 76 ± 76 cal. yr BP, while that at 65 cm is 160 ± 160 cal. yr BP and that at 84 cm is 5830 ± 172 cal. yr BP. Radiocarbon age inversion occurs in KM 4 where charcoal layers at 84, 93 and 112 cm depths yielded dates of 5830 ± 172, 5590 ± 143, and 4668 ± 163 cal. yr BP respectively. The age/depth relationship (Fig. 5) indicates a coherent sequence of increasing age with depth and two different sedimentation rates of ca. 0.07 ~ 0.1 cm/yr between ca. 10,000 and 7000 cal. yr BP and of ca. 0.008 cm/yr between ca. 7000 and 4000 cal. yr BP.

3.2.2 Kalampangan

Radiocarbon dates show that KA 2 covers a period from 7543 ± 119 cal. yr BP (at 19 cm depth) to 9226 ± 245 cal. yr BP (at 150 cm depth) (Table 2). Two dates do not conform to the stratigraphic sequence (radiocarbon age inversion): KA 2 - 26 (7788 ± 175 cal. yr BP) and KA 2 – 116 (8968 ± 328 cal. yr BP). The age/depth relationship (Fig. 2) indicates a coherent sequence of increasing age with depth and relatively constant sedimentation rates of ca. 0.08 cm/ yr throughout the sequence.

Radiocarbon dating of charcoal layer taken from KA 1 at 122, 132, 137 and 146 cm depths yielded 7110 ± 225, 7580 ± 162, 7331 ± 176 and 7453 ± 138 cal. yr BP respectively. Radiocarbon dating of wood samples taken from KA 3 at 110, 160 and 210 cm yielded ages of 6569 ± 162, 6993 ± 103, 7365 ± 59 cal. yr BP respectively.

3.2.2 Gerung

Two wood samples taken from the Gerung section at about 60 and 150 cm yielded ages of 6531 ± 136 and 8066 ± 126 cal. yr BP of age respectively. A wood sample from peat-cutting alluvium yielded a date of 1833 ± 119 cal. yr BP (Fig. 4). Two charcoal samples from a thin peat in GR at 40 and 75 cm yielded ages of 401 ± 108 cal. yr BP and modern respectively.

4. Discussion

4.1 Peat Development

Figures 2, 3 and 4 demonstrate peat stratigraphy and peatland structure, while figure 5 displays age-depth curves derived from dated samples and accumulation rates of peat. Based on these data, phases of peatland initiation, peatland climax, and peatland cessation and degradation can be distinguished:.

4.1.2 Peatland Initiation

The cores taken from Setia Alam (Fig. 2) indicate that peat developed on a basement of greyish-white to white stiff clay and silt alluvial sediments. These stiff sediments, which were deposited from the pre Holocene to ca. 10,000 cal. yr BP, and probably blanketed lowland areas as a consequence of active river migration, and formed an impermeable layer, which allowed the development of a vast waterlogged environment. During the Early Holocene, the wet climatic conditions are considered to have prevailed.

4.1.2 Peatland Climax

Core profiles from Setia Alam (Fig. 2), Kalampangan (Fig. 3) and Gerung (Fig 4) show that peat accumulated from ca. 10,000 to ca 4000 cal. yr BP. During this time, continous peat accumulation occurred at places which are distant from the river (inland peat) as indicated in KM 3 and KM 4.

The accumulation rate is not constant throughout the peatland climax phase. It is relatively high between ca. 10,000 and 7000 cal. yr BP with a rate of 0.07 ~ 0.1 cm/yr as indicated in the linear regression of KA 1, KA 2, KA 3, KM 3 and KM 4 (Fig. 5).

This high accumulation rate suggests that environmental and climatic conditions were favorable for peat formation. The postulation of high precipitation is consistent with evidence elsewhere in the Southeast Asia region (Haberle *et al.*, 2001).

Peat accumulation had significantly slowed down to a rate of 0.008 cm/yr in the period from ca. 7000 to 4000 cal. yr BP as indicated in KM 4. Weiss et al (2002) also reported comparable C-14 data implying such a slow down (see Fig 5). This reduction in the accumulation rate suggests higher rates of decomposition of peat and drier climatic conditions in comparison with the preceding period.

4.1.3 Peatland Cessation and Degradation

The absence of young and presently accumulating peat in KA 1, KA 2 and KA 3 and in the peat outcrop from Gerung, and the absence of peat between 200 and 4000 cal. yr BP of age in KM 4 indicates either that peat did not accumulate during this period (cessation period) or it accumulated at a slow rate and subsequent decomposition exceeded accumulation. **The upper 70 cm of peat with an age less than 200 cal. yr BP in KM 4 must be undergoing decomposition because is situated in the acrotelm zone or in the acrotelm-catotelm boundary as indicated by the ground water level**. From direct observation over the last decade in Setia Alam, the ground water level here was lower than - 80 cm during the dry season of dry years, and it was at - 40 cm or higher during the dry season of the humid years (Takahashi et al., 2003).

The peat outcrop at Gerung demonstrates that peat accumulation had already ended about 6500 cal. yr BP and was followed by the lateral erosion associated with alluvium deposition by the Kahayan River. However, patchy accumulation of peat still occurred around this site as indicated by the thin peat horizon in GR profile.

In case of the Kalampangan site, the absence of young peat might have been caused by serious peatland fires in 1997 and 2002. These fires burned a maximum of 150 cm of peat (Siegert et al., 2002) and an average of 51 cm of peat (Page et al., 2002). It is important to consider the present impact of fire in interpretation of past peat development as well as in the ecological interpretation of peat profiles.

According to previous studies (Neuzil, 1997; Page et al., 1999; Weiss et al., 2002), some C-14 dates obtained from bulk peat samples showed an age of about 2000 yr BP. Bulk of C-14 dates require a substantial quantity of sample. This can cause misleading dates due to serious contamination. Another problem in dating tropical peats is the high amount of wood debris and such wood could remain undecomposed even after a fire. For this reason, it is difficult to evaluate the accuracy of the younger C-14 dates which were reported by Neuzil (1997) and Page et al (1999). Weiss et al. (2002) reported conventional C-14 dates of bulk peat samples of a core taken from low pole forest of Sebangau cacthment area, about 7.5 km from the Sebangau River. Although these dates show comparable evidence of peat development to those of KM 4, KM 3 and KA 2 from the early to mid Holocene, they demonstrate a different picture of peat development from the mid to late Holocene (see Fig. 5). These dates indicate a coherent sequence of increasing age with depth from present to ca. 7000 cal. yr BP. This suggests peat has accumulated continuously at a slow rate through the last 7000 years. The general implication is that the peat accumulation pattern may have been complex since ca. 4000 yr BP: peat accumulation ceased and degradation prevailed in some places (in the case of KM 4 and possibly also KM 3 and KM 2) while patchy accumulation occurred in other places. This difference must have been caused by some variation in hydrological conditions related to small depressional areas within the vast peatland.

4.2 Fire History

We have recognized many charcoal layers in the peat at almost all coring sites. They provide clear evidence that fire occurred frequently in the peatlands since the time of its initial development. C-14 dates imply that fire could have occurred every 100-350 years since 10,000 years BP with different fire frequencies between sites. This demonstrates that the tropical peatlands are not fire-impervious and implies that tropical peatlands may not be completely fire resistant.

However, the forests probably did not burn under natural conditions because they are wet and humid and there is almost no natural fire source. The only source of natural fire is lightening strikes, which occur only during the rainy season. Although lightening strikes could ignite fires occasionally, it is very unlikely that they lead to forest fire because rainfall suppresses the fire quickly. Considering such conditions, the fires might be anthropogenic in origin. Anthropogenic fire during the early to mid Holocene is reasonable because people had already lived in inland Borneo since at least 35,000 years ago (Flood, 1995).

We can not correlate distinct fire events between sites due to overlapping of 2σ confidence intervals in the calibrated age distributions. This overlap makes it difficult to determine whether there were many localised fires or fewer extensive fires. However, differences in frequency of charcoal layers in KM 1, KM 2, KM 3 and KM 4 suggests that fires seems to have been limited in extent.

4.3 C-14 Age Inversion Problem

Age inversion problems may appear when the source of the charcoal for C-14 is dead wood derived from an older period. Because wood has inbuilt ages, related to the time of wood formation, C-14 analysis of derived charcoal will reveal these ages rather than the ages of fire events that produced the charcoal. Burning of old wood may occur when peat accumulation is slow and/or peat degradation is rapid. Slow peat accumulation will result in dead wood remaining unburied while rapid peat degradation will expose buried old wood. Accordingly, C-14 age inversion may indicate slow peat accumulation and/or rapid peat degradation.

5. Conclusions

Based on peat stratigraphy and C-14 dates, peatland development and the history of peatland fire of peat swamp forest around Palangkaraya, Central Kalimantan revealed the following.

1. The recognition f three phases of peat development:
    a. Pre Holocene ~ ca. 10,000 cal. yr BP: Peatland initiation.
    b. ca. 10,000 ~ 4000 cal. yr BP: Peatland climax.
    c. ca. 4000 cal. yr BP ~ present: Peatland cessation and degradation with patchy accumulation.
2. Peatland fires may have taken place every 100 ~ 350 years over the last 10,000 years. The fires were limited in extent and anthropogenic in origin.

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The spectral characteristics of the fire-damaged peatland surface in Central Kalimantan, Indonesia
2. Monitoring peat moisture and vegetation recovery

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ABSTRACT

In this study, we measured the surface condition of the fire-damaged peatland in Central Kalimantan in two consecutive dry seasons from 2003 – 2004 in order to spectrally monitor the vegetation recovery. A FieldSpec UV/VNIR hand-held spectroradiometer was used to measure the spectral reflectance (325-1,075 nm) of the peatland surface. ECH_2O dielectric aquameter was used to measure the peat surface moisture content. The pattern decomposition coefficients of vegetation (C_V), of peat soil (C_S), of water (C_W) and normalized difference vegetation index (NDVI), ECH_2O output value (ECHO) were used as the indicator to monitor the fire-damaged peat surface. By a laboratory experiment, ECHO were found to have a good correlation (r = 0.87) with peat water content on a dry matter basis. By the field measurement, correlation (r = 0.7) between ECHO and C_S was found. Using the relationships of vegetation cover ratio versus NDVI and versus C_V, the vegetation of the fire-damaged study site was calculated to be spatially recovered by 28.9 – 31.6% during the wet season of 2003 – 2004.

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Key words: Central Kalimantan / dielectric aquameter / fire-damaged peatland / pattern decomposition coefficients / spectroradiometer

INTRODUCTION

The peatland fires, during both the 1997 and 2000 ENSO events, have burned large areas of the peat swamp forests in Central Kalimantan (e.g. Shimada et al. 2004). The nitrogen losses by those peatland fires might have destroyed the plant communities on the peatland fire scars as occurred several times within past thousands years (Yulianto et al., 2004). Once this kind of environmental change has occurred, it takes for vegetation a long period to recover. Furthermore, the change in hydrological environment such as lowering of the groundwater level caused by canal construction, might affect to the peatland condition severely for the plant community. In this study, in order to clarify the recovering rate of a plant community on a fire-damaged peatland surface, we measured the spectral reflectance (325-1,075 nm) and the peat moisture in the dry seasons of 2003-2004 in Central Kalimantan.

MATERIALS AND METHODS

Study Plot and Field Measurement

Study plot locates in Kalampangan, the fire-damaged peatland area, affected by both the 1997 and 2000 fires (2° 19’ 24” S, 114° 01’ 00” E; cf. Shimada et al. 2004). Field measurement for this study plot was conducted on both a clear day a.m. of September 13 and on a cloudy day a.m. of September 15, 2004. The groundwater level of the study plot was 110 cm from the surface peat. The surface peat water content was 23 – 53% (30 – 113% on a dry matter basis). The dominant vegetation in the study plot was *Stenochlaena palustris* (kalakai), *Pteridium* spp. (hawuk), *Ficus* spp., and *Euodia* spp. with the height ranging from 20 – 100 cm.

A 50-m × 40-m quadrate was settled at the study plot. The quadrate was divided into twenty grid cells of 10-m × 10-m (cf. Shimada et al. 2004). The spectral reflectance (325-1,075 nm) at each center of the 10-m grid cell (sampling point) was measured by a FieldSpec UV/VNIR HandHeld spectroradiometer of ASD (Analytical Spectral Devices, Inc.). As the indicator for the surface peat moisture, peat dielectric constant values were measured using a dielectric aquameter, ECH_2O-10 soil moisture probe (Decagon Devices, Inc.).

Preliminary Experiment of Moisture and Dielectric Constant of Peat

A preliminary experiment was conducted in order to clarify the relationship between moisture and dielectric constant of peat. Surface peat samples were collected from the fire-damaged peat of the study site, and from forested peatland areas (Setia Alam: 2° 19’ 46” S, 113° 54’ 5” E; and Kalampangan forest site: 2° 20’ 46” S, 114° 2’ 13” E, cf. Shimada et al., 2003). Samples were saved in the plastic container (500 cm^3). ECH_2O output (ECHO) values (mV, excitation voltage = 1.5 V) were measured in various water content (% on a dry matter basis) (WC_d) values of the peat samples (***Figure 1***).

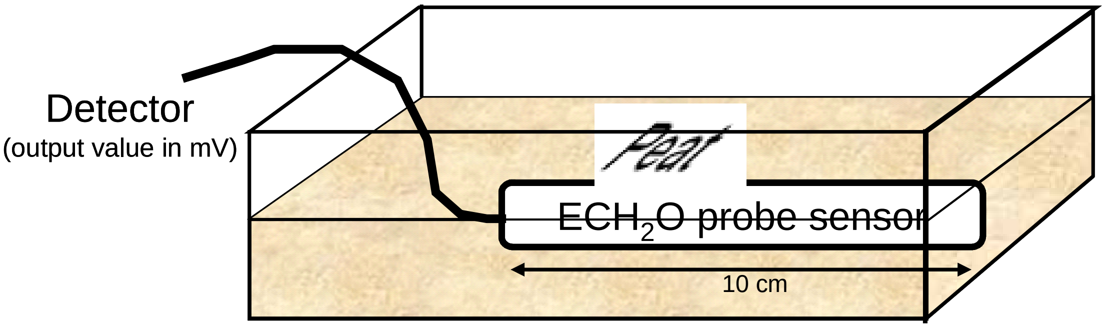

Figure 1. Diagram how to measure peat water content in relation to the peat dielectric constant using ECH_2O soil moisture probe.

Spectral Analysis

The spectral samples were divided into four spectral bands (i.e. 1: 470-501 nm, 2: 539-580 nm, 3: 637-668 nm, and 4: 801-870 nm) for analysis. The pattern decomposition method was conducted to decompose the spectral samples at sampling points into three components (i.e. P_V: vegetation, P_S: peat soil, and P_W: water) (**eq-2, eq-3**). In order to suppress the spectral variability, values of the sample reflectance and of the component reflectance were normalized (**eq-1**, **eq-2**).

$$A_i' = \frac{A_i}{A_1 + A_2 + A_3 + A_4}, \qquad \text{eq (1)}$$

$$P_{Ki}' = \frac{P_{Ki}}{P_{K1} + P_{K2} + P_{K3} + P_{K4}}, \qquad \text{eq (2)}$$

$$A_i' = C_V P_{Vi}' + C_S P_{Si}' + C_W P_{Wi}' + R_i', \qquad \text{eq (3)}$$

where i = 1 (blue), 2 (green), 3 (red), 4 (NIR); $K = V, S, W$; A_i and A_i' are reflectance and normalized reflectance value, respectively, of band i at a sampling plot, C_V, C_S, and C_W are pattern decomposition coefficient of vegetation, peat soil, and water, respectively, and R_i is residual. The least square method was conducted to calculate both C_V and C_S (cf. Shimada et al., 2004).

RESULTS AND DISCUSSION

Correlation of Peat Water Content and Dielectric Constant of Peat

ECH$_2$O soil moisture probe usually have been used to measure soil volumetric water content (m^3 m^{-3}). However, peat volume changes (shrinks) drastically with the water content changes (decreases), it is difficult to trace volumetric water content of peat samples. In this study, WC_d was used as the criterion value for the peat water content condition predicted by using ECH$_2$O soil moisture probe. ***Figure 2*** shows the correlation of the dielectric constant of peat from ECH$_2$O probe and peat water content (% dry basis). It can be mentioned that output value from ECH$_2$O probe can be used as an indicator for the surface peat moisture.

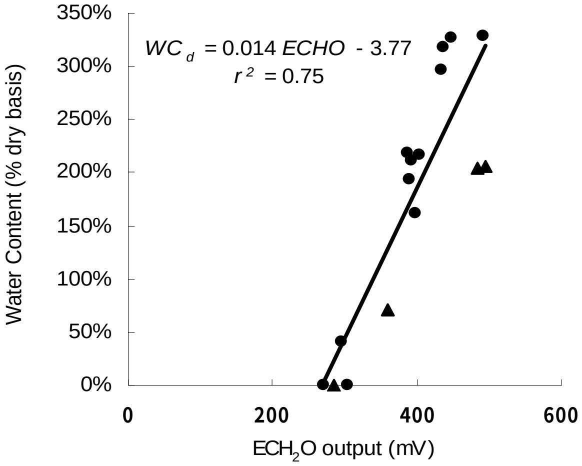

Figure 2. Correlation between ECH$_2$O output (dielectric constant) and water content (on a dry matter basis) for surface peat in Central Kalimantan. ▲ indicates the fire-damaged peat and ● indicates the forested peat surface samples.

Comparison of Sunny Day and Cloudy Day Spectral Measurement

The reflectance values (A_i) at any spectral band i differ by the weather condition or sun elevation angle when the measurements were conducted. However, the spectral reflectance curve shows similar pattern in any measuring condition. Normalization (**eq-1**) is also conducted in order to eliminate those differences in measuring condition, and extract the spectral curve pattern. ***Figure 3*** shows the relationships of normalized reflectance (A_i') in each spectral band i between sunny day measurement (Sept. 13, 2004) and cloudy day measurement (Sept. 15, 2004). Similar values (i.e. slope of the regression line 1) on normalized reflectance can be seen at spectral range in blue (A_1'), red (A_3'), and NIR (A_4'), while differs in A_2' between sunny day and cloudy day measurement. According to this result, indices that contain A_2' values into account, such as pattern decomposition coefficients, are not a suitable indicator to be used for the cloudy day measurement. However, NDVI (normalized difference vegetation index) can be an all-weather indicator since this index consist from values of red (A_3') and NIR (A_4') reflectance values. The correlation coefficient of NDVI values between sunny and cloudy day measurement were calculated to be 0.92.

Vegetation Recovery of the Fire-damaged Site

Table 1 shows the result of the spectral pattern decomposition analysis of fire-damaged peatland surface measured on Sept. 13, 2004. The NDVI value range from 0.27 – 0.84 at the study plot. Summing all the 20 points and comparing from the average values of indices from a year before (Shimada et al., 2004), values of NDVI and C_V increased by 0.048 and 0.146, respectively, while values of C_S and C_W decreased by 0.118 and 0.028, respectively. Using the correlation of vegetation cover ratio (VC) versus NDVI ($VC = 1.30\ NDVI - 0.44$, $r^2 = 0.75$) and C_V ($VC = 0.57\ C_V + 0.078$, $r^2 = 0.73$) (cf. Shimada et al., 2004), 28.9 - 31.6% in VC are estimated to be recovered at this study site during the wet season of 2003 – 2004.

Prediction of Surface Peat Moisture

Surface peat moisture of the study site is extremely low in dry seasons (ca. 1 m deep) since the drainage canal had constructed. This low peat moisture cause wild fire when the moisture content of the peat becomes less than 130% (Usup et al., 2004). It is, therefore, important to predict the surface peat moisture on a wide scale. For the prediction, the most feasible indicator from this study index was found to be C_S (***Figure 4***) and the correlation coefficient was 0.7.

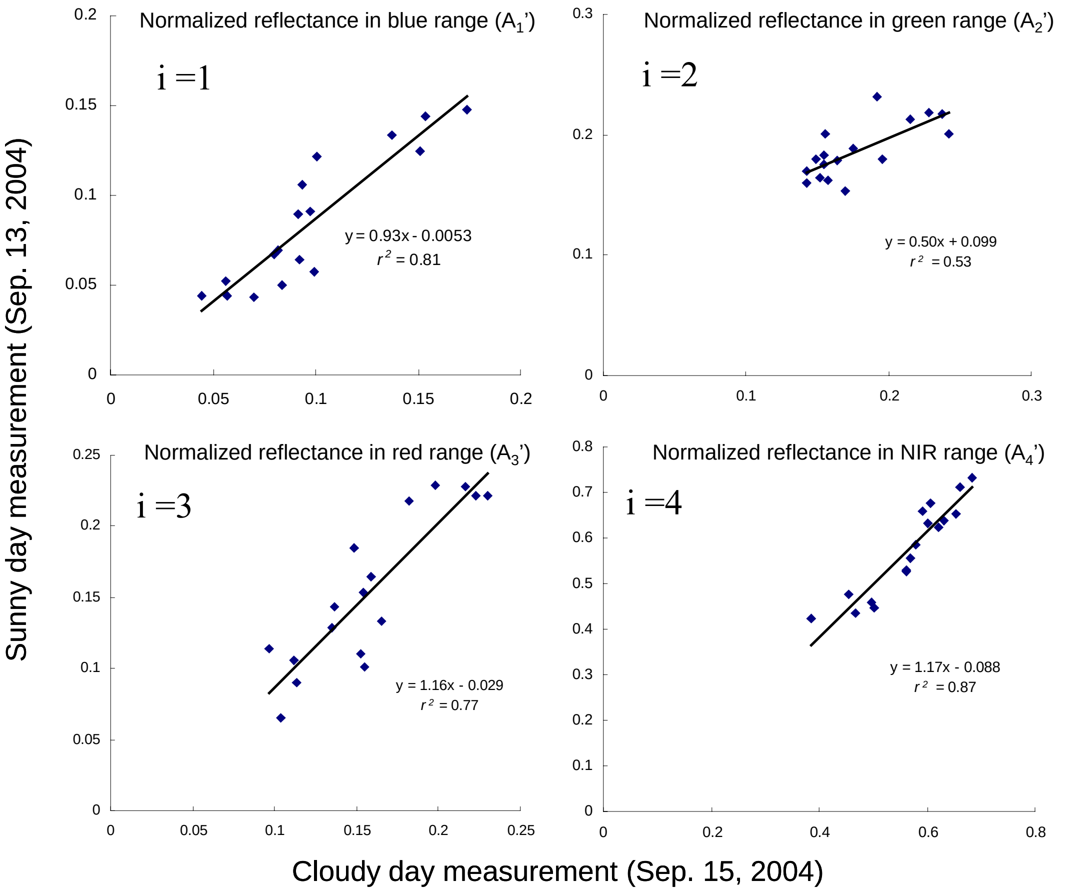

Figure 3. Relationships of Normalized reflectance within each band (i = 1, 2, 3, 4) between sunny day and cloudy day measurement.

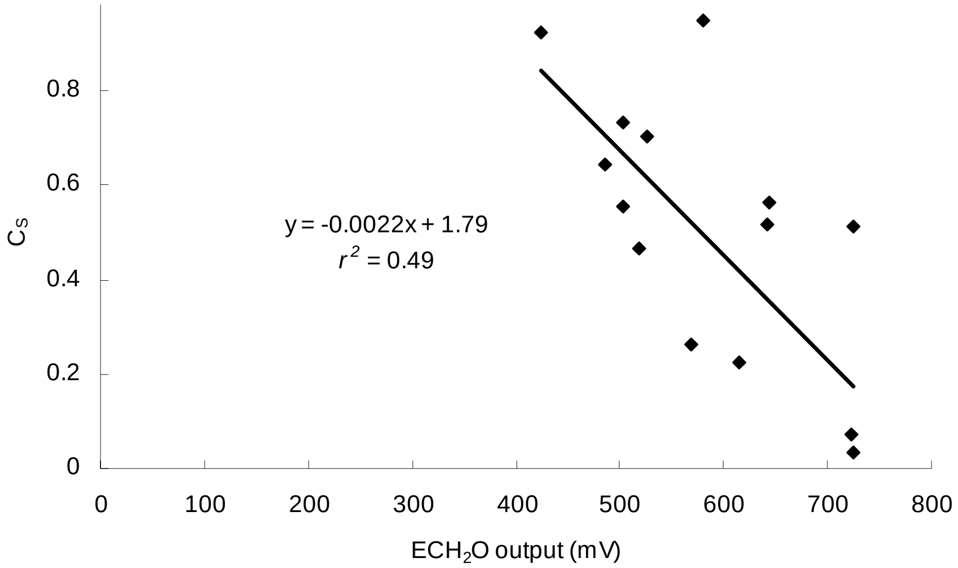

Figure 4. Relationships of ECH_2O output value and pattern decomposition coefficient of peat soil.

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3. Collaborative study

(4)

Function of aquatic ecosystems in Central Kalimantan

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Introduction

During the second phase of the JSPS-LIPI core university program, namely April 2000-March 2005, the collaborative study group for the aquatic ecosystems has been conducting the following research in order to clarify the biological and chemical features of these freshwaters and the ecosystem function of lakes and rivers and also to assess the human impacts at ecosystem levels: (1) Function of aquatic ecosystems: studies on the fauna and flora, trophic interactions and material cycling in lakes and rivers, (2) Human impacts on aquatic ecosystems: aquatic ecosystems affected by the changes in land-use and the subsequent land or forest fire events, (3) Environmental and health effects of heavy metals and chemicals, and (4) Fate of the chemical pollutants in the aquatic environment and the characterization of pollutants.

Since the fiscal year 2004 was the final year of the second-phase study term, we focused on the testing of several hypotheses proposed so far during the past year's study. The hypotheses are related to the mechanisms of maintaining biodiversity in oxbow and floodplain lakes in relation to water level change and those of regulating material cycling associated with alteration of dry and rainy seasons in these ecosystems. Metal pollution and chemical pollution in the tropical waters and the reduction properties of tropical humic acids were also studied.

Visiting of Japanese researchers visiting Indonesia

Japanese team visited the Research Center for Limnology-LIPI, Research Center for Biology-LIPI, Bogor Agricultural University and the University of Palangkaraya to exchange information and to perform field survey in the FY2004. The following Researchers visited Indonesia based on the core university program (in the chronological order):

Toshiyuki Ishikawa, Hokkaido University, 19 May-14 June 2004, Jakarta - Palangkaraya - Bogor and 17-25 March 2005, Jakarta - Palangkaraya - Bogor
Toshio Iwakuma, Hokkaido University, 6-17 December 2004, Jakarta - Bogor - Palangakaraya - Jakarta
Shunitz Tanaka, Hokkaido University, 7-11 December 2004, Jakarta - Bogor - Jakarta
Masaaki Kurasaki, Hokkaido University, 7-11 March 2004, Bogor-Cibinong
Toshiyuki Hosokawa, Hokkaido University, 7-11 March 2004, Bogor-Cibinong
Haruo Fukuhara, Niigata Universitiy, 17-25 March 2005, Jakarta - Palangkaraya - Jakarta
Akifumi Ohtaka, Hirosaki University, 15-22March 2005, Jakarta - Palangkaraya - Jakarta
Hidenobu Kunii, Shimane University, 17-22 March 2005, Jakarta - Palangkaraya - Jakarta
Makoto Uenishi, Ryukoku University, 15-25 March 2005, Jakarta - Palangkaraya - Jakarta

Based on the Grant-in-Aid for Scientific Research from Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan (no. 15405001 "Littoral ecosystems of tropical lowland lakes: their structure and response to water level change, FY2003-2004"), through Japan Society for the Promotion of Science, the following researchers visited Palangkaraya for cooperative survey:

Maki Imai, master-course student, Hokkaido University, 6-10 December 2004, Jakarta - Bogor - Jakarta
Yohsuke Takatsuji, master-course student, Hokkaido University, 6-22 December 2004, Jakarta - Bogor - Palangkaraya - Bogor - Jakarta
Shingo Tada, master-course student, Hokkaido University, 6 December 2004-2 February 2005, Jakarta - Bogor - Palangkaraya - Bogor - Jakarta
Toshiyuki Ishikawa, 10 October -1 November 2004, Jakarta - Palangkaraya - Bogor - Jakarta

Based on the JSPS-RONPAKU Program (LIPI-10212), the following researcher visited Indonesia:

Toshio Iwakuma, 18-30 July 2004, Jakarta - Bogor - Palangkaraya - Jakarta

Visiting of Indonesian researchers to Japan

The following three researchers visited Japan under the core university program:

Yoyok Sudarso, Research Center for Limnology, LIPI, 13-22 September 2004, Osaka - Sapporo - Hirosaki - Sapporo - Osaka

Yusli Wardiatno, Department of Living Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, 13-22 September 2004, Osaka - Sapporo - Niigata - Kyoto - Osaka

Sulmin Gumiri, Lecturer, Faculty of Agriculture, The University of Palangka Raya, Indonesia

As an activity of JSPS-RONPAKU program (LIPI-10212), the following researcher stayed in Japan:

Dede I. Hartoto, researcher, Research Center for Limnology-LIPI, 7 January - 17 March 2005, Osaka - Sapporo - Osaka.

Seminars

In order to present the state-of-the-art of the human dimension research on tropical peatland, an international workshop on human Dimension f tropical Peatland under Global environmental Changes" was held at Darmaga Campus, Bogor Agricultural University on 8 and 9 December 2004. The major scopes of the workshop were (1) to identify actors in environmental changes, (2) to understand the consequences of environmental changes on human well-being and (3) to illustrate human activities based on environment capability for sustainable development. The following members from the aquatic ecosystem study group participated in it and made oral (O) or poster (P) presentations: Shunitz Tanaka, Toshio Iwakuma, Maki Imai, Yohsuke Takatsuji and Shingo Tada (all Hokkaido University), Fifi Widjaya and Yusli Wardiatno (Bogor Agricultural University), Dede I. Hartoto, M. S. Syawal and Yustiawati (Research Center for Limnology-LIPI), Suwido H. Limin, Sulmin Gumiri, Tariono Buchar, Ardianor, Yulintine Liwat, Linda Wulandari, Yuli Ruthena, Welsiana Sepmiarna, Tri Septiani, Trisliana and Yurenfri (all University of Palangkaraya). The senior authors and the titles of the presentations are the following:

Ardianor, I. (O-2): Ambul: a traditional farming system on open water in Kalimantan

Gumiri, S. (O-6): Life on wetland in the Bangkau Village, South Kalimantan

Hartoto, D. I. (O-8): State-of-the-art of fishery reserve management in Indonesia

Imai, M. (O-12): Estimation of the impact of a large-scale development on pond ecosystems in Central Kalimantan

Iwakuma, T. (O-13); How are the lake ecosystems maintained in Central Kalimantan? Implications from the long-term ecological research on oxbow and floodplain lakes

Liwat Yulintine (O-16): Threats to the sustainability of inland water fishery in Central Kalimantan

Buchar, T. (P-2): Toward the domestication of local fishes in Central Kalimantan

Ruthena, Y. (P-11): Non fishery resources of wetland ecosystem in Central Kalimantan

Septiani, Tri (P-12): Traditional methods of freshwater fish preservation in Central Kalimantan

Syawal, M. S. (P-14): Environmental degradation due to human activity changes in River Cikaniki, Bogor

Tanaka, S. (P-15): Chemical properties of humic substances and the possibility of use for environmental remediation: Reduction and solubilization properties

Trisliana (P-16): Freshwater fish market in Palangka Raya

Welsiana S. (P-17): Fish cuisine in Central Kalimantan

Widjaja, F. (P-18): Water hyacinth and water pollution

Wulandari Linda (P-19); The lost of local people income from beje during the Mega Rice Project in Central Kalimantan

Yurenfri (P-20): The life of a local fisherman family in the Takapan Lake of Central Kalimantan

During the stay of three Indonesian researchers in Japan, a seminar entitled “Recent progress in environmental aquatic biology in Indoensia” was held at Room A-803A, Graduate School of Environmental Earth Science, Hokkaido University from 10:00 a.m. to 12:00 a.m. on Tuesday, 14 September 2004.The tiles of the presentations were: “Bioavailability prediction of heavy metal on sediment using triad concept: Case study on Saguling reservoir, West Java” by Yoyok Sudarso, “Benthic organisms of Pa'Raye and Pa'Lutut River system in Kayan Mentarang National Park” by Yusli Wardiatno and “Limnological study at the University of Palangka Raya: integrating recent findings and their application to local community” by Sulmin Gumiri.

Research activities

1. Function of aquatic ecosystems

1.1 Response of lake communities to water level change (S. Gumiri, Ardianor, L. Wulandari, Yulintine, T. Buchar, T. Septiani, Yurenfri, Trisliana, S. Welsiana, Y. Ruthena, M. Imai, T. Ishikawa, D.I. Hartoto and T. Iwakuma)

During the high water level season of December 2003-January 2004, data on lake depths and GPS locations were recorded with an echo sounder equipped with a GPS plotter system and the bathymetrical maps were constructed for Lake Bunter, Lake Tehang, Lake Batu, Lake Hurung, Lake Sabuah, Lake Takapan, Lake Rengas and Lake Tundai (Ishikawa et al. 2005)

Monthly limnological surveys were carried out for various oxbow and floodplain lakes with different conditions of hydrology and watershed forest in the vicinity of Sigi Village, c.a. 18 km north of Palangkaraya (Lakes Hurung, Bunter, Tehang, Batu, Sabuah, and Tundai). Water quality parameters were measured for surface and bottom layers at the center of each lake using combined submersible sensors (U-25, Horiba, Japan). Samples for phytoplankton, zooplankton and chlorophyll a analyses were collected from the lake surface. Phytoplankton were collected with 20-µm plankton net, zooplankton with 40-µm plankton net and zoobenthos were sieved with 0.3-mm net after sediment collection with Ekman-Birge sampler. Chlorophyll a samples on Whatman GF/F filters. All samplings were conducted at the central part of each lake (Gumiri et al. in press).

1.2 Structure and function of lake ecosystems in relation to the hydrological connectivities to the main river (T. Iwakuma, S. Gumiri, T. Ishikawa, H. Yamato, L. Wulandari, Yulintine, Ardianor, T. Buchar, M. Imai, D.I. Hartoto and Sulastri)

The degrees of connectivity of lakes to the main river affected phytoplankton density and biomass (Ardianor and Trisliana 2005) and zoobenthos biomass (Iwakuma et al. in press), since the mixing of water column occurred much more frequently in the lake close to the main river than lakes distant from the river. A study on four lakes in Sigi area revealed that although the annual mean value of similarity indices were higher between adjacent lakes, the indices for pairs of lakes varied greatly between lakes and between months, indicating that the degrees of association of these four interconnected lakes are highly dynamic from time to time (Gumiri et al. in press).

In Lakes Batu and Tehang, water level and water temperatures at 0-m depth, 1-m depth and bottom have been monitored hourly to investigate the time and degree of lake water mixing in relation to water level change. Water levels have also been monitored at the outlet of Lake Bunter and at the bank of the Kahayan River (Bukit Rawi). Precipitation has been monitored at the same time at Sigi Village (02°01'09.5"S, 113°56'54.9"E).

1.3 Primary productivity and matter cycling in the oxbow and floodplain lake ecosystems (T. Ishikawa, Yurenfri, Ardianor and T. Iwakuma)

Litterfall amounts in the riparian forest of lake Batu have been monitored using a series of litter traps set up on three rafts arranged in a transect from inside the forest to offshore region. The traps collected litter successfully even during the high water level period in December-January.

Size-fractionated chlorophyll a concentrations were determined for water samples from Lakes Bunter, Tehang, Batu, Hurung, Sabuah and Tundai. In all the lakes observed, nannoplankton, i.e., the fraction of phytoplankton <10 µm constituted nearly 50% and the fraction 10-20 µm another 10-30%. Cosequently the fraction <20 µm made up the majority of total chlorophyll a amounts (Ishikawa and Iwakuma 2005). Incubation experiment of humic water in bottles under natural light showed that the respiration was higher in light bottles than in dark ones. This might be due to the decomposition of refractile DOM to labile DOM by UV radiation (Ishikawa et al. 2005; Ishikawa et al. in press).

1.4 Study of "Interrhizon" in several oxbow lakes in the peat swamp area of Central Kalimantan (H. Fukuhara, A. Ohtaka, M. Uenishi, L. Wulandari, Yulintine, Ardianor and S. Gumiri)

A preliminary study was carried out on the physico-chemical parameters and structure of invertebrate communities in the root systems of several floating macrophytes in oxbow lakes in the Kahayan River system. Water hyacinth stand in Lake Tundai had the highest standing crop both in submerged and emergent parts. The invertebrate assemblages found in root systems of aquatic macrophytes in Lake Tundai were characterized by having diverse insects (Uenishi et al. 2005).

1.5 Sediment characteristics of oxbow and floodplain lakes (D. I. Hartoto, Sugiarti and M. S. Shawal)

Vertical profiles of sediment characteristics were studied in two oxbow lakes (Lake Takapan and Lake Rengas) and a floodplain lake (Lake Tabiri) of the Kahayan River system. The organic matter content and water content in the sediment varied between stations. Water content, porosity and total phosphorus concentration decreased significantly with sediment depth whereas total nitrogen and organic matter concentrations did not (Hartoto et al.2005).

1.6 Ecological integrity of the Mahakam floodplain ecosystem (D. I. Hartoto, M. S. Syawal, I. Ridwansyah, Rosidah, Sugiarti, Yustiawati, S. Aisyah, M. Badjoeri, F.

Sulawesty)
River Mahakam and its floodplain are well known as the habitat of indigenous Irrawady dolphin and serve as fishery reserves (e.g., Lake Loa Kang Fishery Reserve). The Mahakam floodplain ecosystems were studied for ecological habitat classification (Ridwansyah 2004), heterotrophic processes and nitrogen cycle (Aisyah and Hartoto 2004, Badjoeri 2004), water quality variation (Yustiawati et al. 2004), ion sulfide as the indicator of disruptive processes (Sugiarti and Hartoto 2004), phosphorous finger print as indicator of ecosystem health (Rosidah et al. 2004), humic acid level as an indicator of enhancement or retardation of pollutant's impact (Yustiawati and Hartoto 2004) and plankton community structure (Sulawesty and Hartoto 2004). All the above studies have been published from Research Center for Limnology, Indonesian Institute of Sciences, as a Monograph No. 3 "Ecological Integrity of a Mahakam Floodplain System" edited by Hartoto and Yustiawati (ISBN 9-793-68825-4). The eight papers are also included in the present annual report.

1.7 Phytoplankton in small lakes of West Java (Sulastri)

The composition of phytoplankton were studied in relation to the water quality for some small lakes in West Java. The water quality of small lakes (Lake Cibuntu and Lake Bojongsari) changed seasonally and high inputs of suspended organic matters and nutrients were observed during the rainy season. *Scenedesmus, Staurastrum, Pediastrum, Coelastrum, Kirchneriella, Melosiara, Diatoma, Microcystis aeruginosa, Oscillatoria* and *Phacus* were common to six lakes examined (Sulastri 2005).

2. Human impacts on aquatic ecosystems and restoration of damaged ecosystems

2.1 Comparative survey of water quality and zooplankton faunae in waters of Central Kalimantan (M. Imai, Yurenfri, Anitae, Ardianor, L. Wulandari, Yulintine, S. Gumiri, T. Ishikawa and T. Iwakuma)

Zooplankton faunae were compared between littoral and pelagic zones of six oxbow and floodplain lakes (Lakes Hurung, Bunter, Tehang, Batu, Sabuah, and Tundai) in the rainy season of 2003. The major purposes of this study were to compare the faunae and densities of zooplankton between littoral and pelagic zones of the lakes and to identify the factors controlling the species richness and density of zooplankton. In Lake Sabuah and Lake Tundai where water hyacinth was distributed widely, densities of all the groups of zooplankton were significantly higher than that on the submerged plant leaves in the littoral zones. The presence of this floating plant might be one possible factor that maintained richer taxa and higher densities of zooplankton (Imai et al. in press).

2.2 Experimental study on the role of aquatic plants on maintaining biodiversity and productivity of aquatic organisms (S. Gumiri, Ardianor, L. Wulandari, Yulintine, T. Buchar, Yurenfri, Y. Ruthena, S. Welsiana, Tri Septiani, Trisliana, S. Tada, M. Kurasaki, T. Ishikawa and T. Iwakuma)

Ambul is a traditional cultivation method used by local fishermen in the hypertrophic Lake Panggang in South Kalimantan province - Indonesia. This is a tightly bundled floating unit (approximately 10 m2 in area) of aquatic hyacinth to control its rapid expansion of covering the lake surface hence reducing lake productivity and accessibility. When the floating ambul has decomposed, the local fishermen usually grow various crops such as watermelon, pumpkin, cucumber or even rice on it. During the water hyacinth bloom there are numerous crop islands on the lake that provide additional income for local fishermen. Based on a preliminary survey on the ambul ecosystem, two experimental ponds were constructed in the compound of the University of Palangkaraya to investigate the role of aquatic plants on maintaining biodiversity and productivity of aquatic organisms. The study was funded in part by the Kurita Water and Environment Foundation. The major purposes of the study were (1) to evaluate economical benefits and ecological importance of ambul based on the scientific re-evaluation and (2) to develop a new environmentally friendly technology in controlling a direct load of domestic waste to the river system.

3. Environmental and health effects of heavy metals and chemicals

3.1 Anion and cation ions of rivers in the Central Kalimantan (M. Kurasaki, D. I. Hartoto and T. Iwakuma)

To evaluate water environment in Kalimantan, anion and cation ions were measured at total 13 sites in 4 rivers (Kapuas, Murung, Kahayan and Sebangau rivers), 2 channels (Dadahup and Kelambangau), one lake (Lake Tundai) and one pond (for fish culture) in Central Kalimantan. It was noted that the pH values of water samples from rivers except Kahayan river were low indicating that these river water maintained acidic condition. It is surprising that the water of Dadahup channel located in the region of one hundred million hector planning showed pH 2.6 and 2.9. The acidic condition of the channel water was estimated to be caused by sulphonic ions. In sample water from Lake Tundai, lead concentration was higher than that of Japanese Environmental Standard. In few sampling points from rivers, the lead concentration also showed high level. In the Central Kalimantan, as motorboats are utilized as an important public traffic way, high level of lead might be caused by fuel containing lead. Other risk factors such as cadmium and mercury were scarcely detected in the all sampling points. Further investigation will be needed to study the water environment and effects of water quality on habitant health in Central Kalimantan.

3.2 Metals and environmental contaminants of the river water in West Java (M. Kurasaki, M. Aoki, S. Seki, T. Hosokawa and T. Iwakuma)

Metal and environmental contaminant concentrations were measured at total 12 sites in 5 rivers (CiLiwung, Anak Ciliwung, CiKeas, CiKaniki and CiSarva rivers), one lake (Situ CiKaret) and one pond on the outskirts of Bogor in West Java. As results, Mg and Al concentrations in water samples showed high level. It was thought that these river water was effected on soil environments. In addition, we measured two endocrine disrupting chemicals (nonylphenol and bisphenol) in the water samples, because these compounds are released into the aquatic environment as wastewater. Bisphenol A and alkylphenol, a parent compound of nonylphenol were detected in the river water. On the Basis of data from previous reports, the detected level is consider to be enough to act as endocrine disrupter. In conclusion, these endocrine disrupting chemicals affect on human and wildlife, especially aquatic wildlife.

3.3 Mercury contamination in tropical waters (Y. Takatsuji, S. Tanaka, M. Kurasaki, D.I. Hartoto, M.S. Syawal, Y. Sudarso, Y. Wardiatno, I. Ridwansyah, S. Gumiri, T. Buchar, Ardianor, L. Wulandari, Yulintine, Yurenfri, G.S. Haryani and T. Iwakuma)

For the study of methyl-mercury accumulation in aquatic organisms in tropical waters, fish specimens were collected from Sagling Reservoir, West Java and Lake Takapan, Central Kalimantan. The reservoir is known to be contaminated with mercury and pesticides from its watershed basin. Lake Takapan is suspected to be contaminated with mercury since it occasionally receives water from the Rungan River, one of whose tributary is located in the gold mining sites. Pen-cultured Nile tilapia (Oreochromys niloticus) were collected from the Sagling Reservoir in July 2004. From Lake Takapan several pen-cultured fish specimens (*Mystus singaringan, Hemibagrus nemurus*, etc.) were collected and wild small-sized fish (*Pseudeutropius moolenburghae*, etc.) were collected with a net (salambau) in December 2004. The body lengths and body weights of the fish specimens were measured in the laboratory and their muscular sample was preserved in a freezer. Detailed chemical analyses are to be performed later on.

4. Fate of chemical pollutants in aquatic environments and the characterization of pollutants

4.1 Investigation of mercury pollution of river water in Indonesia (S. Tanaka, M. S. Syawal, Yustiawati, D.I. Hartoto and G.S. Haryani)

In this year, several water and sediment samples of rivers near Bogor in West-Java were collected by researchers of LIPI and Hokkaido University. Analysis and speciation analysis of these samples are now in progress. In order to perform the regular and defined measurement of mercury at the fixed points of some rivers, we discussed the establishment of such system with the researcher of LIPI and started the preparation.

4.2 Characterization and evaluation of humic substances from tropical and northern peat soil (S. Tanaka, A. Morikoshi, M. S. Syawal, Yustiawati, D.I. Hartoto and G.S. Haryani)

Some chemical characteristics and the reducing capacity of tropical humic acid were evaluated by means of elemental analysis, functional group analysis and equilibrium potentiometric titration using hexacyanoferrate(III) as an oxidizing reagent. The characteristics of tropical humic acid were compared with those of northern and commercial available humic acids. The tropical humic acid has the largest total acidity and phenolic hydroxide content. The reducing capacity of tropical humic acid was larger than those of other humic acids (Morikoshi et al. 2005). The solubilizing ability of humic acid for chlorinated benzene and the micelle-like formation of humic acid were investigated(Terashima et al. 2004). The effect of humic acid on the light-induced degradation of chlorophenol was also investigated(Shibata et al. 2004).

4.3 Development of analytical methods for polyaromatic hydrocarbons(PAHs) and some endocrine disrupting chemicals (S. Tanaka, M. S. Syawal, Yustiawati, D.I. Hartoto and G.S. Haryani)

Some analytical methods which are expected to be necessary in future were established for polyaromatic hydrocarbons (PAHs) and some endocrine disrupting chemicals. Analytical method for PAHs is based on the HPLC with fluorescence detector after concentration in the SDS micelle and the method for endocrine disrupters such as 17 estradiol is based on the enzyme immuno assay. The established methods were tested for the determination of these compounds in river waters (Matsumoto et al. in press).

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Bathymetric survey of oxbow lakes of Central Kalimantan

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Introduction

During this JSPS-core University program, our group "Function of aquatic ecosystem in Central Kalimantan" examined oxbow and flooded lakes near PalangkaRaya. Now, monthly monitoring has been conducted in Lake Tehang, Lake Batu, Lake Bunter, Lake Hurung, and Lake Tundai by PalangkaRaya University through JSPS program since 2003.

In these lakes, both water quality and biological community are highly affected by the water level change (Hartoto 2000, Gumiri 2002). However, due to lack of hydrological information, material and organism transfer between water bodies has not been well examined yet. In this study, we examined bathymetric characteristics and connectivity of oxbow and flooded lakes, which will develop understanding of hydrological mechanism resulted by water level change.

We welcome anyone who will ask high-solution map or original GPS data. Contact address: t-ishi@ees.hokudai.ac.jp (Toshiyuki ISHIKAWA)

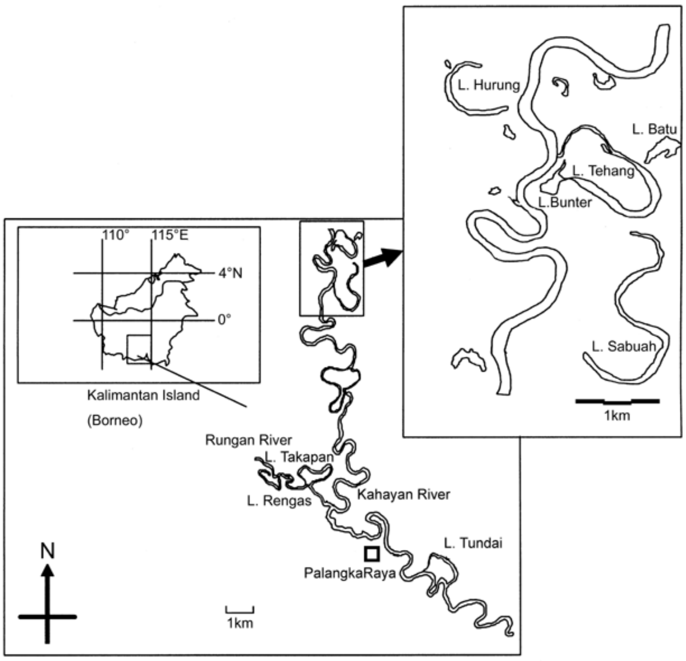

Figure 1. Map showing location of studied lakes

Methods

Field surveys were performed from December 2003 to January 2004. The lakes examined here were Lake Tehang, L. Bunter, L. Batu, L. Sabuah, L. Hurung, L. Tundai , L. Takapan, and L. Rengas) (Fig. 1) In each lake, all data was collected in one day to minimize the effect of water level change.

The location and depth data was obtained by a GPS-plotter system (HFD100-C, Hondex, Japan), equipped with a Windows PC (Libretto 60, Toshiba, Japan) as a data recorder. To avoid the effect of rolling, two canoes (c.a. 4m in length) were tied by wooden rudder. The depth sounder was set upon an iron pole which installed to center of the rudder. At first, the boats traced littoral vegetation at the speed around 5km/h. Then, cross-sectional traits were made at the same speed. Because the vegetation consists of flooded forest, we couldn't penetrate into shallower location to observe depth of 0m. In this study, the GPS was recorded using "Tokyo Datum" as geographic coordinate system.

The raw data of location and depth was processed into 'xyz' data (Longitude, Latitude, depth) using Perl script. Then the 'xyz' data was interpolated into 100*100 grid data using linear interpolation (Akima 1978) performed by "akima package" on the R program (The R Foundation, 2004). Then contour line was drawn by the R program. Appendix 1 shows the script to calculate and draw the maps. After drawing the contour, shoreline traits which indicates the limit of vegetation was drawn by hand using Adobe Photoshop. The size of axis was also adjusted using Adobe Photoshop.

The condition of connection of lakes to other lakes or rivers was observed during the monthly monitoring program (Lake Tehang, L. Batu, L. Bunter, L. Hurung, and L. Tundai) or intensive through-year studies (Lake Takapan, Hartoto 2000a; Lake Rengas, Hartoto 2000b; Lake Sabuah, Gumiri 2002).

Results and Discussion

Lakes in Bukit guha (Desa Sigi=Sigi village)

Lake Tehang (Max 7.9m, Fig. 2)

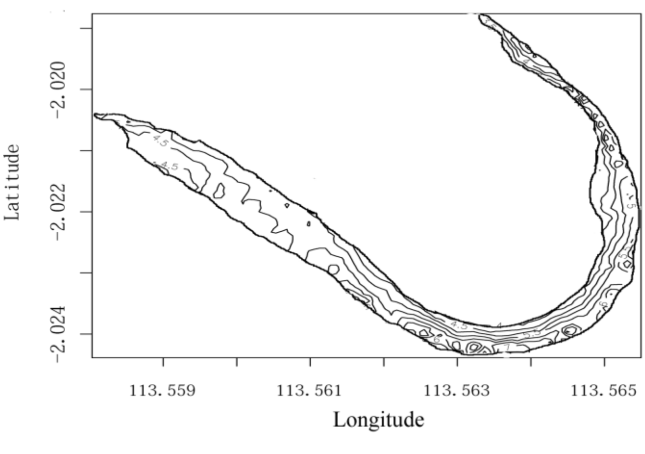

Figure 2 Bathymetric map of Lake Tehang

Lake Tehang connects to Kahayan River at the northern end, to Lake Bunter at the southern end, and to Lake Batu through small canal located near northern end.

During rainy season, water inflow from Kahayan River at the northern end and outflow to Lake Bunter at the southern end. There is also water exchange with Lake Batu through the small canal. During dry season, the northern end dries up and the connection to Lake Batu disappears, but the southern end still connects to Lake Bunter. Water exchange with Kahayan River cannot occur at the lowest water level because Lake Bunter separates into two basins during this period. Note that small channel is now constructed between Lake Sabuah, which operates only at the highest water level.

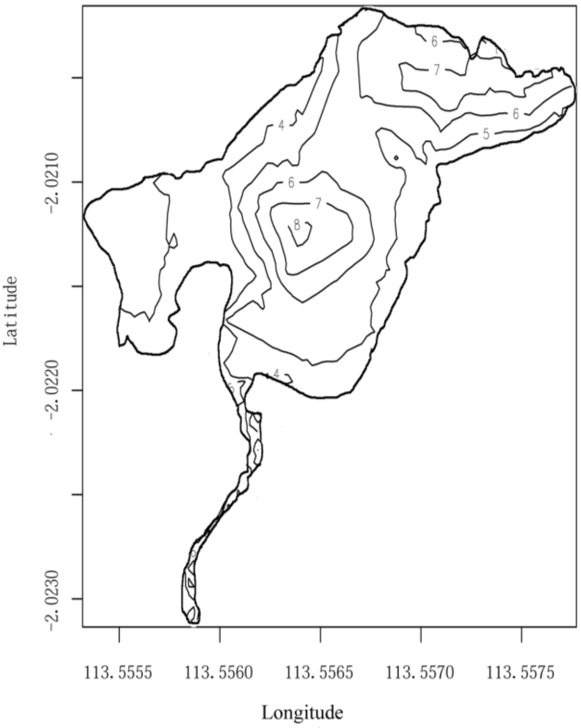

Figure 3. Bathymetric map of Lake Bunter

Lake Bunter (Max 8.4m, Fig.3)

Lake Bunter connects to Lake Tehang at northeast end, to Kahayan River at southern end through a channel. According to local people, there was a small channel connecting to Kahayan River at the northern part, but it disconnected now. This lake consists of two basins. During rainy season, water inflows from Lake Teang at the northeast end and outflows to Kahayan River at the southern end. During dry season, the lake still connects to Lake Tehang and Kahayan River, but the lake dries to separate two lake, north and south basin, at the lowest water level.

Lake Batu (Max.12.2 m, Fig.4)

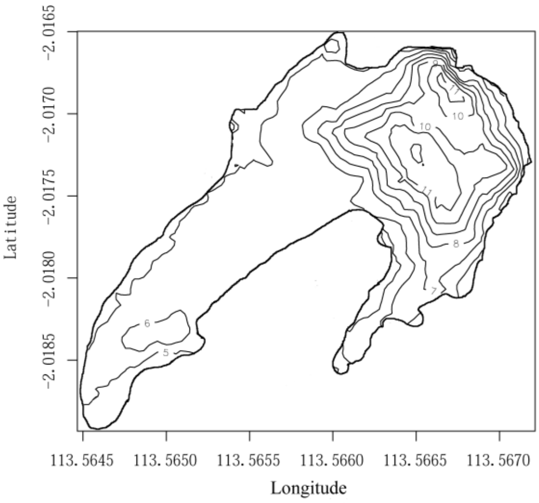

Figure 4 Bathymetric map of Lake Batu

Lake Batu connects to Lake Tehang at west end. During rainy season, water exchanges with Lake Tehang and the direction is not fixed. During the drying season, this connection disappears. Two small streams from forest area inflow to the lake throughout the year. One is from north (a) and the other is from east (b). The northern stream has unique feature: the water is from spring just near the lake during dry season but from far forest during rainy season. The water stains strong brown at rainy season whereas the water is almost colorless at dry season. Near the eastern inflow stream, there is a spring inside the lake. This lake is only one lake which does not connect Kahayan River directly, among the examined lakes here.

Lake Sabuah (Max 15.0m, Fig.5)

Lake Sabuah connects Kahayan River at the southwest end but there is no connection at the northern end. During rainy season, water outflows to Kahayan River at the southwest end. This lake also connects to Lake Tehang through manmade channel as described in Lake Tehang. During dry season, this lake is isolated from other lakes and Kahayan River. This lake has at least 4 inflow streams from forest but the condition of the streams was not well examined in this study.

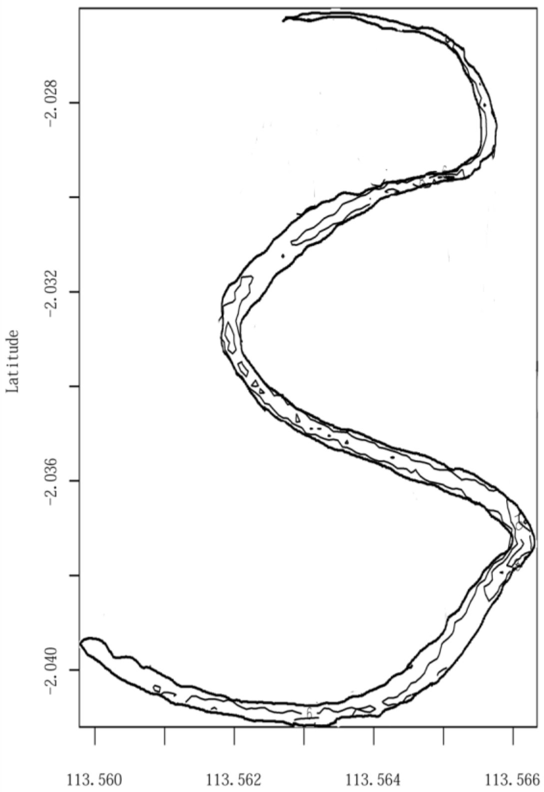

Figure 5 Bathymetric map of Lake Sabuah

Lake Hurung (Max 9.8m, Fig. 6)

Lake Hurung locates the right bank of Kahayan River, although other four lakes shown above locate the left bank. Lake Hurung connects to Kahayan River at the southeast end but there is no connection at the northern end. During rainy season, water exchanges with Kahayan River at the southeast end. During dry season, the southeast end disconnects from Kahayan River.

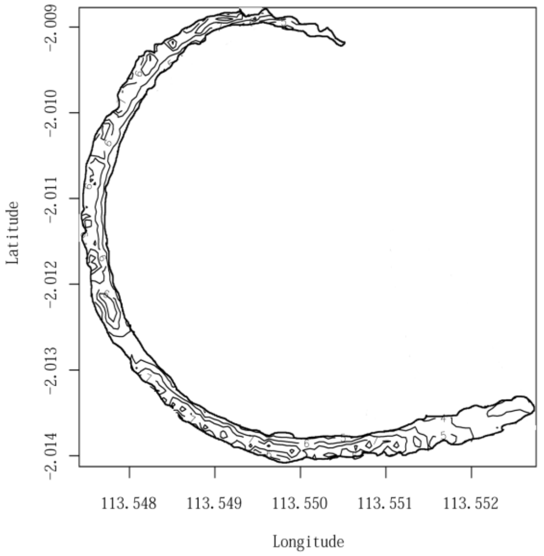

Figure 6 Bathymetric map of Lake Hurung

Lake located lower Kahayan River

Lake Tundai (Max 15.8m, Fig. 7)

Lake Tundai locates southward PalangkaRaya, which is the first oxbow lake from the mouth of Kahayan River. The lake connects to Kahayan River at the northern end and southern end. The northern end is a channel but the southern end connection is not channel: this lake connects the river directly like a branch. During rainy season, water inflows from northern end. But there is no apparent direction of water at the southern end. During dry season, the northern end disconnects from Kahayan River, although the southern end connects to the river throughout the year. There is also one inflow of Jengahen River throughout the year.

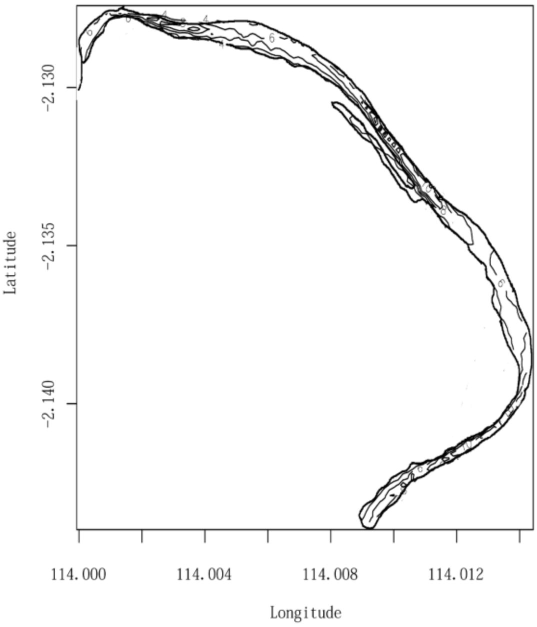

Figure 7. Bathymetric map of Lake Tundai

Lakes along Rungan River

Lake Takapan (Max 13.2m, Fig.8)

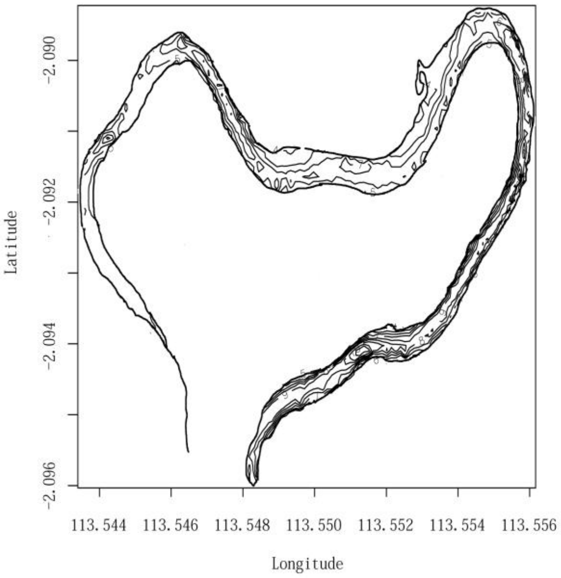

Figure 8 Bathymetric map of Lake Takapan

Lake Takapan connects to Rungan River at southeast end and southwest end. During rainy season, the both ends connect Rungan River. During dry season, the southwest end disconnects although the southeast end connects Rungan River throughout the year. Lake Takapan receives inflow from Kahayan River during rainy season through a channel located west (113.5539E, 02.8930S). Lake Takapan also connects to Lake Tabiri through a channel (Hartoto et al. 2000), which is not examined well in this survey. This lake locates nearest to the junction of Kahayan River and Rungan River.

Lake Rengas (Max 7.4m, Fig.9)

Lake Rengas connects Rungan River at both ends. During rainy season, both ends connect Rungan River. During dry season the west end disconnects from Rungan River. The east end usually connects Rungan River but it would dry up at the extremely low water level (Hartoto *personal communication*).

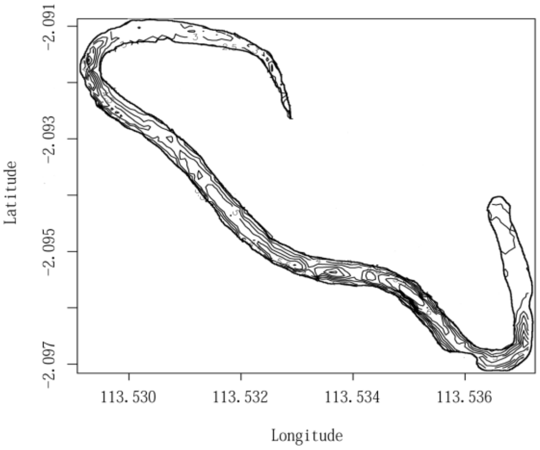

Figure 9 Bathymetric map of Lake Rengas

Acknowledgement

We would like to thank to local people living nearby studied lakes for kind support of our study. Also thanks to skillful boat drivers, Mr Djaman, Mr. Andi, Mr. Achar, and Mr. Sukri. Mr. J. Indra and Ms M. Imai also helped field survey. This study was supported financially by the JSPS-Core University program, the 21st-century Center of Excellence Program (10101-E3), and the grant in aid for scientific research (15405001) from Ministry of education, culture, sports, science and Technology, Japan through JSPS.

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Gumiri, S. (2002) Ecological studies on zooplankton communities in humic oxbow lakes of Kalimantan, Indonesia. PhD. Thesis, Hokkaido University.

Hartoto, D. I. (2000) An overview of some limnological parameters and management status of fishery reserves in Central Kalimantan. Rep. Suwa Hydrobiol. Stn., Shinshu, Univ., 12: 49-74.

The R Foundation for Statistical Computing (2004) R (Version 2.0.1) [Computer software]. Web site: http://www.r-project.org.

Appendix 1.　The R script to draw bathymetric maps

```
# load package and define file name of drawing
        library(akima)   # load package “akima”, which contains interpolation
        pdf("./filename.pdf", horizontal=F) #assign save file type

# load data file
        points.old <- read.csv("filename")

# assign interpolation points (100*100 grids)
        xx <- (seq(min(points.old$E)*100000,max(points.old$E)*100000,length=100))
        yy <- (seq(min(points.old$S)*100000,max(points.old$S)*100000,length=100))

# define constant
        range.depth <- range(0:max(points.old$M))
        range.depthN <- range(-max(points.old$M):0)
        labX = "Longitude"
        labY = "Latitude"

# interpolation and drawing (interpolation: linear interpolation)
        akima.li <- interp.old(points.old$E*100000, points.old$S*100000, points.old$M,
        xx, yy, ncp = 0,extrap = FALSE, duplicate = "strip")
        image(akima.li$x/100000,akima.li$y/100000,-akima.li$z,
        zlim = range.depthN, xlab = labX, ylab = labY, col = gray(1:1))
        contour(akima.li$x/100000, akima.li$y/100000, akima.li$z,
        zlim = range.depth, add=TRUE, labcex=0.5)

#choice of drawing observation points
        #points(points.old$E,points.old$S,pch=".")

# save the figure
        dev.off()
```

Sediment Characteristics of Tropical Oxbow and Floodplain Lakes

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Abstract

Vertical profiles of sediment characteristics, i.e., water content, organic matter content, bulk density, particle density, porosity, total phosphorus and total nitrogen, were studied in two oxbow lakes (Lake Takapan and Lake Rengas) and a floodplain lake (L. Tabiri).of the Kahayan River, Central Kalimantan. The organic matter content and water content in the sediment varied between stations. Porosity of the sediment in the oxbow lakes varied between 44-89 % among sites and decreased at the deeper layer of the sediment. Water content, porosity and total phosphorus concentration decreased significantly with sediment depth whereas total nitrogen and organic matter concentrations did not.

Introduction

Riverine lakes, irrespective of temporary or permanent, are the water bodies that are strongly influenced by the water level fluctuation in the adjacent river. These lakes include floodplain lakes and oxbow lakes. Limnology of riverine lakes have been neglected for years in Indonesia, but recently various limnological aspects of tropical oxbow lakes in Central Kalimantan are receiving more attention. The studies include basic water quality features and changes (Hartoto 2000a, Awalina & Hartoto 2000, Iwakuma *et al.* 2000, Kurasaki *et al.* 2000), phosphorus nutrient fingerprint (Yustiawati & Hartoto 2000), fish ecology (Hartoto *et al.* 1999, Komatsu *et al.*, 2000, Doi *et al.* 2000), plankton ecology (Gumiri *et al.* 2000, Kusakabe *et al.* 2000, Sulastri & Hartoto 2000a, b, c), heavy metal contamination in water and fish (Hartoto & Awalina 1998, Awalina & Hartoto 2001) and conservation issues (Hartoto 2000b).

The oxbow lakes and adjacent river segment are parts of the riverine landscapes where the connectivity between landscape elements is crucial for sustaining functional processes (Ward *et al.* 2002). Limnological features of oxbow lakes is strongly dependent on the dynamics of its connectivity to other patches of floodplain landscapes and also to the alluvial aquifer. Connectivity may be defined as the ease with which organism, matter or energy traverse the ecotones between adjacent ecological units (Ward *et al.* 1999). There are four dimensions of hydrological connectivity, i.e., longitudinal, lateral, vertical and temporal. Vertical connectivity includes exchange between surface and groundwater via infiltration into alluvial aquifer and exfiltration of phreatic water. Water and material are transported most rapidly through the floodplain aquifer within a net work or lattice of high porosity “paleochannels”. (Standford & Ward 1993). Connectivity of a floodplain water body is pulsing or changing from time to time, and this phenomenon controls nutrient inputs and the alternation of production and transport phases. Pulsing connectivity depends on the hydrological regime of the river, which is influenced by the processes operating on the catchment scale, and by the local topography and sediment porosity (Amoros & Bornette 2002).

The uppermost sediment layers in tropical oxbow lakes probably function as a kind of transitional zone between the surface water and the alluvial aquifer. This sediment layers are microzones that control material and energy transfer between the surface water and alluvial aquifer. The bottom sediment of the lake usually developed through the deposition of materials originated from autochthonous bio-production in the upper water layer or allochthonous materials carried by surface runoff. The present study was aimed to reveal the vertical profile of porosity and organic and inorganic materials in the sediment of two types oxbow lakes and a floodplain lake of the Kahayan River system. The oxbow lakes under study are Lake Rengas, a representative of type II oxbow lake, and Lake Takapan, a representative of type III oxbow lake (Hartoto 2000). Lake Tabiri is a floodplain lake that exchanges water with Lake Takapan and the Kahayan River.

Materials and Methods

Description of study sites

All three lakes are located in Palangkaraya Municipality of Central Kalimantan (Fig. 1). Lake Rengas (33.33 ha) is an oxbow lakes that exchange water with the Rungan River, a tributary of the Kahayan River. This lake is a fishery reserve managed by Central Kalimantan Fishery Department. It has two connecting channels with the Rungan River. The morphology and limnological data are reported in Awalina & Hartoto (2000). Lake Takapan (50.42 ha) is an oxbow lake that exchanges water with both the main river (Kahayan River) through two connecting channels and the tributary (Rungan River) through two connecting channels. The morphology and limnological character of Lake

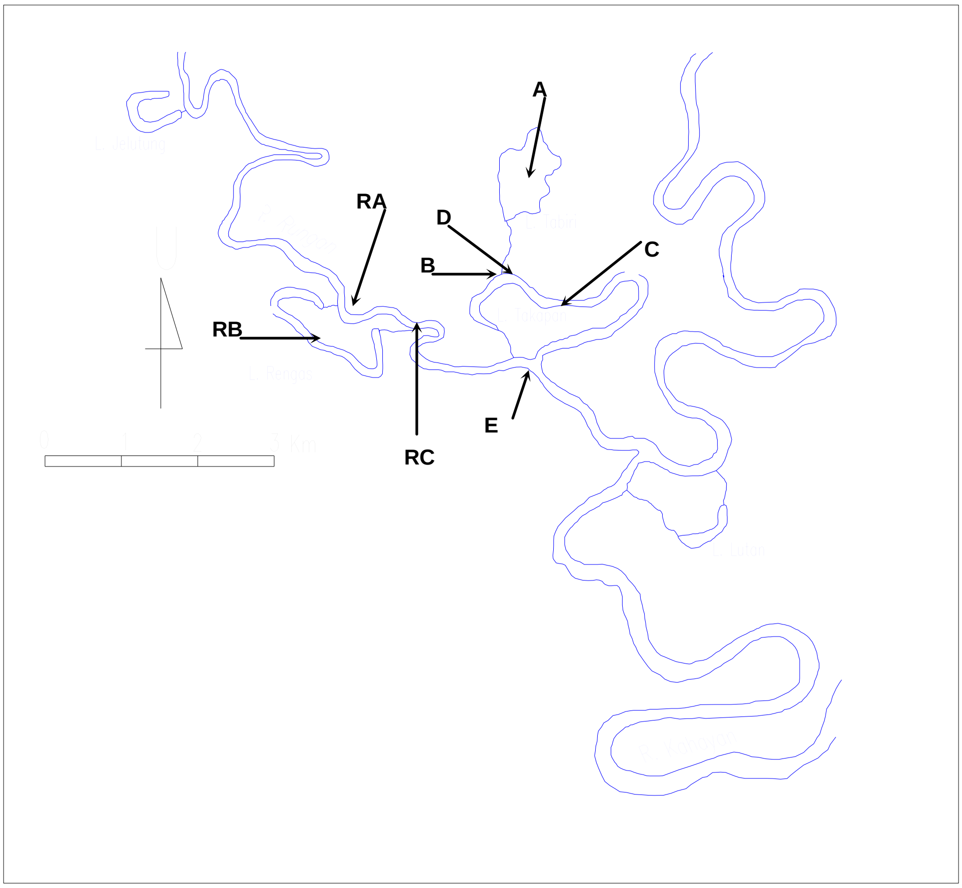

Figure 1. The location of sampling sites in L. Takapan, L. Tabiri and L. Rengas of the Kahayan River floodplain near Palangkaraya.

Takapan were described by Hartoto (2000) and Awalina & Hartoto (2000). Lake Tabiri (ca. 150 ha) is a floodplain lake with 2-2.5 m depth that develops under temporary inundation with water from the Kahayan River. The lake is known by local fishermen as the spawning site of black water fishes such as snakeheads (*Channa micropeltes*) and feeding ground of several species of white water fishes such as *Osteochilus* spp, *Dangila* spp and *Puntius* spp. This lake is located in the disturbed peat swamp forest adjacent to Lake Takapan. Besides exchanging water with River Kahayan, the lake also exchanging water with Lake Takapan through one of the connecting channel from Lake Takapan to the Kahayan River.

Sampling methods

We selected three sampling stations in Lake Rengas , three in Lake Takapan and two in Lake Tabiri (Table 1). Six randomly selected sampling sites were chosen for each station of Lake Takapan and Lake Tabiri whereas there randomly selected sampling sites were chosen for each station in Lake Rengas. The sampling in Lake Takapan and Lake Tabiri was conducted during the beginning of decreasing water level in Lake Takapan, i.e., 14-15 July 2000. In Lake Rengas sampling was conducted during the period of low water level, i.e., 15 September 2000.

The sediment samples were collected with a missile core sampler 25-cm iron tube that has three wings on one end and PVC pipe (19 mm inner diameter × 40-cm) on the other end (Fig. 2). The PVC pipe was cut in to half and re-attached by adhesive tapes to facilitate sampling of sediment section after each operation. After the core was pulled up, the PVC tubes were opened to expose the sediment samples in the shapes of a cylinder. Then the sediment cylinder was cut into several 2-cm long segments (5.79 cm^3) and weighed in the field using an electric balance. After weighing, sediment segment samples were kept separately in polyethylene bags. In the present paper, 0-2 cm depth sample is referred to as 0-cm, 2-4 cm depth sample as 2 cm and so on. A total of 315 sediment segment samples were collected for further analysis in the laboratory.

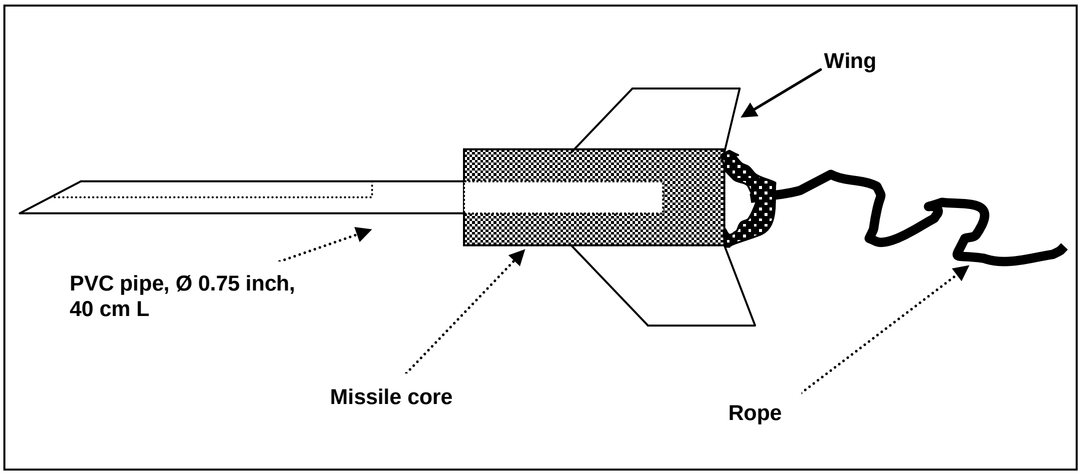

Figure 2. The design of the missile core sampler.

Analytical methods

Analysis of water contents and organic matter concentration in the sediment was conducted by the gravimetric method. Two to fourteen grams of sediment sub samples were weighed in wet and dried at 105°C for 2 h, re-weighed and re-dried until constant weight. The proportion of weight loss to initial wet weight is calculated as the water content (%). Re-dried sample was ignited at 600°C for 6 h with a muffle furnace. According to Luczak *et al* (1993), the weight losses increase during ignition was significant at temperature range above 500-550°C, and the weight loss was stable until 6 h of ignition. Organic matter concentration was calculated by dividing the weight loss after ignition to the weight of non-ignited but pre-dried sample. Bulk density was calculated according to the formula by Yamamoto *et al.* (1987):

Bulk density (g/cm^3) = {the weight of pre dried sediment sample (g)}/{volume of fresh sample (cm^3)}

Porosity is calculated through the relationship between dry bulk density and the particle density using the formula proposed by Danielson & Sutherland (1986):

Porosit (%) = 100 {1 – (*bulk density / particle density*)}

Weighed average sediment particle density (g/cm^3) is calculated using correcting formulae of Boyd (1995):

Weighed average sediment particle density (g/cm^3) = 1.25 (% *organic matter*) + 2.65 (100 – % *organic matter*)

Anivemelech *et al* (2001) has found that sediment bulk density was inversely related to the organic carbon concentration as follows:

Bulk density (g/cm^3) = 1.776 – 0.363 $\log_e$ *Organic Carbon* (mg/g)

or $\log_e$ *Organic Carbon* (mg/g) = {1.776 – *bulk density* (g/cm^3)} / 0.363

Sampling for determining nutrient profile was conducted at Station A to D in Lake Takapan – Lake Tabiri system. Total nitrogen, total phosphorus and total organic matter concentration in the sediment were analyzed according to APHA-AWWA-WEF (1998) after water extraction of 1 g sediment following the methods described by Hartoto (1990).

Data analysis

Two way analysis of variance (ANOVA) without replication was conducted to test the differences between station, between core and between sediment layers (Sokal & Rohlf 1995) using the R statistics program (http://www.r-project.org).

RESULTS AND DISCUSSION

Water content and organic matter

The data on water content and organic matter concentration in Lake Takapan –Lake Tabiri Complex and Lake Rengas are shown in Table 1 and Table 2. The highest average water content (72.8 ± 3.2 %) in Lake Tabiri-Lake Takapan complex was observed at Station A that was located in the middle of Lake Tabiri (Table 1). This fact indicate that the newest sediment was deposited in the middle of Lake Tabiri. Natural sediments contain the interstitial water in the pore space among solid grain (Yamamoto *et al*. 1987). While the pore spaces of sediments are relatively large just after deposition of grains, the spaces should diminish more and more as the deposition of grain continues, because the weight of overlaid grains raises the pressure of underlying water to squeeze. The squeezing of pore water in sediments causes compaction of the sediment layer as time passes. This process is referred to as consolidation process. The lowest water content (51.99 %) was observed at Station B located in the mouth of connecting channel that links Lake Tabiri with Lake Takapan.

Table 1. The water content and organic matter concentration in the sediment of Lake Tabiri and Lake Takapan (14-15 July 2000).

a. Station A, Center of Lake Tabiri (02C08’12.8”S, 113°55’18.1”E, z_{max}= 2.1 m)

Depth (cm)	**Water content (% w/w, wet)**							**Organic matter concentration (% w/w, dry)**						
	Sites						**Average**	**Sites**						**Average**
	A1	**A2**	**A3**	**A4**	**A5**	**A6**		**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	
0	77.72	76.38	75.7	53.87	74.90	70.95	71.59	29.28	24.84	32.96	16.70	27.92	29.11	26.80
2	74.41	72.90	75.42	51.66	73.99	68.58	69.49	33.72	29.43	39.37	13.71	42.3	29.77	31.38
4	73.33	75.28	75.34	44.82	73.21	66.85	68.14	34.03	26.35	40.64	13.26	43.09	32.43	31.63
6	72.25	72.83	73.89	37.75	72.52	67.20	66.07	34.29	43.77	42.50	19.59	38.35	34.96	35.58
8	70.82	73.37	71.79	46.18	71.60	67.21	66.83	33.48	43.02	38.68	13.81	39.48	36.35	34.14
10	69.61	74.09	73.11		70.34	67.03	70.84	31.87	49.17	41.09		43.31	35.26	40.14
12	75.72	75.7	84.45		91.14	74.84	80.37	45.82	56.96	53.52		39.61	42.87	47.76
14	88.02	79.27	83.56		69.95	71.92	78.54	71.17	46.13	29.60		43.23	36.80	45.39
16					71.77	71.50	71.64					44.35	39.80	42.08
18						78.95	78.95						44.92	44.92
20						79.17	79.17						41.41	41.41
Average	75.24	74.98	76.66	46.86	74.38	71.29	**72.88**	39.21	39.96	39.80	15.41	40.18	36.70	**38.29**
95%CL	4.00	1.51	3.28	5.54	4.24	2.72	**3.17**	9.56	8.12	4.90	2.37	3.30	3.05	**4.00**

b. Station B, mouth of connecting channel (Tabiri River) from Lake Tabiri to Lake Takapan (02°08’37.9”S, 113°55’18.4”E)

Depth (cm)	**Water content (%, w/w, wet)**							**Organic matter concentration (% w/w, dry)**						
	Sites						**Average**	**Sites**						**Average**
	B1	**B2**	**B3**	**B4**	**B5**	**B6**		**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	
0	58.11	59.76	54.22	62.55	58.44	50.37	57.24	11.25	11.11	7.28	11.01	10.76	11.52	10.45
2	39.18	56.78	56.97	58.34	55.25	49.25	52.63	49.41	13.25	11.7	11.83	11.69	11.63	12.02
4	67.82	56.78	58.62	58.09	50.02	42.88	55.70	15.44	11.81	12.53	11.92	11.52	11.83	12.51
6	62.88	54.74	59.81	54.41	44.25	40.49	52.76	15.77	5.18	11.37	12.12	12.09	11.1	11.27
8	55.77	52.83	50.00	52.30	40.89	37.42	48.20	14.12	3.51	10.04	11.86	10.99	12.23	10.46
10	58.60	48.84	51.32	47.30	40.93	36.24	47.21	12.70	10.39	4.26	11.39	11.13	11.29	10.19
12	67.20	47.69	50.47	49.51	38.73		50.72	17.64	23.19	12.76	12.17	11.29		15.41
14	66.25	53.03	50.62	48.09	38.56		51.31	17.44	13.91	10.69	11.78	12.11		13.19
16	56.35	54.16	49.6	48.69			52.20	12.72	13.21	12.83	12.12			12.72
18	54.90	52.56	50.38	47.22			51.27	11.80	8.91	12.79	12.38			11.47
20	68.61	53.08	52.04	43.67			54.35	12.81	26.25	13.97	12.82			16.46
22	49.23	53.98	63.96	33.75			50.23	12.24	13.02	18.97	13.4			14.41
Average	58.74	53.69	54.00	50.30	45.88	42.78	**51.99**	13.99	12.81	11.60	12.07	11.44	11.60	**12.25**
95%CL	4.91	1.87	2.68	4.32	5.36	4.75	**1.63**	**5.91**	3.66	2.03	0.35	0.34	0.32	**1.14**

c. Station C, middle of Lake Takapan (02°08’46.7”S, 113°54’50.6”E, z_{max}= 5.0 m)

Depth (cm)	**Water (% w/w, wet)**							**Organic Matter (% w/w, dry)**						
	Sites						**Average**	**Sites**						**Average**
	C1	C2	C3	C4	C5	C6		C1	C2	C3	C4	C5	C6	
0	75.23	70.12	55.01	70.01	74.40	62.28	67.84	20.95	16.43	18.16	18.74	19.3	18.49	18.68
2	74.99	64.23	60.19	70.02	71.01	58.02	66.41	20.12	18.08	15.47	19.61	18.42	20.67	18.73
4	66.81	57.67	56.54	59.93	60.43	51.64	58.84	19.75	15.26	15.53	18.07	16.06	18.12	17.13
6	56.38	53.00	55.35	38.02	54.58	47.53	50.81	14.32	13.35	14.95	6.81	14.66	12.42	12.75
8	52.45	52.62	52.61	25.24	55.64	48.25	47.80	13.63	12.53	12.80	3.01	14.84	14.24	11.84
10	37.63	49.80	50.39		50.90	47.19	47.18	13.44	11.25	12.66		12.20	12.37	12.38
12	44.84	52.39	51.00		45.39	50.71	48.87	13.05	12.59	12.44		12.56	12.38	12.60
14	71.04	54.75	48.63		48.03		55.61	14.19	12.79	12.49		12.03	12.82	12.86
Average	59.92	56.82	53.72	52.64	57.55	52.23	**55.42**	16.18	14.04	14.31	13.25	15.00	15.19	**14.62**
95%CL	9.89	4.81	2.62	17.65	7.26	4.28	**5.72**	2.37	1.61	1.43	6.79	1.93	2.34	**2.08**

Station D, plumes of connecting channel (Tabiri River and Kahayan River) in Lake Takapan (Tabiri Plumes, 02°08’34.8”S; 113°55’23.2”E, z_{max}= 4.8 m, Kahayan Plumes, 02°08’30.3”S; E: 113°55’26. 2”E, z_{max}= 3.6 m)

Depth (cm)	**Water content (% w/w, wet)**								**Organic matter concentration (% w/w, wet)**							
	Tabiri Plumes				**Kahayan Plumes**				**Tabiri Plumes**				**Kahayan Plumes**			
	Sites				**Sites**				**Sites**				**Sites**			
	D1	D2	D3	**Avg.**	D4	D5	D6	**Avg.**	D1	D2	D3	**Avg.**	D4	D5	D6	**Avg.**
0	57.57	56.24	50.37	54.73	40.85	50.71	60.54	50.70	10.37	12.16	9.48	10.67	7.87	8.34	11.80	9.34
2	55.29	57.64	59.39	57.44	49.45	49.65	56.38	51.83	10.73	11.08	10.62	10.81	8.19	8.45	11.05	9.23
4	54.39	57.12	58.13	56.55	46.94	43.93	54.92	48.60	11.42	12.05	11.27	11.58	8.20	7.90	10.70	8.93
6	56.03	55.35	58.88	56.75	52.26	52.32	52.45	52.34	11.78	11.59	11.64	11.67	11.71	11.85	10.94	11.50
8	53.55	54.25	56.07	54.62	46.38	52.07	51.42	49.96	12.97	11.42	11.03	11.81	8.84	10.9	11.90	10.55
10	52.75	52.95	53.14	52.95	45.04	48.59	51.76	48.46	11.67	15.90	10.49	12.69	9.15	10.17	11.33	10.22
12	53.32	53.86	54.32	53.83	40.27	10.19	51.89	34.12	12.46	12.4	11.67	12.18	7.46	8.62	12.10	9.39
14	51.62	52.61	48.26	50.83	51.18	50.61	50.12	50.64	11.82	11.86	9.32	11.00	11.47	9.74	10.67	10.63
Average	54.32	55.00	54.82	54.71	46.55	44.76	53.69	**48.33**	11.65	12.31	10.69	11.55	9.11	9.50	11.31	**9.97**
95%CL	1.33	1.31	2.82	1.53	3.06	9.85	2.37	4.09	0.58	1.05	0.62	0.48	1.12	0.97	0.39	0.62

e. Station E, Lake Takapan, the Junction of the Rungan River and Lake Takapan (02°09’12.05”S, 113°54’47.3”E, z_{max}= 6.7 m)

Depth	**Water content (% w/w, wet)**						Average	**Organic matter concentration (% w/w, wet)**						Average
m	E1	E2	E3	E4	E5	E6		E1	E2	E3	E4	E5	E6	
0	59.92	58.12	53.11	55.62	55.38	58.46	56.77	12.91	13.17	12.97	12.38	12.23	12.44	12.68
2	56.98	57.24	55.18	54.02	54.87	56.34	55.77	13.57	14.10	12.75	11.17	12.74	13.31	12.94
4	57.83	55.60	53.28	50.74	50.39	58.67	54.42	13.65	13.59	12.34	10.33	11.37	13.35	12.44
6	58.19	52.82	47.52	51.84	45.54	55.31	51.87	16.20	13.40	9.06	11.12	9.10	14.12	12.17
8	55.08	51.10	33.53	45.56	37.86	53.21	46.06	14.69	13.20	5.10	7.85	6.29	13.21	10.06
10	31.02	53.04	34.08	28.39		53.17	39.94	13.36	13.70	4.17	2.68		13.61	9.50
12	52.90	52.40		26.07		52.3	45.92	18.79	13.31		2.14		12.87	11.78
14	48.82	50.79				53.18	50.93	12.33	12.79				13.31	12.81
Average	52.59	53.89	46.12	44.61	48.81	55.08	**50.21**	14.44	13.41	9.40	8.24	10.35	13.28	**11.8**
95%CL	6.09	1.79	7.21	8.43	5.72	1.63	3.76	1.37	0.26	2.90	2.89	2.09	0.32	0.85

Table 2. The water content and organic matter concentration in the sediment of Lake Rengas

a. Station RA, the mouth of connecting channel of Lake Rengas and Rungan River (02°08’46.0”S; 113°52’53.9”E, z_{max} = 2.1 m)

Depth (cm)	**Water (% w/w, wet)**				**Organic matter (% w/w, dry)**			
	Sites			**Avg.**	**Sites**			**Average**
	A1	**A2**	**A3**		**A1**	**A2**	**A3**	
0	79.79	64.85	63.85	69.50	14.31	15.43	14.66	14.80
2	64.41	58.20	68.34	63.65	16.60	14.93	15.62	15.72
4	58.74	58.07	65.20	60.67	13.29	13.90	13.75	13.65
6	57.02	62.22	65.04	61.43	14.00	14.02	14.42	14.15
8	58.63	59.96	61.57	60.05	13.64	16.84	14.11	14.86
10	56.11	58.42	58.75	57.76	14.16	14.90	14.84	14.63
12	54.85	58.16	59.37	57.46	14.58	16.20	14.02	14.93
14	52.53	56.73		54.63	13.74	14.76		14.25
Average	60.26	59.57	63.16	60.64	14.29	15.12	14.49	**14.62**
95%CL	5.97	1.86	2.39	3.13	0.71	0.70	0.43	0.43

b. Station B, middle of Lake Rengas (02°09’09.1”S; 113°53’18.2”E, Z_{max}= 3.1 m)

Depth (cm)	**Water (% w/w, wet)**				**Organic matter (% w/w, dry)**			
	Sites			**Avg.**	**Sites**			**Avg.**
	B1	**B2**	**B3**		**B1**	**B2**	**B3**	
0	53.42	73.35	60.04	62.27	17.90	19.99	16.01	17.97
2	69.56	64.80	71.13	68.50	17.06	16.29	17.00	16.78
4	68.11	66.21	68.03	67.45	17.30	16.90	16.23	16.81
6	69.03	67.71	64.71	67.15	19.12	16.89	18.13	18.05
8	64.01	66.94	65.16	65.37	20.72	18.25	15.44	18.14
10	64.53	69.67	60.87	65.02	19.17	21.03		20.10
12	58.48	63.97		61.23	18.22	16.14		17.18
14	56.82	60.04		58.43	15.46	14.92		15.19
Average	63.00	66.59	64.99	64.43	18.12	17.55	16.56	**17.53**
95%CL	4.22	2.74	3.37	2.42	1.11	1.43	0.91	0.98

c. Station RC,Lake Rengas, at the mouth of disconnected southern channel (02°09’16.4S; 113°53’39.8”E, Z_{max}= 5.0 m)

Depth (cm)	**Water (% w/w, wet)**				**Organic matter (% w/w, dry)**			
	Sites			**Avg.**	**Sites**			**Avg.**
	C1	**C2**	**C3**		**C1**	**C2**	**C3**	
0	69.42	69.55	70.07	69.68	14.98	15.84	16.04	15.62
2	68.24	68.66	65.36	67.42	15.77	16.57	15.79	16.04
4	65.49	66.32	59.76	63.86	15.36	15.67	16.21	15.75
6	64.77	65.48	62.32	64.19	15.48	15.87	16.75	16.03
8	62.00	63.59	63.25	62.95	16.12	16.12	16.24	16.16
10	59.29	64.86	61.34	61.83	14.79	16.71	15.07	15.52
12	58.57	70.57	53.44	60.86	15.16	23.3	15.23	17.90
14	57.50		55.16	56.33	14.75		14.98	14.87
Average	63.16	67.00	61.34	63.39	15.30	17.15	15.79	**15.99**
95%CL	2.92	1.68	3.47	2.63	0.31	1.76	0.41	0.57

The highest concentration of organic matter (38.2 ± 4 % dry or 10.23 % wet) in Lake Takapan-Lake Tabiri system was also observed in Station A but the lowest organic matter concentration (9.97 % dry or 4.82 % wet) was found at Station D in Lake Takapan area where we often observe the Kahayan River plumes. Actually the water flow into Lake Takapan at this station and so-called Lake Tabiri Plumes (Site D1-D3) or River Kahayan Plumes (Site D4-D6) are originated from the Kahayan River the water of which is yellowish-white (Hartoto & Yustiawati 1999). The yellowish-white colour indicates that the Kahayan River water contains a lot of iron compounds. The highest organic matter content observed at Station A probably due to its location in the middle of Lake Tabiri peat swamp forest system. Preliminary observation on the appearance of the "furnaced sediment" (samples that had already been combusted at 600°C for 6 h) free of organic material, from Station A showed a whitish colour, due probably to siliceous material. Meanwhile the colour of the furnaced sediment at Station B showed brownish red due probably to iron containing material. Chemical analyses are required for the furnaced sediment to determine the composition of these materials.

Highest concentration of organic matter was observed in the middle of Lake Rengas. There was no significant difference in organic matter concentrations between sediment layer and cores in Lake Rengas (ANOVA), whereas there were significant differences in the water content between stations and sediment layer depths ($P<0.05$, ANOVA). Relationship of the sediment depth and water content in Lake Rengas is shown in Fig. 3.

As for Lake Takapan-Tabiri system, no significant difference was observed for organic matter concentration between depths (ANOVA), whereas for water content in the sediment of Lake Takapan-Tabiri system, significant differences were observed between stations and depth ($P<0.05$, ANOVA) (Fig 4)

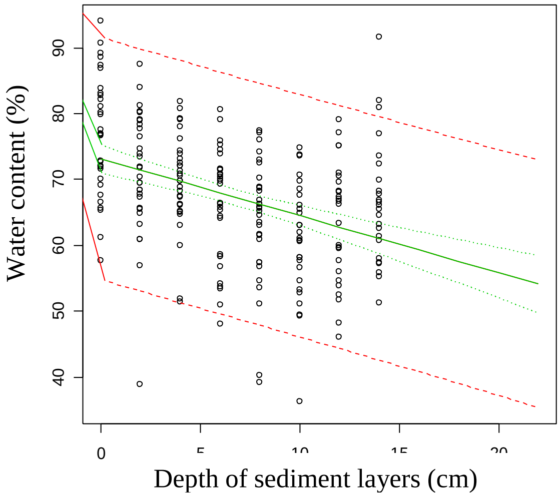

Figure 3. Relationship of water content and sediment layers in Lake Takapan-Tabiri complex

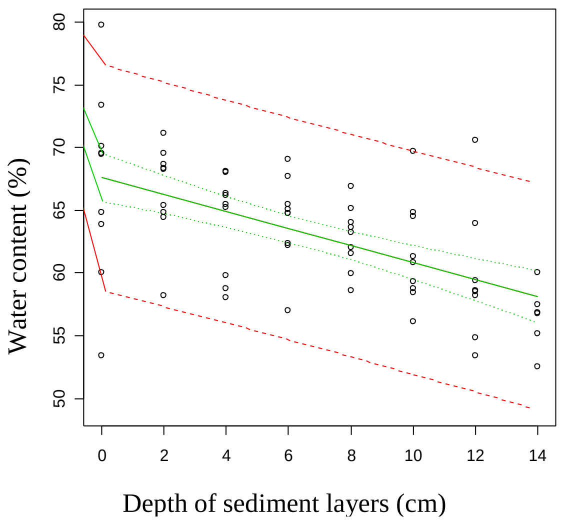

Figure 4. Relationship of water content and depth of sediment layers in Lake Rengas

Porosity

Bottom sediment layers that showed a high porosity could be interpreted as a layers that facilitated the easy movement of material (nutrient) and organism between sediment and water, or in the case of oxbow lakes, between bottom water layers with sediment interstitial spaces or further down with hyphorheic zones. The highest porosity was observed at Station A (71.49 %), followed by Station C (55.75 %), Station B (52.02 %), Station D (51.52 %) and Station E (50.61 %). In Lake Rengas, The porosity was significantly different between stations and depths ($P<0.05$, ANOVA). Also in Lake Takapan-Tabiri system the porosity was significantly different between station and depths ($P<0.05$, ANOVA). In general the porosity of the bottom sediment in these two lake systems was relatively high (43-89 %) and the porosity tend to decrease towards deeper sediment layers (Fig .5 and Fig .6)

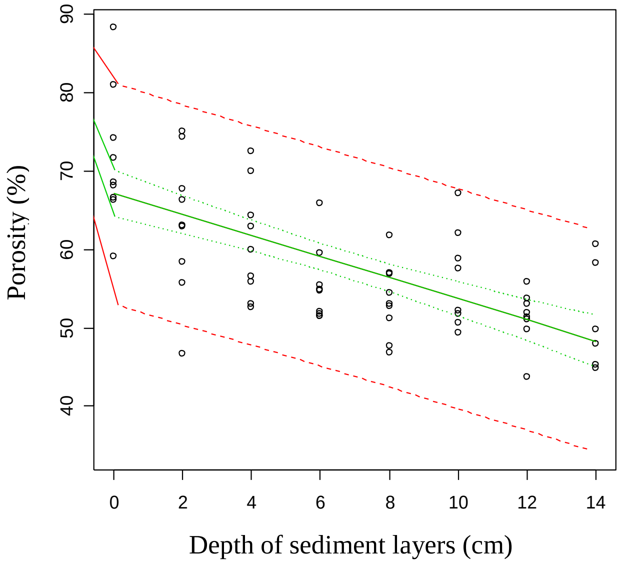

Figure 5. Relationship of porosity and depth of sediment layers in Lake Rengas

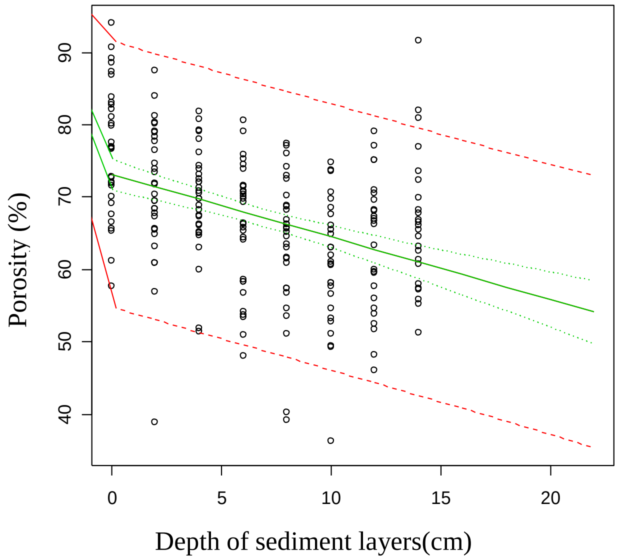

Figure 6. Relationship of porosity and depth of sediment layers in Lake Takapan-Tabiri complex.

Nutrients

The data of nutrient and total organic matter were collected only from four stations of Lake Takapan–Tabiri system (Table 3). The depth of sediment layers was strongly correlated with total phosphorus concentration in sediment (Fig. 7), but not with total nitrogen.

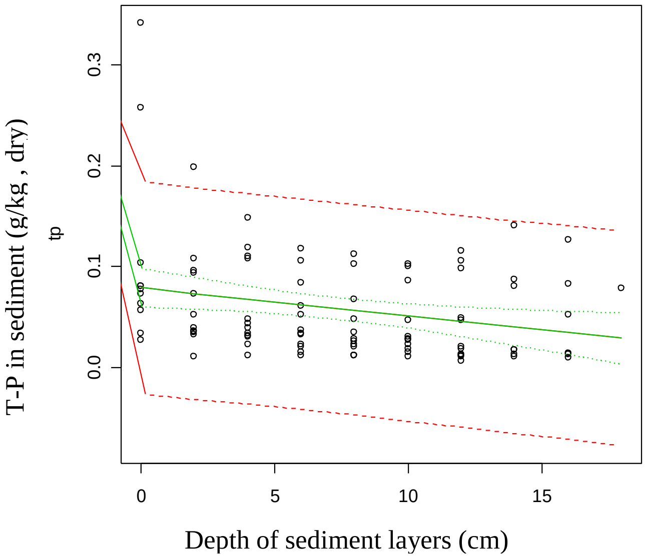

Figure 7. Relationship of the depth of sediment layers with Total-P in sediment of L Takapan –Tabiri complex

Table 9. Concentration of total phosphorus, total nitrogen and total organic matter in the sediment of Lake Takapan –Tabiri Complex, (2 August 2001).

N	Station	Depth	Core	TN g/kg	TP* g/kg	TOM %
1	A	0	1	NA	NA	NA
2	A	2	1	0.855	0.108	14.4
3	A	4	1	1.283	0.119	15.3
4	A	6	1	1.152	0.105	15.47
5	A	8	1	1.298	0.102	14.22
6	A	10	1	0.742	0.102	13.38
7	A	12	1	1.432	0.115	15.37
8	A	14	1	1.301	0.087	12.32
9	A	16	1	0.716	0.083	12.99
10	A	18	1	1.502	0.078	12.66
11	A	0	2	0.849	0.257	15.24
12	A	2	2	0.85	0.198	14.04
13	A	4	2	1.043	0.148	14.96
14	A	6	2	1.174	0.084	14.43
15	A	8	2	0.959	0.112	13.82
16	A	10	2	0.925	0.100	11
17	A	12	2	1.027	0.105	13.52
18	A	14	2	NA	NA	NA
19	A	16	2	NA	NA	NA
20	A	18	2	NA	NA	NA
21	A	0	3	0.923	0.103	15.29
22	A	2	3	1.387	0.096	14.03
23	A	4	3	0.504	0.11	13.28
24	A	6	3	1.341	0.117	12.59
25	A	8	3	1.511	0.067	14.24
26	A	10	3	1.11	0.086	13.09
27	A	12	3	1.289	0.098	12.36
28	A	14	3	2.51	0.141	12.84
29	A	16	3	1.577	0.126	12.31
30	A	18	3	NA	NA	NA
31	B	0	1	1.593	0.08	23.2
32	B	2	1	0.987	0.073	22.66
33	B	4	1	1.047	0.039	24.49
34	B	6	1	0.872	0.022	24.47
35	B	8	1	0.67	0.022	22.87
36	B	10	1	0.754	0.022	15.44
37	B	12	1	0.371	0.018	14.73
38	B	14	1	NA	NA	NA
39	B	16	1	NA	NA	NA
40	B	18	1	NA	NA	NA
41	B	0	2	1.417	0.342	23.35
42	B	2	2	0.876	0.039	23.82
43	B	4	2	1.009	0.108	23.97
44	B	6	2	0.424	0.011	10.16
45	B	8	2	0.401	0.028	11.02
46	B	10	2	0.254	0.027	8.96
47	B	12	2	0.661	0.011	6.28
48	B	14	2	0.765	0.017	9.36
49	B	16	2	0.811	0.013	7.94
50	B	18	2	NA	NA	NA
51	B	0	3	0.296	0.073	25.3
52	B	2	3	0.292	0.035	17.46
53	B	4	3	0.263	0.033	11.15
54	B	6	3	0.115	0.052	9.73
55	B	8	3	0.135	0.034	9.09
56	B	10	3	NA	NA	NA
57	B	12	3	NA	NA	NA
58	B	14	3	NA	NA	NA
59	B	16	3	NA	NA	NA
60	B	18	3	NA	NA	NA
61	C	0	1	0.227	0.077	20.64
62	C	2	1	0.451	0.094	23.36
63	C	4	1	0.271	0.043	25.12
64	C	6	1	0.66	0.032	19.98
65	C	8	1	0.575	0.012	16.82
66	C	10	1	0.663	0.018	16.25
67	C	12	1	0.034	0.010	15.84

68	C	14	1	0.485	0.017	17.62
69	C	16	1	NA	NA	NA
70	C	18	1	NA	NA	NA
71	C	0	2	0.465	0.080	26.16
72	C	2	2	0.543	0.034	20.36
73	C	4	2	0.208	0.022	30.31
74	C	6	2	0.267	0.020	30.57
75	C	8	2	0.485	0.012	19
76	C	10	2	0.727	0.015	14.68
77	C	12	2	0.392	0.006	12.87
78	C	14	2	0.414	0.01	12.44
79	C	16	2	0.532	0.014	6.53
80	C	18	2	NA	NA	NA
81	C	0	3	0.421	0.056	32.51
82	C	2	3	0.227	0.010	26.79
83	C	4	3	0.608	0.012	15.57
84	C	6	3	0.374	0.015	15.09
85	C	8	3	0.387	0.011	15.48
86	C	10	3	0.271	0.010	12.68
87	C	12	3	0.675	0.013	12.04
88	C	14	3	0.507	0.013	11.39
89	C	16	3	0.376	0.009	11.64
90	C	0	3	NA	NA	NA
91	D	0	1	0.412	0.063	15.72
92	D	2	1	0.413	0.032	17.11
93	D	4	1	0.57	0.030	14.73
94	D	6	1	0.42	0.061	18.63
95	D	8	1	0.397	0.026	18.84
96	D	10	1	0.388	0.047	14.28
97	D	12	1	0.44	0.049	21.26
98	D	14	1	0.314	0.080	16.16
99	D	16	1	0.343	0.052	18.77
100	D	18	1	NA	NA	NA
101	D	0	2	0.29	0.027	13.45
102	D	2	2	0.255	0.036	13.1
103	D	4	2	0.366	0.031	15.65
104	D	6	2	0.369	0.033	15.98
105	D	8	2	0.357	0.048	17.43
106	D	10	2	0.284	0.028	15.64
107	D	12	2	0.401	0.047	22.64
108	D	14	2	NA	NA	NA
109	D	16	2	NA	NA	NA
110	D	18	2	NA	NA	NA
111	D	0	3	0.185	0.033	13.14
112	D	2	3	0.169	0.052	14.02
113	D	4	3	0.079	0.048	16.35
114	D	6	3	0.15	0.037	15.4
115	D	8	3	0.151	0.020	30.56
116	D	10	3	0.143	0.030	18.82
117	D	12	3	0.12	0.020	21.62
118	D	14	3	NA	NA	NA
119	D	16	3	NA	NA	NA
120	D	18	3	NA	NA	NA

* based on dry weight

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Evaluation of Some Chemical Characteristics of Tropical Humic Acid Extracted From Peat Land Soil in Central Kalimantan

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Abstract

Some chemical characteristics and the reducing capacity of tropical humic acid were evaluated by means of elemental analysis, functional group analysis and equilibrium potentiometric titration using hexacyanoferrate(III) as an oxidizing reagent. The characteristics of tropical humic acid were compared with those of northern and commercial available humic acids. The tropical humic acid has the largest total acidity and phenolic hydroxide content. The reducing capacity of tropical humic acid was larger than those of other humic acids.

Introduction

In Central Kalimantan Island, there are many areas of peat land. The soil of peat land contains a large amount of humic substances. Humic substances, one of main soil organic matters, are polymer electrolytes having many kinds of functional groups, such as carboxyl and phenolic hydroxide groups. Humic substance, therefore, has some chemical abilities such as complexing with heavy metal ions, reducing them and solubilizing water-insoluble compounds(1). Since humic substances are distributed widely and ubiquitously in environment, it is thought that the presence of humic substances affects the movement and the effect of pollutants on environment. Then the interaction between humic substances and some pollutants has been investigated. We also have reported the reducing ability of humic acid for hexavalent chromium(2) and the solubilizing ability for some water-insoluble compounds(3).

In this study, some chemical characteristics such as elemental composition, the contents of functional groups and the reducing capacity of tropical humic acids extracted from peat soil in Central Kalimantan were evaluated and compared with those of humic acid extracted from soil of Bibai in Hokkaido and commercial available humic acids.

Preparation of humic acid and methods

Humic acids were prepared by extraction from peat soil at Central Kalimantan in Indonesia and at Bibai in Hokkaido followed by the purification according to the protocol recommended by IHHS (International Humic Substances Society). The humic acids prepared from Kalimantan and Bibai soil are represented by KHA and BHA, respectively. Aldrich humic acid and Acros humic acid perchersed from reagent company were also purified by the similar method. The elemental composition of these humic acids was measured by elemental analysis of the analytical center of Hokkaido University. The functional group analysis was performed by barium hydroxide method for the total acidity, calcium acetate method for carboxyl group content. The reducing capacity was measured by equilibrium potentiometric titration using platinum electrode and hexacyanoferrate(III) as oxidizing reagent.

Results and Discussion

The results of four kinds of humic acids by elemental analysis are summarized in Table1. No large difference in the elemental composition presences between KHA and BHA. The commercial available humuc acids, Aldrich and Acros humic acids, also have the similar elemental composition. Table 2 shows the total acidity, the functional group contents of carboxyl and phenolic hydroxide of each humic acid. The content of phenolic hydroxide was obtained by subtracting the contents of carboxyl group from total acidity. It is noteworthy that KHA has the largest total acidity and phenolic hydroxide, while the amount of carboxyl group of KHA was smaller than those of other humic acids. This may be due to the difference in original and precursor materials for the formation of humic acid between tropical and northern area, although the more samples of tropical humic acids is necessary in order to discuss the difference in detail.

Table 1 Elemental composition of several humic acids.

Sample	C (%)	H (%)	O (%)	N (%)	S (%)	Ash(%)
KHA	51.66	5.39	34.23	3.59	0.79	4.34
BHA	52.32	5.12	38.42	3.52	0.62	0
Aldrich -HA	58.39	3.96	32.63	0.80	4.22	0
ACROS-HA	56.87	4.50	35.38	1.35	1.90	0

Table 2 The contents of functional groups in humic acids(meq/g humic acid).

Sample	Total Acidity	Carboxyl Acid	Phenolic Hydroxide
KHA	7.53	2.46	5.07
BHA	6.11	3.05	3.06
Aldrich -HA	6.80	4.14	2.66
ACROS-HA	6.69	3.55	3.14

The reducing capacities of humic acids were measured by the means of potentiometric titration using hexacyanoferrate(III), $[Fe(CN)_6]^{3-}$, as a titrant for titration. In general, the reaction rate between the titrant and humic acid is very slow. Therefore, it takes long time to reach to the equilibrium potential. In this study, an equilibrium titration method, where the titrant was added dropwisely to the solution after equilibrium was reached, was adopted. The typical redox titration curve is shown in Fig.1. The redox potential changed largely for each addition of titrant, however, by connecting the equilibrium potential, the titration curves having an inflection point was obtained. From the inflection point, the reducing capacity of each humic acid can be evaluated.

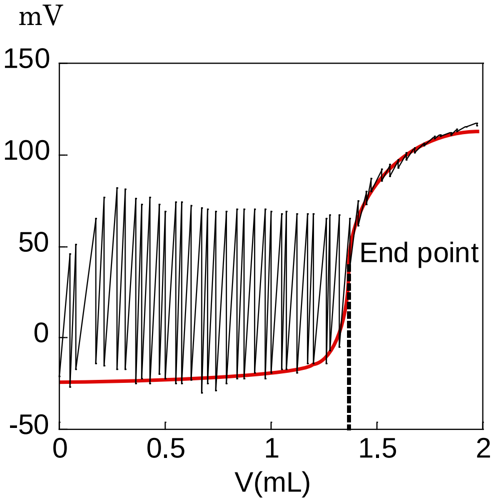

Fig.1 Typical equilibrium redox titration Curve of humic acid.

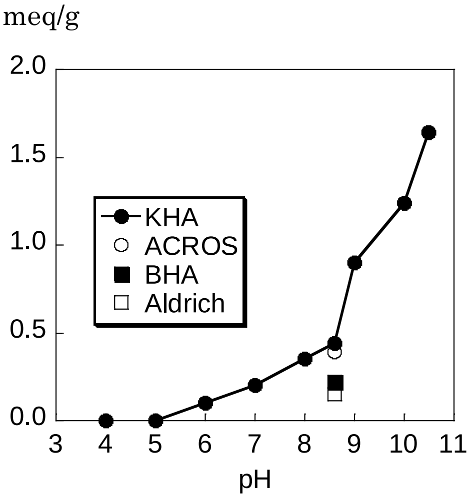

Fig.2 pH dependency of reduction capacity of humic acids.

The reduction capacity of humic acid shows the pH dependency and it increased with increasing pH as shown in Fig.2. At pH 8.6, KHA has the largest reduction capacity among four types of humic acids. This is attributed to the largest amount of phenolic hydoxide group of KHA. The reduction capacity of humic acids showed the strong correlation with the amount of phenolic hydroxide. However, the correlation coefficient was much smaller than the unit. This means that little parts of phenolic hydroxide group can participate in the redox reaction. One of the reasons may be due to the bulky structure of humic acid, that is, most part of phenolic hydroxide is buried under the bulky structure of humic acid not to participate in the reaction. The number and the position of phenolic hydroxide in benzene ring may affect the redox potential. The detail investigation is now in progress.

Acknowledgement

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Bioavailability and photodegradation of dissolved organic carbon in peat swamp area

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Introduction

In Kalimantan Island, there are a lot of small lakes (oxbow lakes and floodplain lakes) along large rivers (McKinnon et al. 1996). Although these lakes are relatively small in size (several km in length), they have rich biodiversity. For example, Hartoto (2000) reported over 40 fish species from small lakes. However, ecological structures of these lakes are not yet well examined. Recently, Ishikawa et al (2004) showed that primary production in oxbow lakes are relatively low, which cannot satisfy oxygen consumption in lakes. This result indicates high dependence upon allochthonous energy source for lake ecosystem. One of probable source is dissolved organic carbon supplied from catchment area. Actually, water of these lakes and rivers stain dark-brown color due to high dissolved organic carbon (e.g. Yamato 2004). DOC in peat swamp usually consists of humic substances (Steinberg 2003) which means DOC rather refractory substrate than that originated from phytoplankton. Recent studies, however, show that exposure to sunlight, especially UV radiation make DOC more usable to microorganism (e.g. Wetzel et al. 1995). This mechanism, called photodegradation, seem to play substantial role lakes in tropical area because environmental changes such as cutting of riparian forest and haze would affect light environment in aquatic ecosystem. In this study, therefore, we tested bioavailability and photodegradation of DOC of water from peat swamp area.

Method

Experiment was conducted in a small ditch (c.a. 2.5m in depth, 3m in width) in front of Laboratory of Limnology, Faculty of Agriculture, University of PalangkaRaya on July 2004. The ditch water was supplied by rain water, groundwater and from surrounding fen.

The water used in the experiment was collected from surface of the ditch directly into 10 L Plastic tank. The collected water was filtered by 0.2µm millipore filter to remove all organisms. The filtrate was poured into 9 bottles. (1.6L, polyethylene terephthalate)

At the beginning of experiment, all bottles were set upon a floating frame on the ditch. To control light intensity and water temperature, the floating frame was made to keep the surface of the bottles not to be covered by water but the lower half of the bottles to be immersed into the ditch water. Duration of exposure experiment to sunlight of bottles was decided by period of covering by aluminum foil: at the beginning of exposure period, all bottles were covered by aluminum foil. Then the aluminum foil was removed after 0day (just after the beginning), 2day, 4day, 5day, 6day, 6+4/3day, and 2hour and 2hour before 7day, which corresponds to the exposure period of 7day, 5day, 3day, 2day, 1day, 6hour, 2hour and 1 hour, respectively.

Bioavailability of the light-exposed water was assessed as oxygen consumption rate by microorganism. Before the assessment, water from same ditch was filtered using GF/F filter (c.a. 0.7 µm in pore size) to remove heterotrophic organism expect for bacteria. The filtrate was mixed with the light-exposed water in the ratio of 1 to 1. The mixture for each the light-exposed was poured into four BOD bottles (100mL in volume). Two of the four bottles were used for the measurement of initial dissolved oxygen (DO) concentration. The other two bottles were covered by aluminum foil to avoid photosynthesis and DOC degradation. Then, the two bottles were set on a container (30±2°C) for 8hours. Oxygen consumption rate was calculated as the changes in the oxygen concentration, which obtained by difference in initial and oxygen concentration after 8 hour incubation.

Dissolved oxygen concentrations were determined by the Winkler method using a potentiometer with auto burette (AT-500N, Kyoto Electronics, Japan). DOC concentrations were measured using a TOC analyzer (TOC-5000, Shimadzu Japan) after filtration of GF/F. For characterization of DOC, 3-dimensional fluorescence spectra were measured using a fluorescence spectrophotometer (RF-5300PC Shimadzu, Japan).

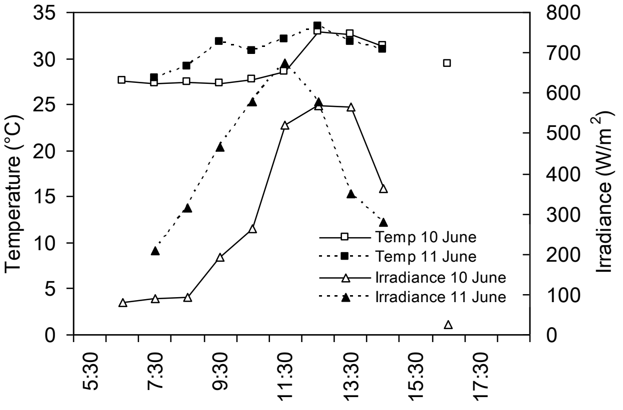

Figure 1. Daily changes in water temperature and irradiance intensity at the ditch on 10 and 11 June 2004.

Electrical conductivity (EC) and pH were measured using a combined sensor (U-22, Horiba, Japan). On 10 and 11 July, light condition at the ditch was measured using a radiometer (HD9021, Delta OHM, Italy; with sensors HD9021 RAD/C for irradiance, HD9021UVA for UVA, HD9021UVB for UVB). On the same dates, water temperature on the surface of the ditch was measured using a DO sensor (Model 55, YSI, USA)

Results

Light environment and temperature of the ditch

On 10 July (1 day before the end of light exposure), it was cloudy in A.M. whereas it was fine until late afternoon on 11 July. Figure 1 shows water temperature and irradiance changes in 10 and 11 June in WIB time (GMT +7:00). Because time of culmination is around 11:30 in PalangkaRaya, visible irradiance was highest at 11:30 on shiny day (11 June). However, on cloudy 10 June, daily changes in the temperature and visible irradiance was not highest at the culmination, which indicates high effect of cloud on light condition in the ditch. Figure 2 shows UVA and UVB irradiance, which indicates same tendency as visible irradiance.

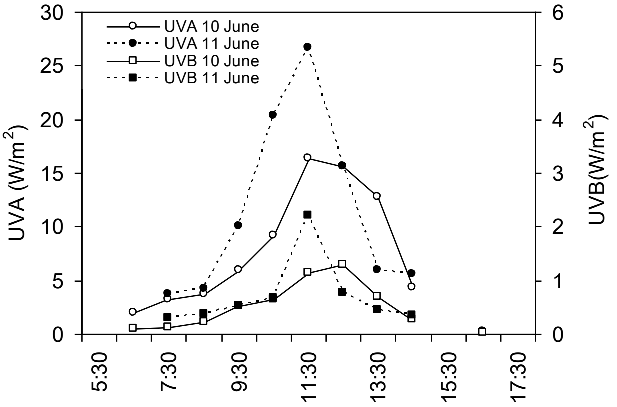

Figure 2. Daily changes in UV-A and UVB intensity at the ditch on 10 and 11 June 2004.

Changes in DOC concentration, EC and pH by exposure to sunlight

pH of water was constant around 4.4 independently of exposure time to sunlight. In contrast, electrical conductivity (EC) was 5 mS/m in the water without exposure to light. However, short period exposure (1h, 2h, 6h and 1 day) shows slight decrease of EC. This decrease was not seen in 2day exposure, but exposure longer than 3days results decrease of EC according to duration of exposure (Fig. 3).

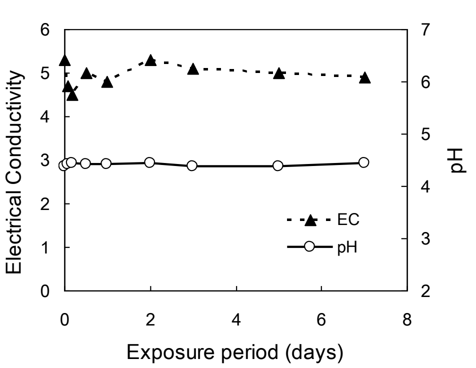

Figure 3. Electrical Conductivity (mS/m) and pH of the light-exposed waters.

Dissolved organic carbon concentration after exposure to sunlight shows similar trend to changes in EC. Short time exposure shows slight decrease in DOC, but such decrease did not occur in 2 days exposure. Longer exposure than 2 days shows decrease of DOC according to length of exposure to sunlight (Fig. 4)

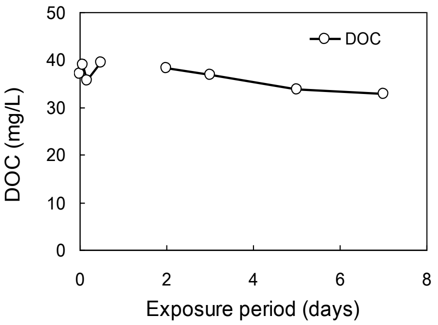

Figure 4. Dissolved organic carbon concentration of the light –exposed waters.

3-dimensional fluorescence spectra

The ditch water used for this experiment has a peak around the point (Em 350nm, Ex 450nm) (Fig.5). Water exposed to sunlight longer time shows weaker peaks and surrounding points also became weaker.

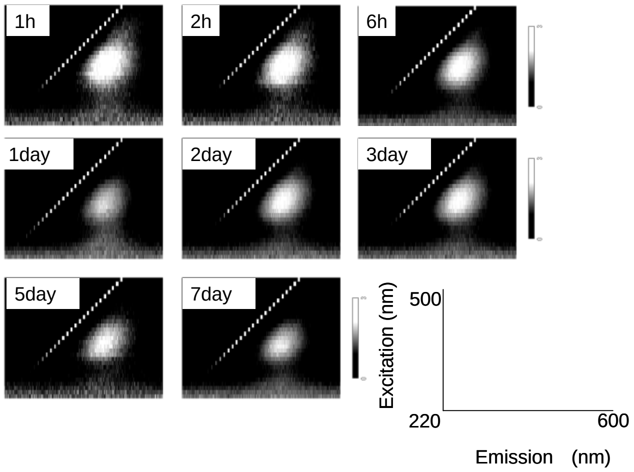

Figure 5. 3-dimensional fluorescence spectrometry of the light –exposed waters.

Bioavailability test

Short term exposure (1h – 1day) showed higher oxygen consumption rate than the water without sunlight exposure (0 exposure). However, water exposed to sunlight for 2days and 3days showed similar or lower oxygen consumption compared to 0 exposure water. However, the water exposed to sunlight for 7dars shows 3times higher oxygen consumption than 0exposure water. Note that due to experimental failure, we could not measure oxygen consumption rate for the water of 5 days exposure.

Table 1. Oxygen consumption rate by microorganism with the addition of light-exposed waters

Exposure peiord	0	1h	2h	6h	1day	2day	3day	7day
Oxygen comsuption rate ($mgO_2\ L^{-1}\ h^{-1}$)	0.017	0.030	0.038	0.032	0.032	0.017	0.011	0.056

Discussion

This study shows that DOC of peat swamp area in Kalimantan Island is affected by sunlight both quantitatively and qualitatively. After exposure to sunlight, DOC concentration decreased and bioavailability in terms of oxygen consumption by bacteria was enhanced. Photodegradation of DOC has been studied in boreal area, which is key role in black water lake in that area (e.g. Morris et al.1995). In Kalimantan, oxbow lakes have sometimes higher DOC concentration to boreal humic lakes (Ishikawa unpublished). Furthermore, irradiance of sunlight is highest in the equatorial area. Therefore, photodegradation of DOC might have important role in lake ecosystem.

In this study, DOC concentration and bioavailability showed inverse pattern, enhancement of bioavailability occurred with decrease of DOC. This suggests exposure of sunlight not only make molecular size of DOC small, but also change DOC into inorganic carbon. Therefore, it is possible that exposure of DOC would make more CO_2 by both biologically (respiration) and non-biologically (photodegradation it self). Note that changes of both quantity and quality of DOC occurred within short term (<1 day) and long term (>2days). Because we adjusted the exposure period using sunlight, the exposure period <1 day did not reflect sum of irradiance. If reaction induced by sunlight differs under strong and weak irradiance, our result for 1hr and 2hr was extreme control. This possibility can apply the difference between 2day and 1day because it was cloudy on one day of 2 days exposure water where as it was fine throughout the day of 1 day exposure (Figure 1). In anyway, result in this study suggests that effect of photodegradation under natural sunlight should depend upon both exposure period and intensity.

A peak detected by three-dimensional fluorescence spectrophotometry seem to coincident with that of fluvic acid by other studies (Senesi 1990). Because the water used in this experiment was acidic and supplied from peat land, it seem reasonable that the water contains fluvic acid, not humic acid. Therefore, our results indicate that fluvic acid was decomposed by exposure of sunlight.

In conclusion, this study showed that DOC from peat wetland in Kalimantan Island was decomposed by exposure of sunlight. This photodegradation enhanced respiration of microorganism which means bioavailability of DOC was increased by photodegradation. These results suggest alternation of light environment of water, such as logging of peat swamp forest and haze by forest fire, has strong impact on aquatic ecosystem in tropical area, especially Kalimantan Island.

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Phytoplankton of oxbow and backwater flood plain lakes in a fresh water swamp ecosystem of Central Kalimantan

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Abstract

The composition of species and spatial and temporal distribution of net phytoplankton and chlorophyll-a were studied in oxbow and backwater flood-plain lakes in relation to lake water level and the connectivity to the main river. Research was conducted in oxbow lakes, namely Lakes Tehang, Bunter and Hurung and the backwater Lake Batu from September 2002 to September 2003.

Dominant phytoplankton in the observed lakes were the flagellates, i.e., *Euglena*, *Phacus* and *Trachelomonas*. These genus presumably contained less amount of chlorophyll-a in terms of biovolume. Phytoplankton density fluctuated monthly except *Trachelomonas* that appeared nearly throughout the year. Annual mean density, annual mean biomass and the number of species of phytoplankton all decreased in the order, Lakes Tehang, Bunter, Hurung and Batu, which was coincided with the order of the lakes based on the degree of open connection to the Kahayan River. Annual mean phytoplankton biomass in lakes Tehang, Bunter, Hurung and Batu were 2330, 2041, 1331 and 623 mgC·m^{-3}, respectively.

In all of the observed lakes, phytoplankton density and biomass in low water (dry) season from July to October, tended to be higher than that in high water (rainy) season, from December to May. June and November were presumably transitional periods.

Key words: Net phytoplankton, biomass, chlorophyll-a, open connection, water level, flagellates.

Introduction

Phytoplankton are microscopic plants that suspend in water column and major primary producers in aquatic ecosystems, including species with various sizes and shapes, from few micrometers long of single-celled species to colonial or filamentous (Kagami, 2002). Its production rate is primarily a function of light intensity, temperature and nutrient. According to Reynolds (1984), seasonal changes in species composition result from species-specific difference in the growth and loss rates in response to temporal changes in abiotic (e.g., light, nutrient and temperature) and biotic (e.g., grazing and parasitism) factors.

Since 1997 an intensive research on limnology in lakes and rivers in Central Kalimantan, particularly phytoplankton has been carried out by the members of the Core University Program, JSPS-LIPI. Several topics on phytoplankton have been studied, such as spatial distribution of phytoplankton in lakes (Sulastri and Hartoto, 2000; Ardianor and Veronica, 2003) and their temporal change and cell-size distribution (Kusakabe et al., 2000). Cell sizes of phytoplankton in Lake Sabuah ranged from 10 to 50 μm (i.e., nano-phytoplankton) (Kusakabe et al., 2000). Ardianor and Veronica (2003) have collected phytoplankton larger than 20 μm in size using plankton net in Lakes Batu, Hurung, Tehang and Bunter.

So far, past studies were not performed throughout a year. Thus, the objectives of the present study were to examine the composition of species and spatial and temporal distribution of net phytoplankton and chlorophyll-a in oxbow and backwater flood-plain lakes in relation to location of lakes and water level change. Phytoplankton were collected during one year period for size classes of ≥ 20 μm and the biomass of dominant species were estimated.

Study Sites

Study was conducted in oxbow and backwater floodplain lakes in the vicinity of Sigi Village, approx. 18 km from Palangkaraya, capital city of Central Kalimantan Province. The observed lakes were L. Hurung (02°00'57.2" S, 113°54'48.0" E), L. Batu (02°00'57.4" S, 113°56'54.9" E), L. Tehang (02°01'10.8" S, 113°55'43.7" E) and L. Bunter (02°01'45.8" S, 113°55'36.2" E). Typically, Lake Batu is a backwater floodplain lake whereas Lakes Hurung, Tehang and Bunter are oxbow lakes (Figure 1).

Measurement and sampling of lake water were performed from September 2002 to September 2003 in the center or middle part of the lakes.

Methods

Depth of lake bottom was measured using a depth sounder (Hondex PS-7, Japan) at the center or middle part of the lakes.

Phytoplankton samples were taken by filtering 30 L of lake water through plankton-net (mesh opening of 20 μm), preserved in Lugol's solution of 1% of final concentration (Wetzel and Likens, 2000) and identified and counted under an inverted microscope (Nikon TMS). Phytoplankton were identified according to Edmonson (1952), Prescott (1970) and Mizuno 1979. Biovolume of dominant phytoplankton species were estimated after Miyai et al. (1988) and Hillebrand et al. (1999) and biomass and carbon content were estimated using equations by Miyai et al. (1988) and Strathmann (1967), respectively. Phytoplankton abundance was estimated by the sedimentation method (APHA, 1995) and the Simpson diversity indices were calculated (Margalef, 1988). Species richness was estimated by the jackknife and bootstrap methods (Krebs, 1989). Similarity among lakes were calculate based on correlation distance ($d_{ij} = 1- \rho_{ij}$, where ρ = Pearson correlation) and dendrogram clustering was performed using average linkage method.

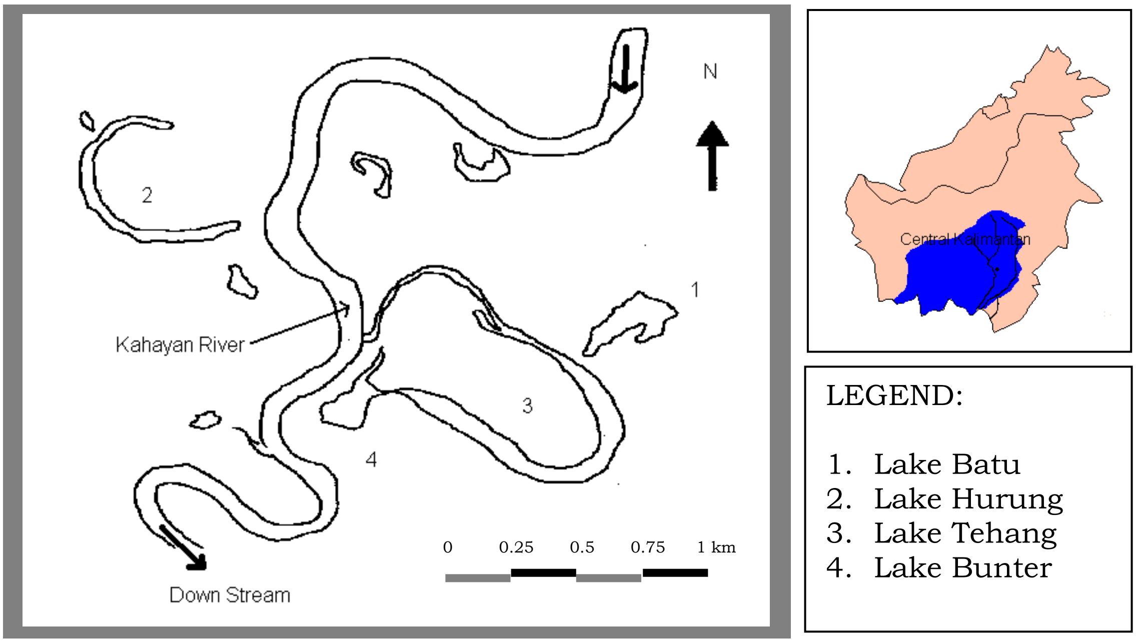

Figure 1. Map showing study sites

For the determination of chlorophyll-a concentration, 300 ml of lake water was passed through Whatman GF/F glass microfibre filter. The filter was placed in a 15-ml polyethylene tube with 8-ml methanol, stored in a refrigerator for 1 day and then centrifuged at 3500 rpm for 20 minutes. After centrifugation absorbances of its supernatant were measured spectrophotometrically at wavelengths of 750 and 664 nm. Chlorophyll-a concentration was calculated by the following formula (Marker et al. 1980):

$$\text{Chlorophyll-a} = 13.4\ v(\text{ABS664} - \text{ABS750}) / (Vd)$$

Where :
V = Volume of sample filtered (L)
v = Volume of methanol (8 mL)
d = Path length (1 cm)

Results and Discussion

Species composition

A total of 68 species of phytoplankton belong to 25 families were identified for four observed lakes. The dominant taxa were Euglenidae (27 species), Desmideaceae (6 species), Naviculaceae (5 species) and Oscillatoriaceae (3 species). The other 21 families had no more than two species. *Euglena*, *Phacus* and *Trachelomonas* were the dominant genus in term of density. Total number of species were 42, 36, 47 and 43 for Lakes Hurung, Batu, Tehang and Bunter, respectively. The number was highest in Lake Tehang and lowest in Lake Batu. The jackknife estimates of the number of species in Lake Hurung, Batu, Tehang and Bunter were 55, 51, 65 and 56, respectively. The bootstrap estimates for these lakes were 49, 43, 60 and 51 species, respectively, which were smaller than the jackknife estimators. As shown in Figure 2, the order of these estimators among the lakes was the same as that for observed number of species. Smith and Van Belle (1984) in Krebs (1989) recommend the jackknife estimator when the number of observations is small (less than or equal to 20) and the bootstrap estimator when the number of observations is large (more than 20). The jackknife estimate may be appropriate since the number of observation was 13 in the present study.

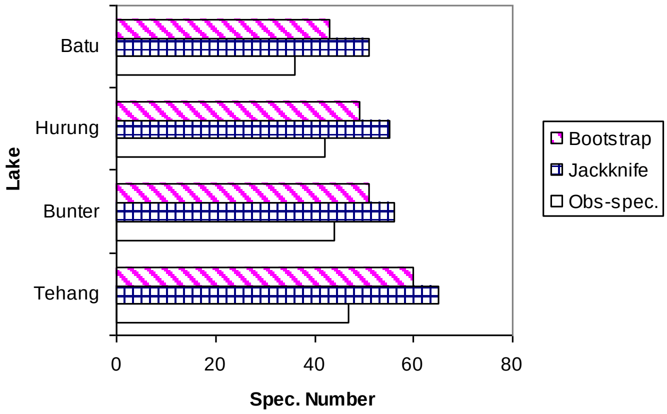

Figure 2. Comparison of the number of species observed (Obs-spec) and estimated species.

Average number of individuals in Lake Hurung, Batu, Tehang and Bunter were 395, 113, 948 and 792 inds./L, respectively. The highest density was found in Lake Tehang while the lowest in Lake Batu. Simpson diversity indices for those lakes were 0.88, 0.91, 0.86 and 0.71, respectively. Annual mean density and the number of species decreased in the order, Lakes Tehang, Bunter, Hurung and Batu, which was coincided with the order of the lakes based on the degree of open connection to the Kahayan River. However, the reason for the increase of diversity index from Lake Bunter to Lake Batu was not clear. Annual mean chlorophyll-a concentrations among the lakes were not consistent with the order observed for density and number of species. Highest value was observed in Lake Hurung (4.9 µg/l) and the lowest in Lake Bunter (3.1 µg/l, Figure 3a).

Due to high similarity values (82.6%), Lake Tehang, Hurung and Batu were clustered as closely related based on the number of individuals of species identified (Figure 3b). It was clear that the high similarity among three lakes was created by high density of Euglenidae found. Lake Batu, however, was different from other lakes due to the occurrence of small number of Euglenidae.

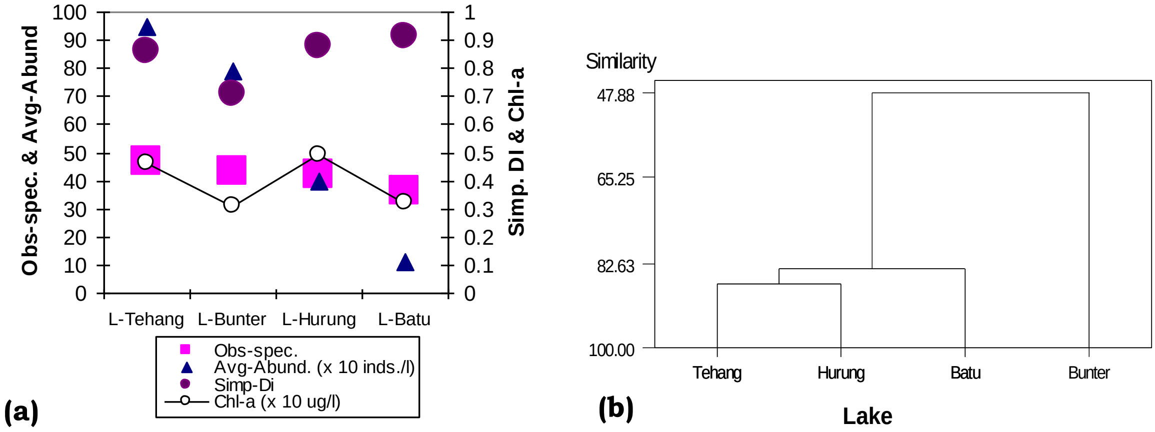

Figure 3. (a) The number phytoplankton species, cell density, chlorophyll-a concentration and diversity index on annual basis for lakes arranged in the order of open connection to the Kahayan River. (b) A dendrogram showing the similarity of phytoplankton species between lakes.

Spatial and temporal distribution

Spatially, the degree of open connection of observed lakes to the main river highly regulated phytoplankton community since the river usually supply organic and inorganic matter to the lakes, especially during high water level period. However there was no significant correlation was observed between phytoplankton density and chlorophyll-a concentrations for each of the lakes. One possible explanation for this phenomenon was that phytoplankton communities were dominated by species containing small amount of chlorophyll-a, such as larger heterotrophic-flagellates, *Euglena*, *Phacus* and *Trachelomonas*. Among the lakes observed, Lake Batu showed highest but still insignificant correlation between the phytoplankton density and chlorophyll a (R^2 = 0.21) (Figure 4). On the contrary to the present results, a previous study on the same lakes during June-August 2002 showed that increase in phytoplankton density was followed by the increase of chlorophyll-a concentration, except in July for Lakes Hurung and Bunter (Ardianor and Veronica, 2003).

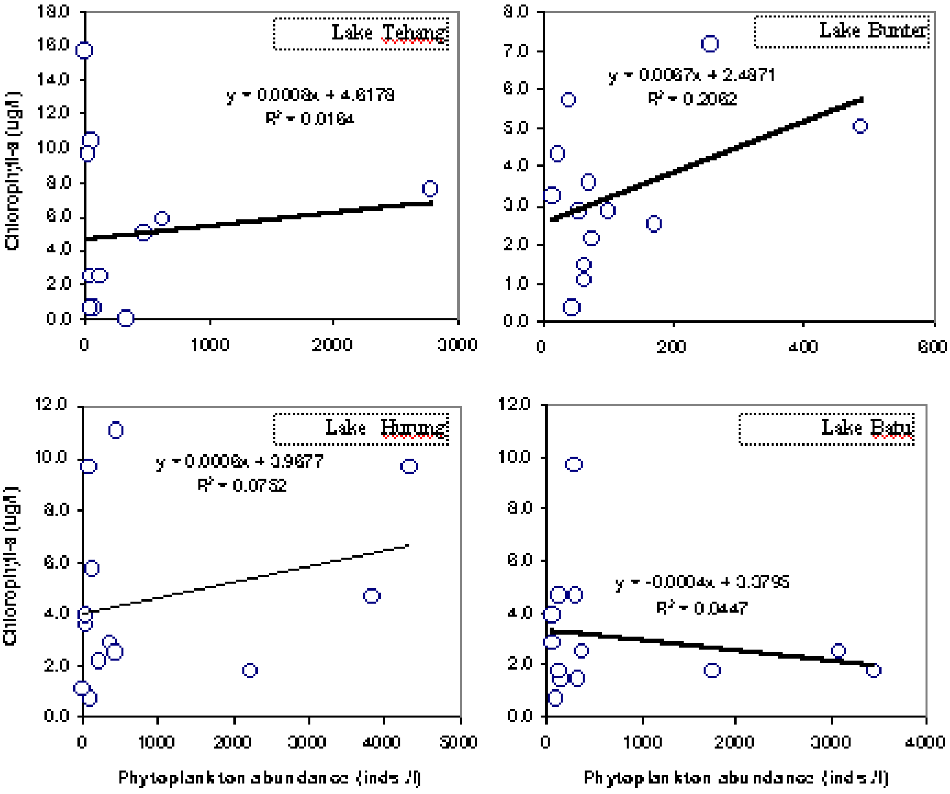

Figure 4. Chlorophyll-a concentrations against phytoplankton densities for observed lakes.

In Lake Tehang, phytoplankton density and chlorophyll-a concentration fluctuated independently to each other from September 2002 until April 2003 and phytoplankton density increased with increasing chlorophyll-a concentration from May to September 2003. In Lake Bunter, the increase of phytoplankton density coincided with that of chlorophyll-a concentration during a period from December 2002 to April 2003. On the contrary to the previous lakes, decrease of phytoplankton density in Lake Hurung was concomitant with decreasing of chlorophyll-a concentration from October 2002 to January 2003. These events explained in part the observed weak but insignificant correlations between phytoplankton densities and chlorophyll-a concentrations. In Lake Batu, however, no obvious coincidence was observed between phytoplankton density and chlorophyll a concentration (Figure 5).

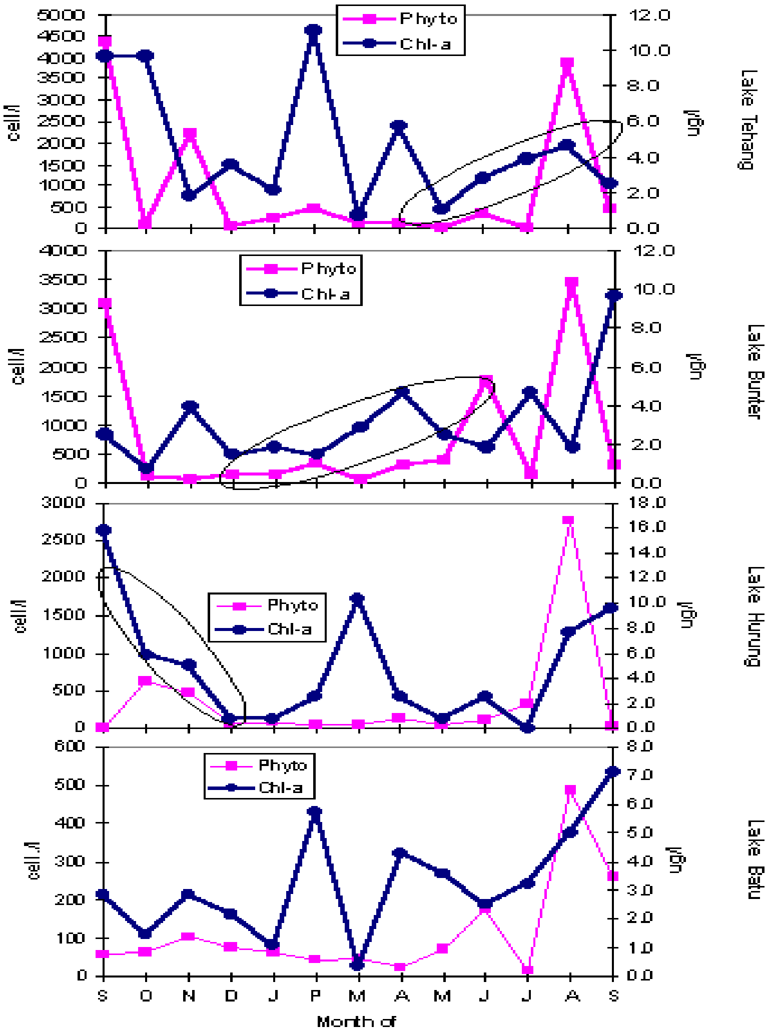

Figure 5. Seasonal changes of phytoplankton density and chlorophyll-a concentrations.

Seasonal changes of composition of phytoplankton families are shown in Figure 6. In Lake Tehang, Euglenidae was dominant from September 2002 to March 2003 and from July to September 2003. However, the family Oocystaceae was dominant during March-May 2003. In Lake Bunter, phytoplankton were dominated by Euglenidae in September 2002 and June 2003. For other months, dominant family was Oocystaceae from October 2002 until May 2003 and Surrirellaceae from July to September 2003. Euglenidae were also dominant in Lake Hurung from September 2002 to February 2003 and also from June to September 2003, while there was no dominant family from March to May 2003. In Lake Batu, phytoplankton was dominated by Oscillatoriacese in September 2002 and by Eglinedae from October to November 2002 and from July to September 2003. Vorticella was dominant from December 2002 to May 2003.

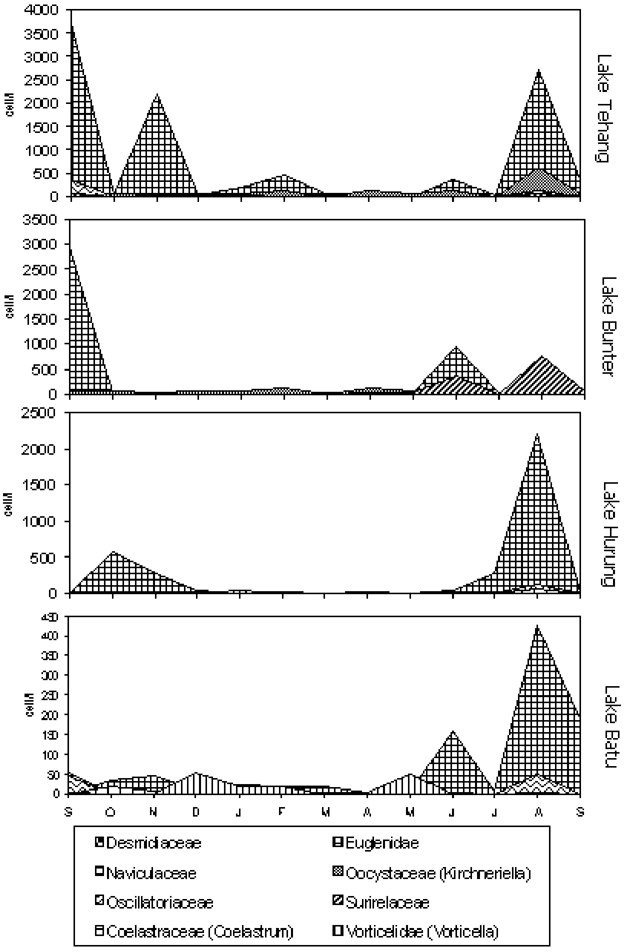

Figure 6. Seasonal changes in the composition of phytoplankton families.

Euglenidae were remarkably dominant throughout the year: percentage density of species belonging to Euglenidae to the total density of phytoplankton were 83, 79, 74 and 60% in Lakes Tehang, Bunter, Hurung and Batu, respectively. In Figure 7, we show the seasonal changes of densities of Euglenidae family, especially genus of *Euglena*, *Phacus* and *Trachelomonas*.

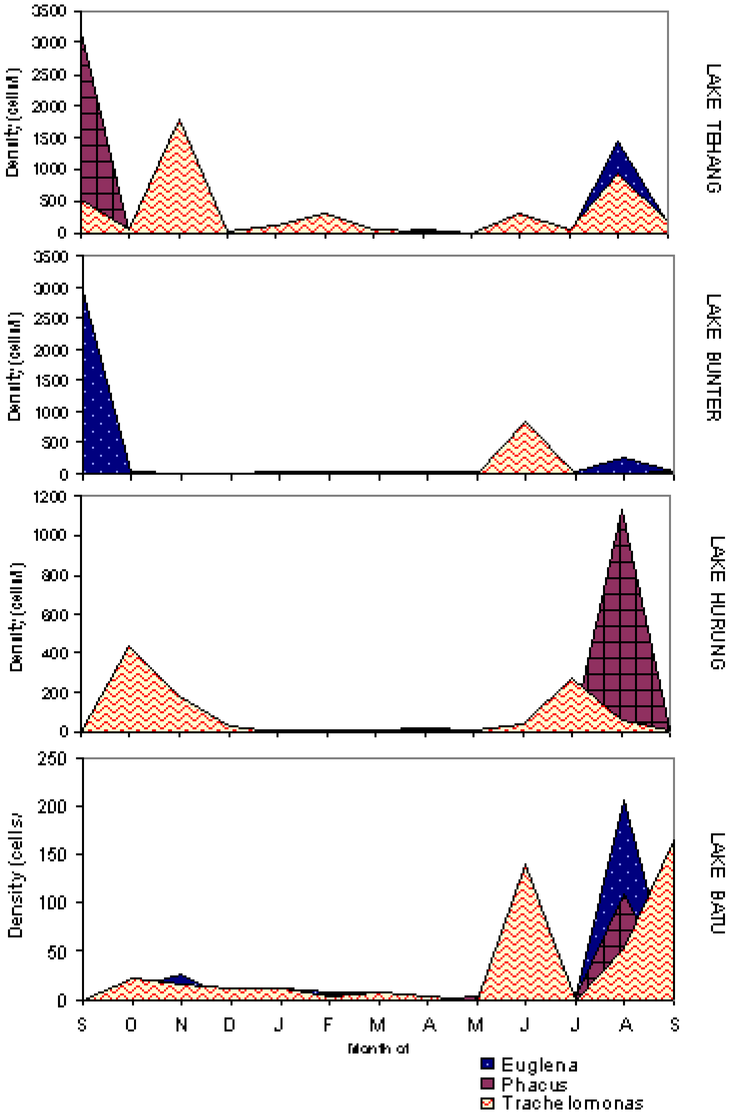

Figure 7. Seasonal changes in density of dominant phytoplankton genus belonging to Euglenidae.

In Lake Tehang, *Trachelomonas* was dominant from October 2002 to July 2003, while *Phacus* were dominant in September 2002 and *Euglena* in August 2003. In Lake Bunter *Euglena* appeared throughout the year with two peaks in September 2002 and August 2003, while *Trachelomonas* became predominant only in June 2003. In Lake Hurung, *Trachelomonas* occurred throughout the year with two peaks in October 2002 and in July 2003. In August 2003 this lake was dominated by *Phacus* (1009 inds./L) and *Euglena* (1135 inds./L). Similarly in Lake Batu, *Trachelomonas* were dominant from September 2002 to 2003 except in August 2003 when *Phacus* and *Euglena* were dominant.

In tropical region, river and lake ecosystems are highly affected by the fluctuation of water level. During higher water level or rainy season, peripheral areas of lakes are flooded. The flooded area is called "Igapo" in Brazil, while "Napu or Tayap" in Central Kalimantan. When watershed of a lake is flooded, delayed decomposition of organic matters, such as litter fall from riparian forests, may take place releasing nutrients that support phytoplankton growth until the low water level. These processes might be explained in part by the relation of phytoplankton density and chlorophyll-a concentrations to lake water depth (level) although the relationship was not significant (Figure 8).

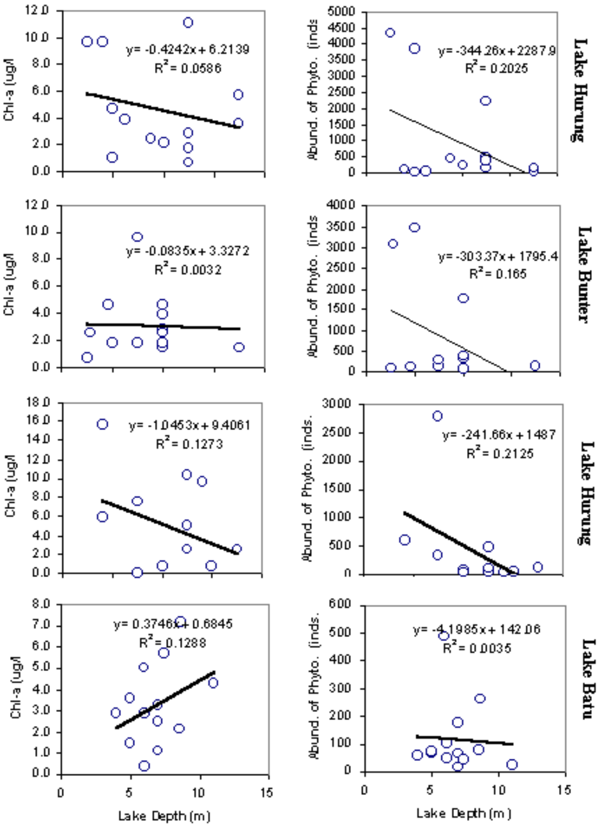

Figure 8. Effect of lake water level on phytoplankton density and chlorophyll-a concentration

The periods of connection and disconnection of observed lakes to the Kahayan River were rainy and dry seasons, respectively (see Figure 6). In all of the observed lakes, phytoplankton density during low water (dry) season, i.e., from July to October, was higher than that in high water (rainy) season, i.e., from December to May. June and November were presumably the transitional periods.

Function of net phytoplankton

Phytoplankton are the source of autochtonous energy to the lakes ecosystems in terms of biomass. Similar to their density, biomass of phytoplankton also fluctuated temporary and spatially among lakes (Figure 9). In Lakes Tehang, Bunter and Hurung phytoplankton biomasses were high in

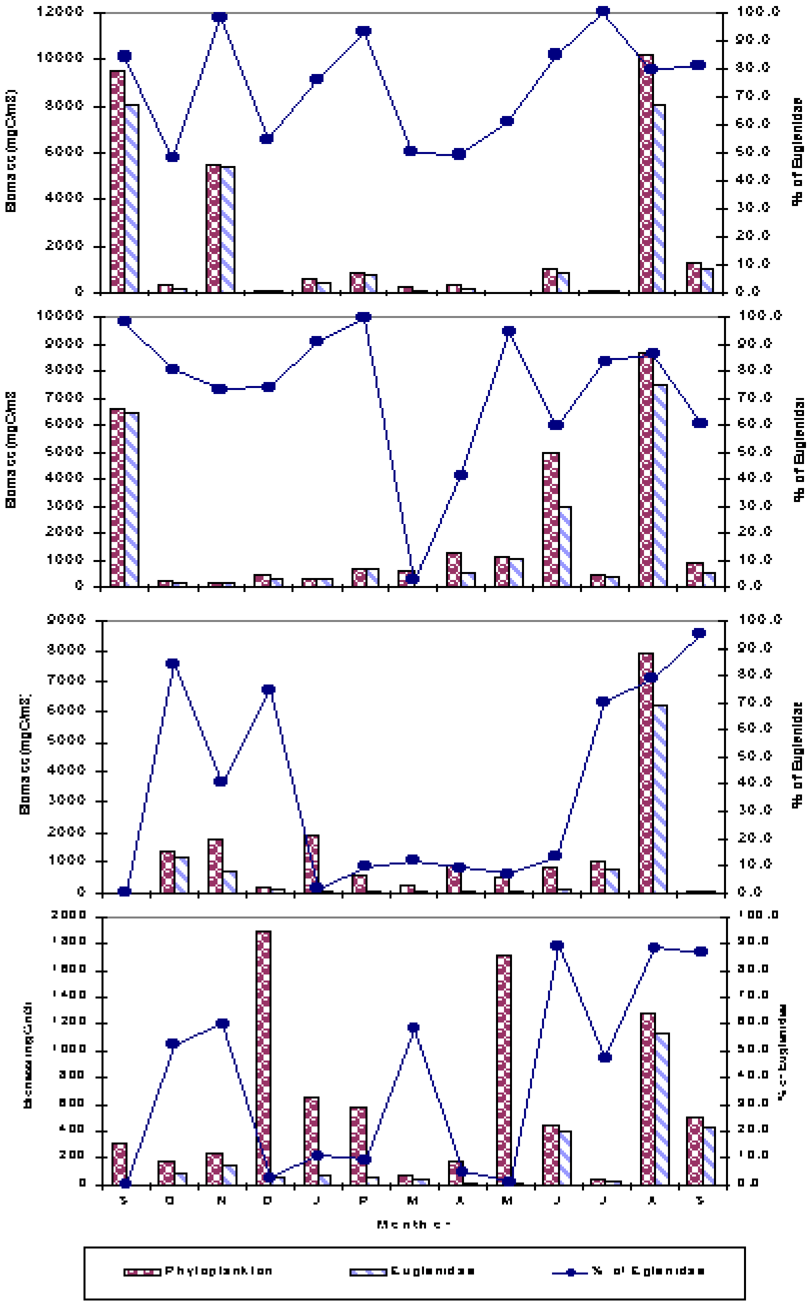

Figure 9. Phytoplankton biomass and the contribution of the dominant group, Euglenidae.

low water level period or dry season, especially in August and September. Conversely in Lake Batu, high biomass was observed in wet season, i.e., December 2002 and May 2003. Annual mean phytoplankton biomasses (±SE) were 2330±1006, 2041±780, 1331±575 and 623±171 $mgC \cdot m^{-3}$. for Lakes Tehang, Bunter, Hurung and Batu, respectively. High biomasses of phytoplankton in Lake Tehang, Bunter and Hurung were achieved mainly by the euglenid genera *Euglena*, *Phacus* and *Trachelomonas*. As shown in Figure 9, percentage contribution of Euglenidae to total biomass of phytoplankton was high throughout the year except for some months during rainy season for all the lakes observed.

Conclusion

1. Phytoplankton species dominant in the oxbow and backwater floodplain lakes were the euglenid flagellates, *Euglena*, *Phacus* and *Trachelomonas,* which presumably contained less amount of chlorophyll-a.
2. Density of phytoplankton changed greatly with time except *Trachelomonas*, which occurred throughout the year. Annual mean density, annual mean biomass and the number of species of phytoplankton all decreased with decreasing degree of lake's open connection to the main river.
3. Density of phytoplankton was higher in low water level (dry) season than in high water level (wet) season.
4. High biomass of phytoplankton in Lake Tehang, Bunter and Hurung were achieved mainly by the family of Euglenidae.

Acknowledgements

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Phytoplankton Composition and Water Quality Condition of Some Small Lakes in West Java

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Abstract

The composition of phytoplankton and the water quality condition of some small lakes in West Java have been evaluated through the primary and secondary data. The result showed that in general the water quality condition of some small lake showed a high nutrient concentration. Each lake has a different water quality characteristic. Seasonally the water quality of small lake was change and indicated the high input of suspended and organic material and nutrient in rainy season such as in Lake Cibuntu and Lake Bojongsari. There were some genera or species of phytoplankton common occurred in small lake such as *Scenedesmus, Staurastrum, Pediastrum, Coelastrum,Kirchneriella, Melosiara, Di*atoma, *Microcystis aeruginosa, Oscillatoria* and *Phacus*. Each lake has a different dominant genera or species that may be relation to the condition of the lake. There were seasonal changes the composition, index diversity and abundance of phytoplankton in small lake such as Lake Cibuntu. Spatially the abundance of phytoplankton showed a different distribution such as in Lake Bojongsari

Introduction

In West Java, small lake has many functions such as flood control, irrigation, fisheries, tourism and source of domestic water. More than 200 small lakes are located around Bogor, Jakarta, Bekasi and Tangerang. In general, small lake in West Java is a man made lake with the area range from 1.0 to 160 ha. Those small lakes have a variety of morphology since they was made by damming the water flows. Some of them are eutrophic as indicated by phytoplankton and macrophyte bloom. The degree of these small lakes sometimes proceed to the stage of hipereutrophic characterized by extremely high biological productivity, which further triggered the lake alteration into a terrestrial areas.

The awareness of people to maintain the existence of these small lakes is more increased now since the function of lake is important to support their life. Therefore some efforts have been done to restore the damaged lake by taking out the sediment and improving the water flow connection. Some lakes have been restored such as Cibuntu in 1998, Bojongsari 2003 and also Cikaret.

In order to restore the lake is not only considered physical approach but also to understand the biological and chemical characteristics of the lake. The irregular and heterogeneity of morphometry of small lake leads to large variability the distribution and productivity of higher vegetation and microbiota associated with those plants and their detritus. As a result, the growth and interactive metabolic properties of shallow lake tend to be most variable (Wetzel, 2001). This study was aimed to evaluate the phytoplankton composition characteristic and water quality condition of some small lake as a base for small lake management.

Methods

The data was collected from Lake Bojongsari, L. Cibuntu, L. Cikaret, L.Citayam, L. Lido and L. Tegal Abidin. L. Bojongsari, L. Cibuntu, L. Cikaret, L. Citayam are located in Bogor Regency while L. Tegal Abidin is located in Bekasi Regency. The morphometric features is presented in Table 1. The data is also compiled from primary and secondary data.

The primary data was collected from L. Bojongsari in 2003 when part of sediment was taken out to increase the surface area and after this physical work was completed. Some parameters observed include phytoplankton composition and abundance, chlorophyll-a concentration, physical and chemical parameters such as turbidity, conductivity suspended solid (SS), temperature, DO, pH, nitrite, nitrate, ammonia total nitrogen, total phosphorous and orthophosphate. Phytoplankton samples were collected by passing 1 l of water through a plankton net number 25 (40 µm size mesh opening) then fixed in 1% Lugol's solution for taxonomical study. The phytoplankton taxon was identified according to Prescott (1963, 1951), Scott and Prescott (1961). Quantitative analyses of phytoplankton was performed using modified Lackey drop microtransect method (Anonymous, 1995). Some water quality such as turbidity, temperature and conductivity were measured in situ using Horiba U-10 instrument. The dissolved oxygen was analysed using titrimetric method while chlorophyll-a and suspended solid were analysed by spectrophotometric and gravimetric method respectively. Chlorophyll-a and SS samples were collected by passing 100 m L of lake water through glass fiber filter Whatman GF/C and Whatman GF/A respectively. Other water quality parameter such as nitrite, nitrate, ammonia, total nitrogen, total phosphorous and orthophosphate were analysed in the laboratory. Preservation and analyses of samples were conducted as according to the standard methods (Anonymous, 1995).

The secondary data including phytoplankton composition and some water parameters were compiled some reports such as Nurcahyo (1988), Maha (1995), Mayani (2000) cited by Wardianto et al. (2003), Kusnanto (2003), and Sulastri (2004a, b).

Table 1.The morphometric features of some small lakes in West Java.

Parameters	Bojongsari	Cibuntu [1]	Tegal Abidin [2]	Cikaret [3]	Citayam [4]	Lido [5]
Maximum area (ha)	29	1.5	9.8	15	7	21
Makximum Depth (m)	8	2	1.7			19.8
Average Depth (z) (m)	3.9	0.88				
Volume (Vo) (m^3)	1.43 x !0^6	13.535 x 10^3	450 x 10^3			
Hidroulic retention time (day)	27	10				
Secchi Depth (cm)	54.0 - 94.0	34.0-57.5	9.0 - 25.0	36.4 -49.2	27.0 -47.1	43.5-123.5
Turbidity (NTU)	30.0 - 999.0	27.2-45.5	141.5-454.1		23.0 - 51.0	6.13 - 30.8

Source: 1: Sulastri (2003 b) & Fachrudin (1989); 2: Kusnanto (2003) ; 3: Nurcahyo (1988) ; 4. Mayani (2003) ; 4 Maha (1995) & Santana (1991) Cited by (Wardianto et al, 2003).

Result and Discussion

Physico-chemical parameters

The value of some water quality parameters were presented in table 2. Some of physico-chemical parameter seems that each lake indicates a different condition of water quality. The conductivity showed not so high different between lake. The range value of temperature in each lake showed the condition of tropical area. The lower concentration of dissolved oxygen was observed in L. Citayam, it indicates that this lake has lack of water quality for aquatic organism. The lack of water quality in L Citayam was also supported by the highest of nitrite and nitrate concentration. The value of pH showed that the water of L Tegal Abidin is more alkali compared to other lake. This lake was also characterized by the high of nutrient concentration especially total nitrogen and ammonia. Lake Bojongsari was characterized by high of total nitrogen, ammonia and chlorophyll-a indicate this lake is eutrophic waters. Lake Lido has a high concentration of organic matter. It may be comes from the activity of fish aquaculture in this lake that possibility some feed of fish is loss and enter into the lake. Lake Lido is deepest one with irregular bays that possibility the material organic is more longer stay in the lake. The different of water quality characteristic of the lake may be influenced by some factors such as morphometric, geological condition and external factor.

Table 2. Some physico-chemical parameters of some small lakes in West Java

Parameters	Bojongsari	Cibuntu [1]	Tegal Abidin [2]	Cikaret [3]	Citayam [3]	Lido [5]
Conductivity (mS/cm)	0.057 0.068	0.071-0.085		0.049.052		
Temperature (°C)	28.1 - 30.1	25.50-30.10	28.55-32.65	30.0-31.0	26.27-29.00	21 - 30
Dissolved Oxygen (mg/l)	4.41-14.9	4.40-7.68	4.17-12.61	2.8 - 6.4	1.51-3.58	0.41 - 10.20
pH	6.02 - 6.71	6.00-7.46	7.17 - 8.47	6.0 -6.5	6.0 - 7.0	6.37 -6.98
Nitrite (mg/l)	0.001-0.093	0.018 0.029	0.045 - 0.135	0.012-0.036	0.111-0.266	0.001 - 0.087
Nitrate (mg/l)	0.139 - 0.915	0.420-0.478	0.274-0.720	0.141-0.201	0.999-3.145	
Ammonia (mg/l)	0.009 - 1.232	0.281-0.334	0.234 - 0.796			0.006-0.144
Total nitrogen (mg/l)	0.413 - 3.116	1.851-2.256	2.189 - 3.440			
Orthophosphate (mg/l)	0.001- 0.243	0.048-0.077	0.032 - 0.67	0.141-0.201	0.051-0.161	0.001-0.223
Total phosphorous (mg/l)	0.014 - 0.423	0.092-0.271	0.083 - 0.106			0.038 - 0.428
Total organic matter (mg/l)		16.31-25.88	35.88-42.73		19.28- 40.45	189.6-1447.28
Chlorophyll-a (mg/m^3)	12.20-426.94	11.15-21.04	11.148-34.02			

Source: 1: Sulastri (2004 b) ; 2: Kusnanto (2003) ; 3: Nurcahyo (1988) ; 4. Mayani (2003) ; 4 Maha (1995) & Santana (1991) Cited by (Wardianto et al, 2003).

Spatial distribution of some water quality parameter in L Bojongsari showed a different pattern between sampling site. The highest value of SS and turbidity were observed in pelagic station especially in deeper column (Figure 1). It may be because of the suspended material tend to sink into the deepest column. The highest value of DO concentration was observed in littoral I station. Littoral I station is located near the inlet so the highest value of DO could come form the photosynthesis activity of macrophyte that was abundance around this station. The value of pH also indicates same phenomenon that the highest value was observed in pelagic station especially in the surface layer. It may be related with the DO concentration and photosynthesis of algae.

The concentration of nitrogen compound in L.Bojongsari showed a different value during observation. In October after restoration part of water body of this lake, the nitrogen compound concentration was higher compared to the concentration of

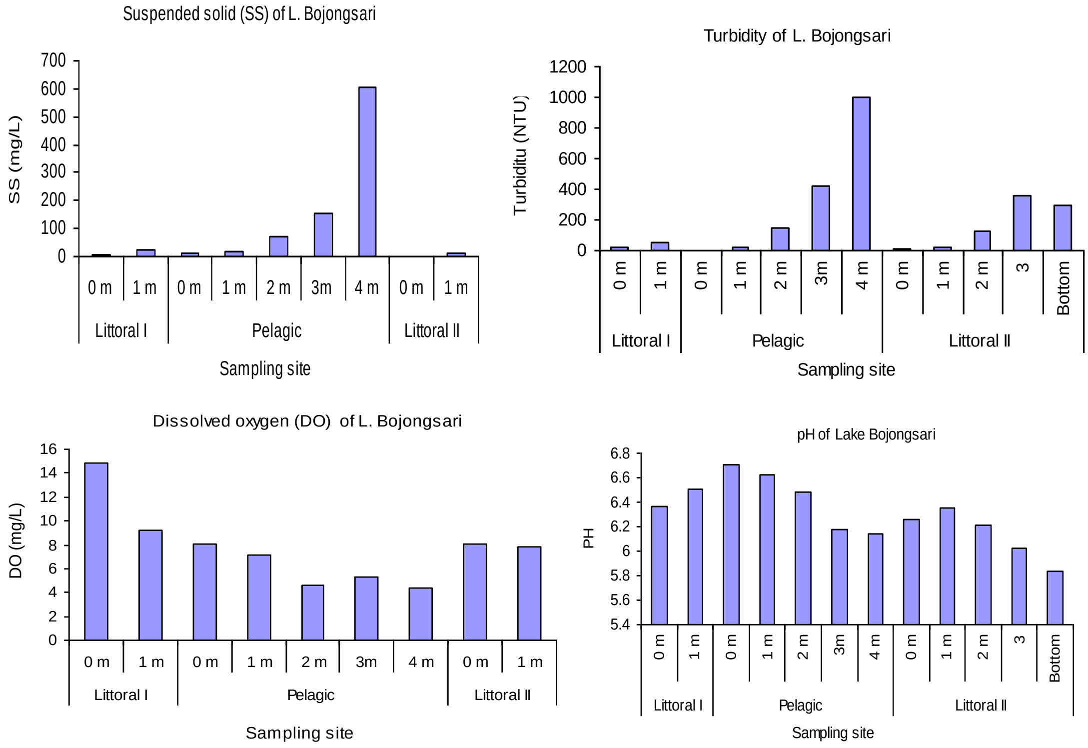

Figure 1. Spatial distribution of Suspended solid, Turbidity, DO and pH in Lake Bojongsari.

Nitrogen compound observed in August (Figure.2). The higher value of nitrogen compound in October may because of higher input of this compound come from run off. October is the beginning of rainy season and nitrogen compound from surrounding area enter into the lake through the inlet. On the other hand after restoration the macrophyte *Eichornia crassipes* has been taken out from around the inlet that may trapped the nitrogen compound from run off. In contrast to phosphorous compound that showed lower concentration in October compared to the value in August (Figure 2). The lower of phosphorous compound may be used by phytoplankton that indicated by the higher of chlorophyll-a concentration in this period (Figure 2).

The seasonal change of the water quality parameter was also occurred in L. Cibuntu (Figure 3). The concentration of suspended solid, total organic matter, ammonia and orthophosphate were higher in rainy season or in October and November. The higher of suspended solid, material organic and nutrient in rainy season may cause the small lake is more became shallow and eutrophic. As reported by Wetzel (2001) that shallow lakes tend to become an area for accumulation of material organic, nutrient and other materials from terrestrial surrounding the lake that enter through the inlet. The input of nutrient into shallow lake is higher compared to deep lake (Wetzel, 2001). Therefore to prevent small lake from sedimentation and eutrophication, it should be trapped the nutrient and other materials from run off before enter into the lake.

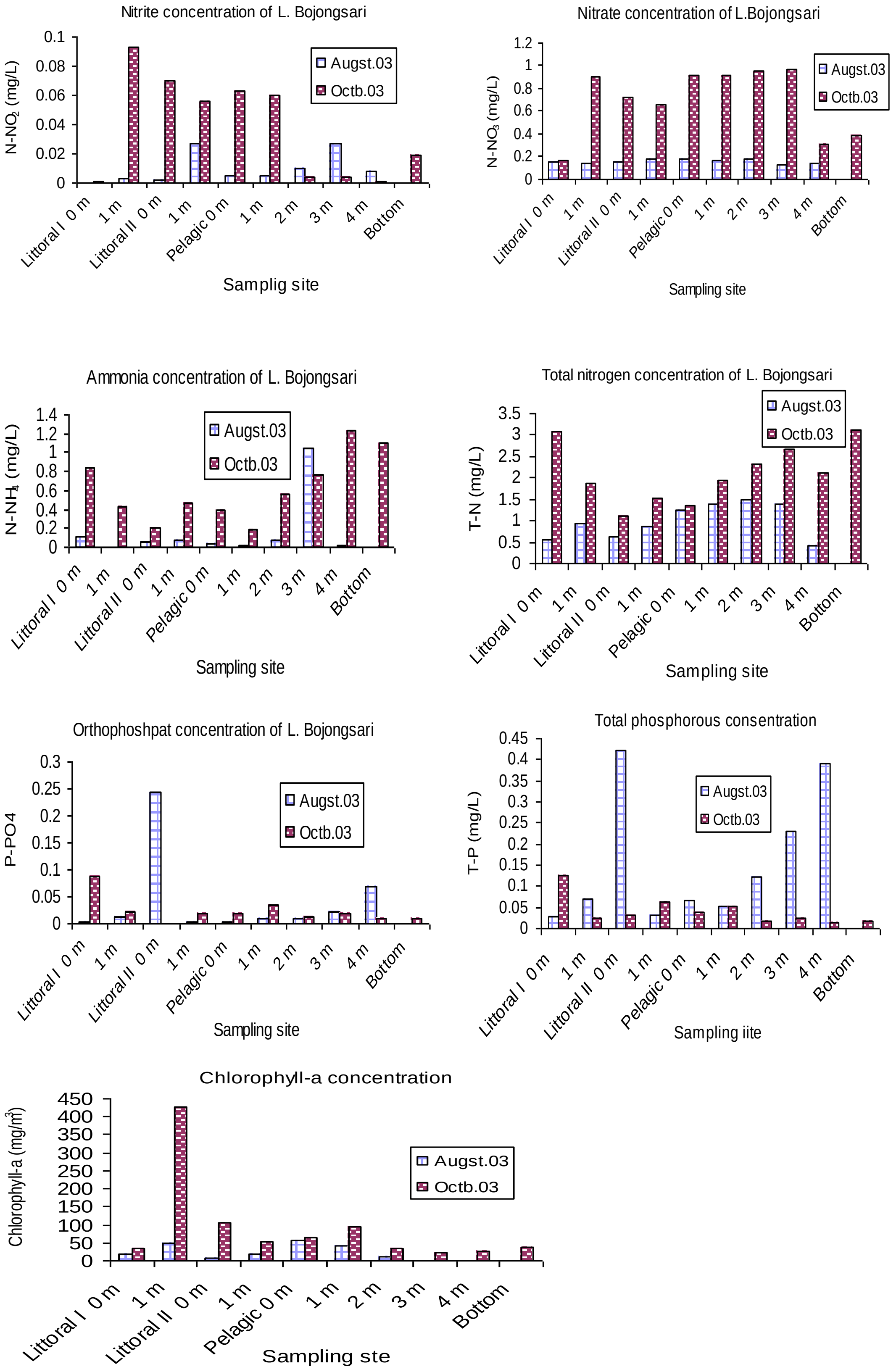

Figure 2. Distribution of nitrogen and phosphorous compound and chlorophyll –a concentration in Lake Bojongsari.

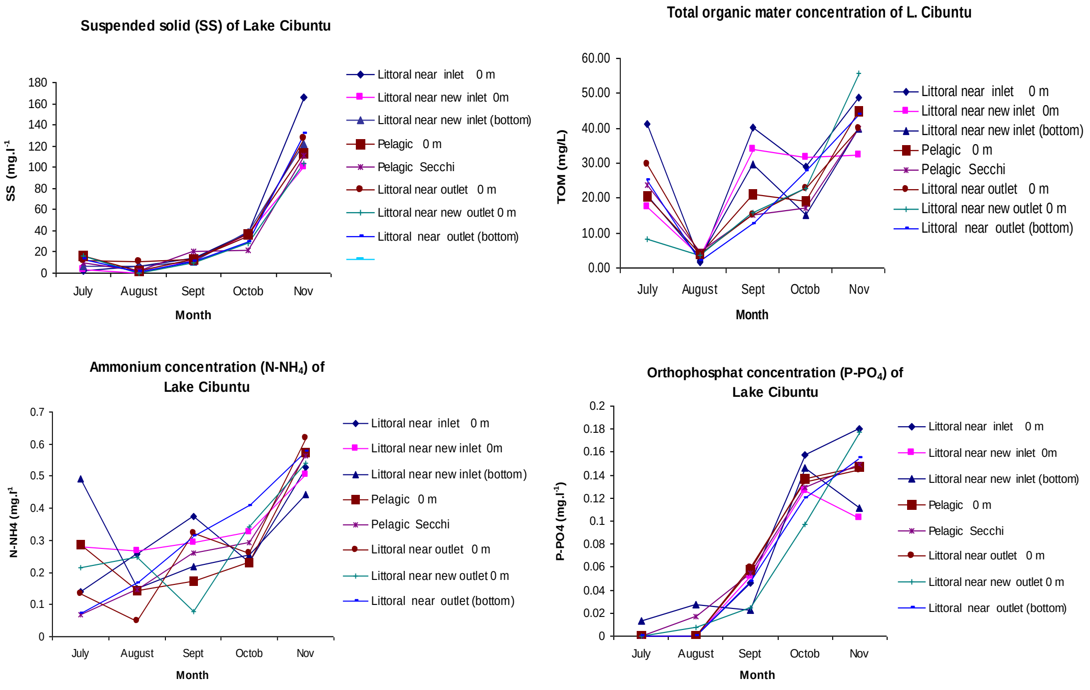

Figure 3. Seasonal change of some water quality parameter in Lake Cibuntu (Sulastri 2004b).

Phytoplankton Composition

The composition of phytoplankton in some small lakes in West Java is presented in table 3. Chlorophyta is a group with the higher genera occurred in these small lake. In general, there were some genera or species that was common found in these small lakes such as *Coelastrum*, *Closterium*, *Pediastrum*, *Kirchneriella* and *Staurastrum* for Chlorophyta group. While the common genera belong to Chrysophyta group are *Melosira* and *Diatoma*. *Microcystis aeruginosa* and *Oscillatoria* belong to group of Cyanophyta were also often found in the small lakes. Euglenophyta group of phytoplankton that were a few of genera occurred in these small lake. From this group *Euglena* and *Phacus* were common found in these small lakes.

The dominant of phytoplankton showed different genera in each lake. L. Bojongsari and Cibuntu were dominated by *Scenedesmus* and ***Spondylosium*** respectively. In L. Tegal Abidin, the composition of phytoplankton was dominated by Chrysophyta group with *Melosira* as the dominant genera. Phytoplankton composition in L. Citayam and L. Lido were dominated group of Euglenophyta and Phyrophyta with the dominant genera *Lepocyclis* and *Ceratium* repectively.

Tabel 3 Phytoplankton composition of some small lakes in West Java.

Taxonomic group			**Name of Lake**			
	Bojongsari	**Cibuntu**	**Tegal Abidin**	**Cikaret**	**Citayam**	**Lido**
Chrysophyta						
Asterionella			*			
Coconeis			*			
Coscinodiscus						*
Cyclotella	*					*
Cymbella	*	*		*		
Mellosira		***	*	*		*
Navicula	*	*	*			*
Nitzschia	*		****	*		*
Diatoma	*	*		*	*	*
Eunotia		*		*	*	
Epithemia				*		
Fragillaria	*					*
Frustulia					*	
Gomphonema				*		
Gyrosigma			*			
Pinnularia		*		*	*	*
Pleurosigma		*				
Synedra	*	*		*	*	
Synedra ulna	*					
Surirella				*	*	*
Tabellaria			*	*		
Chlorophyta						
Ankistrodesmus	*					
Aktinastrum	*		*	*		
Asterococcus						*
Botryococcus						*
Centritractus		*				
Centritractus belanopterus	*					
Closteriopsis	*	*				
Coelastrum	***	*	*		*	*
Cosmarium	*	*	*			*
Crucigenia spp	***	*			*	
Crucigenia crucifera	*					
Chlorella	*	*	*			
Chrysocapsa	*					
Closterium	*	*	*	*	*	*
Dicyospaerium	*	*			*	
Dimorphococcus		*				
Euastrum			*			
Eundorina						*
Franceia						*
Gonatozygon				*		*
Hydrodiction			*			
Kirchneriella	*	*	*			*
Kirchneriella lunaris	*					
Lagehermia	*					
Malomonas		*				
Meugotia			*		*	
Micrasterias				*		*
Netrium					*	
Oedogoium				*		

Oocystis	*	*	*			
Ophycitium		*				
Pediastrum		*	*	*	*	*
Quadrigula	*	*				
Rhizoclonium		*				
Selenastrum			*		*	
Scenedesmus	****	*	*	*	*	
Scenedesmus truncata	*	*				
Sphaerocystis	*				*	*
Spondylosium	*	****				
Spyrogira				*	*	*
Staurastrum	*	*	*	*	*	
Tetrapedia	*		*			
Tetraedron	*	*		*		
Tetraspora				*		
Treubaria			*			
Ulothrix			*		*	*
Volvox						*
Zygnema			*			*
Cyanophyta						
Anabaena		*	*	*		
Aphanocapsa	*	*	*	*		
Chroococcus		*	*		*	
Coelospaerium	**	*				
Gomphosphaeria	**	*				
Lyngbya				*		
Microcystis aeruginosa	**	*	*	*	*	
Merismopedia	*	*	*			
Nostoc	*	*	*			
Oscillatoria	*	*	***	*	*	*
Phormidium	*		*	*		
Sphaerocystis	*					
Phyrrophyta	*					
Ceratium						****
Peridinium	*		*			****
Euglenophyta	*					
Astasia						*
Euglena	*	*	*	*	*	*
Lepocynclis					****	
Phacus	**	*	*		*	*
Trachelomonas	*	*	*		*	

Source: 1: Sulastri (2004 b) ; 2: Kusnanto (2003) ; 3: Nurcahyo (1988) ; 4. Mayani (2003) ; 4 Maha (1995) & Santana (1991) Cited by (Wardianto et al, 2003).

Remark: **** = dominant; ***= abundance; ** = Frequently found; * = rare.

The difference of dominant species or genera could be related with the characteristic of water quality in each small lake. As reported by Wetzel (2001) that there was characteristic of common phytoplankton relation to Lake fertility such as for eutrophic water with the characteristic of water are alkaline and nutrient enrichment, the dominant phytoplankton diatom group especially *Melosira granulata*, *Synedra*, *Fragillaria, Stpanodiscus*, *Asteronella*. This condition seems to be observed in L. Tegal Abidin that the characteristic of water is more alkaline and high nutrient concentration such as nitrogen compound (Table 2). Furthermore, it was also reported that for the polluted water the common algae dominant was group of Euglenophyta such as found in L. Citayam.

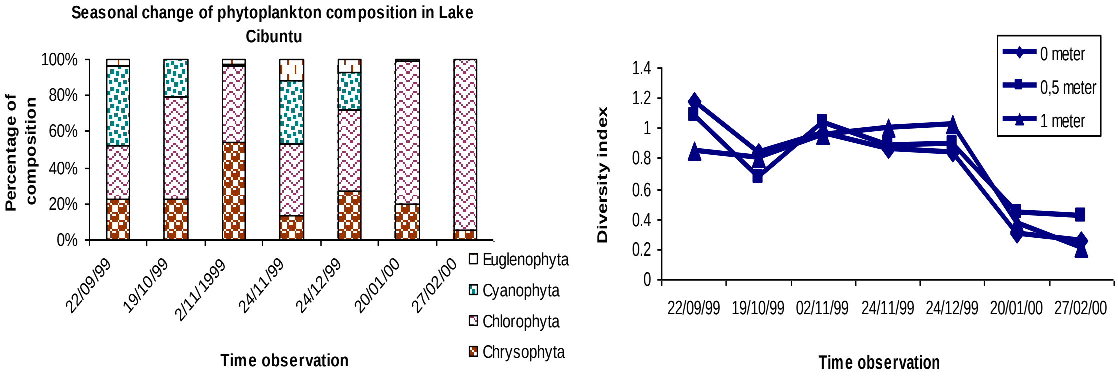

Figure 4. Seasonal composition and index diversity of phytoplankton in Lake Cibuntu. (Sulastri, 2004a)

Seasonally the composition of phytoplankton was change in small lake such as in Lake Cibuntu (Figure 4). In this lake Cyanophyta was dominant in dry season or in September while Chlorophyta was dominant in rainy season (January and February). The changing of phytoplankton composition may be also related to the seasonal change of the water quality parameters that give an impact on nutrient balance change. The seasonal change of phytoplankton composition also indicated the change of diversity index of phytoplankton (Figure 4) in this lake. The change of nutrient balance may cause a certain species abundant and dominant that influences the low of diversity index.

Seasonally the abundance of phytoplankton was also change in small lake such as in Lake Cibuntu (Figure 5). The high input of nutrient in rainy season may support the growth and abundance of phytoplankton in this season. The spatial distribution of phytoplankton in L. Bojongsari showed that that high abundance was observed in littoral station (Figure 6). It may be related with the nutrient concentration that was higher in the littoral area. The highest abundance of phytoplankton was observed in Littoral II or station near outlet. In this station because of water flows all material abundance in this station.

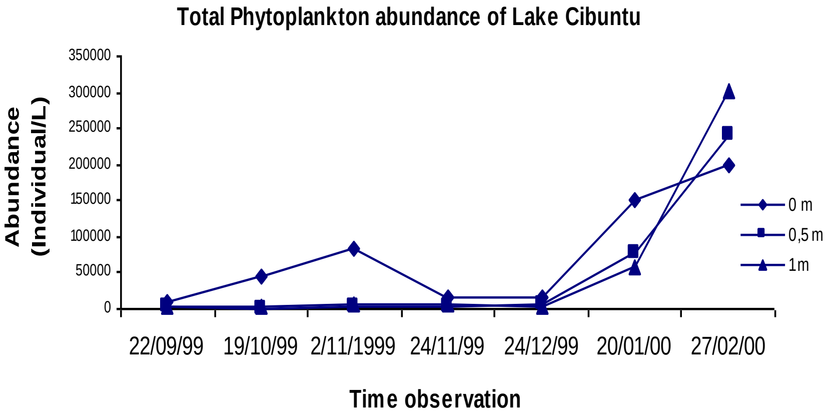

Figure 5. Phytoplankton abundance in Lake Cibuntu (Sulastri, 2004a)

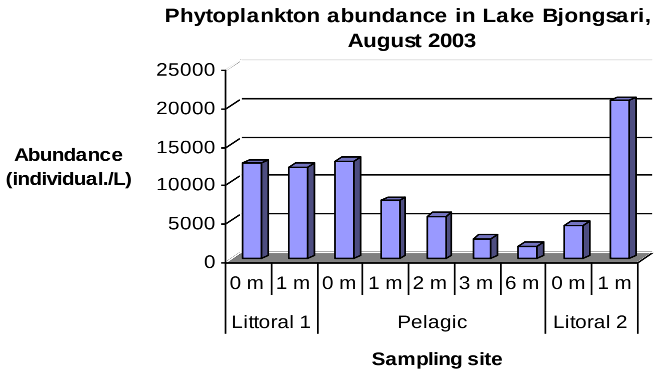

Figure 6. Spatial distribution of phytoplankton abundance in Lake Bojongsari.

Conclusion.

In general the water quality condition of some small lake in West Java showed a high nutrient concentration. Each Lake has a different water quality characteristic. Seasonally the water quality of small lake was change and indicated the high input of suspended and organic material and nutrient in rainy season such as in L. Cibuntu and L Bojongsari. There were some genera or species of phytoplankton common occurred in small lake. Each lake has a different dominant genera or species that may be relation to the condition of the lake. There were seasonal changes the composition, index diversity and abundance of phytoplankton in small lake such as L. Cibuntu. Spatially the abundance of phytoplankton showed a different distribution such as in L. Bojongsari.

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Preliminary study of "Interrhizon" in several oxbow lakes in the peat swamp area of Central Kalimantan, Indonesia

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Introduction

It has been widely recognized that aquatic macrophytes serve important habitats for aquatic animals including vertebrates and invertebrates. The interrhizon is defined as "the biotic community consisting mainly of vagile invertebrates that conceals itself in the roots and rhizoids of the floating macrophytes that cover vast area of the water surface", by Heckman (1994). He recognized it as one of the most important biotic communities in tropical water bodies, especially in tropical wet-and-dry climatic zone. Three representative plants providing habitats for interrhizon were reported as *Salvinia*, *Pistia*, *Eichhornia* stands from the investigation in a Brazilian huge wetland, Pantanal (Heckman, 1998). Heckman (1997) also listed up many species of plants and animals selected for their extensive distribution in the tropical wet-and-dry climatic zone.

There are many oxbow lakes distributed in the peat swamp area of Central Kalimantan. They have unique limnological features of high concentration of humic materials which make the water color brownish, low pH, low transparency and subsequent low dissolved oxygen concentration (Iwakuma *et al.*, 2000). Water levels largely change seasonally in these lakes, and floating vegetation develops in their littoral zones. Therefore, some interrhizon communities can develop in the area, and they might be unique for the region. However, such a community has poorly been studied in tropical Asian freshwaters.

In the present study, therefore, a preliminary study was carried out on the physico-chemical parameters and structure of invertebrate communities in the root systems of several floating macrophytes in oxbow lakes in Kahayan River system, Central Kalimantan.

Study site and Methods

Field researches were carried out in four oxbow lakes in the Kahayan River system (Fig. 1), Central Kalimantan from 21 to 26 March, 2004; L. Tundai (02°12'30"S, 114°00'37"E), L. Sabuah (02°03'19"S, 113°56'37"E), L. Batu (02°00'57"S, 113°56'55"E) and L. Bunter (02°01'46"S, 113°55'36"E). The lake waters have been characterized in having brownish colored, with a large amount of humic material, low pH and low oxygen concentrations (e.g. Iwakuma *et al.,* 2000). Composition and community dynamic have been studied in some of these lakes for phytoplankton (Kusakabe *et al*., 2000; Ardianor and Veronica, 2003), macrophytes (Kunii, 2000), zooplankton (Gumiri *et al*., 2000; Gumiri and Iwakuma, 2000, 2002; Yantrinata *et al*., 2003), benthos (Iwakuma *et al*., 2000; Iwakuma and Gumiri, 2002; Wulandari *et al*., 2003), falling insects (Yulintine, 2001) and fishes (Komatsu *et al*., 2000). Epiphytic invertebrate assemblages associated with aquatic macrophytes in this area were once studied, and some faunal differences from those in West Java were pointed out by Ohtaka *et al*. (2003).

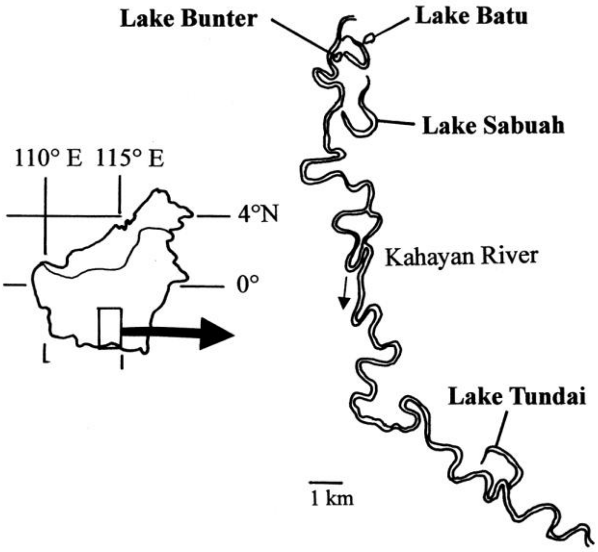

Figure 1. Kahayan River in Central Kalimantan, showing four oxbow lakes studied.

Two kinds of floating macrophytes, *Eichhornia crassipes* and Graminae spp. were studied for interrhizon communities in L. Tundai. In addition, an emergent plant, *Polygonum* sp., which was excluded from the point of Heckman's definition, was also investigated for interrhizon because of predominance in L. Tundai. Furthermore, interrhizon in a *Salvinia* sp. stand was studied in the canal of the campus in Palangka Raya University in 21 March, 2004.

In each macrophyte stand, three selected areas of 30 cm by 30 cm, or 50 cm by 50 cm were cut off, and aquatic animals among the root systems were collected by using a dipnet with a mesh size of 0.25 mm. Animal specimens collected were not fixed and they were identified, counted, and weighed in laboratory within two days after collected. Meiofauna, for example protozoans, rofiters, cladocerans, copepods and naidine oligochaetes, were not examined in the present study. Macrophyte body studied was divided into submerged part including root system and emergent part, then their standing crops (fresh weight) were weighed separately. In each study site, water temperature, transparency, pH, turbidity, conductivity and dissolved oxygen concentration were measured both in the macrophyte stands and in open waters near by the vegetation. To compare the composition with interrhizon invertebrates, bottom animals were collected quantitatively with an Ekman-Birge bottom sampler at beneath the macrophyte stands studied and at open waters near by the macrophyte stands. Benthic animals collected were identified and counted in the laboratory.

Comparative measurements of environmental factors for a *Eichhornia crassipes* stand and open water were conducted in L. Sabuah. In Lake Bunter and L. Batu, only environmental factors were measured in central part of lakes, because of little cover of macrophytes.

Results

Standing crop of macrophyte stands

Standing crop of five vegetational stands which interrhizon communities were sampled, is shown in Table 1. *Eichhornia crassipes* stand in L. Tundai had the highest standing crop both in submerged and emergent parts. This means that the rhizoids of *Eichhornia crassipes* provides vast sphere for organisms constituting interrhizon community compared with other plant stands. The E/S ratio (weight of emergent part/weight of submerged part) was high in the *Salvinia* stand, meaning the abundance of photosynthetic organ compared to root system.

Table 1. Standing crops (wet weight) of macropyte stands selected for interrhizon study.
E/S: mean weight of emergent part/mean weight of submerged part.

Species	Lake	Emergent part (kg/m^2)	Submerged part (kg/m^2)	E/S
Polygonum sp.	L. Tundai	0.13 ± 0.04	1.17 ± 0.30	0.11
Graminae spp.$^{1)}$	L. Tundai	0.87 ± 0.53	9.69 ± 5.93	0.09
Eichhornia crassipes	L. Tundai	2.54 ± 0.00	13.62 ± 1.73	0.19
Salvinia sp.	Canal of UNPAR$^{2)}$	1.22 ± 0.43	4.69 ± 1.18	0.26

1) This stand contains a small quantity of *Salvinia* sp. and dead leaves of Graminae sp.

2) UNPAR: University of Palangka Raya

Comparison of some environmental factors between aquatic vegetational stand and open water

Some environmental factors measured in macrophyte stands and open water are shown in Table 2-6. Macrophyte stands had no effects on conductivity and water temperature. It is well known that waters of this area show acidic values of pH (e.g. Iwakuma *et al*., 2000). Values of pH in open waters ranged from 3.86 to 4.88. Slightly higher values of pH were observed in the stands of *Polygonum* sp., Graminae spp. and *Eichhornia* sp. comparing with near open water. Though very low concentrations of dissolved oxygen were determined in lake water, higher contents of oxygen were detected in the water in macrophyte stands. Turbidity of water in the stands of *Polygonum* sp., and Graminae spp. were slightly higher than in open water. Concentration of chlorophyll-*a* differs greatly in water of macrophyte stands. High concentrations of chlorophyll-*a* by phytoplankton were observed in the 4 stands except *Eichhornia* sp. from L. Sabuah that was not determined. In water of the stands of Graminae spp. and *Salvinia* sp., chlorophyll-*a* contained about 20-fold of concentration compared with open water. The pH of surface open water of L. Bunter indicated the highest value of 5.14 in four lakes (Table 7).

Table 2. Some environmental factors measured in Polygonum sp. stand and open water of Lake Tundai.

	Polygonum sp.		Open water	
Parameter	Surface	Bottom（1.1m)	Surface	Bottom (6.0m)
Transparency (cm)	39	-	54	-
pH	4.30	4.17	3.86	4.34
Temperature (°C)	30.4	27.4	31.0	28.8
Conductivity (mS/m)	5.3	1.7	7.0	1.7
Turbidity (NTU)	9.50	23.2	5.4	18.8
DO (mg/L)	2.17	0.67	2.06	1.05
Chl-*a* (μg/L)	2.50	-	0.9	

-：not measured

Table 3. Some environmental factors measured in Graminae spp. stand and open water of Lake Tundai.

	Graminae spp.		Open water	
Parameter	Surface	Bottom（5.2m)	Surface	Bottom (5.5m)
Transparency (cm)	-	-	38	-
pH	4.38	4.55	4.19	4.28
Temperature (°C)	30.2	28.1	30.0	28.1
Conductivity (mS/m)	3.2	1.7	3.6	1.7
Turbidity (NTU)	44.0	22.5	12.0	20.4
DO (mg/L)	1.89	0.93	2.02	0.80
Chl-*a* (μg/L)	16.9	-	1.0	-

-：not measured

Table 4. Some environmental factors measured in *Eichhornia crassipes* stand and open water of Lake Tundai.

	Eichhornia crassipes		Open water	
Parameter	Surface	Bottom（2.6 m)	Surface	Bottom(3.3 m)
Transparency (cm)	-	-	41	-
pH	4.24	4.31	4.2	4.41
Temperature (°C)	28.9	28.3	29.1	28.2
Conductivity (mS/m)	2.5	1.8	2.7	1.8
Turbidity (NTU)	13.3	20.3	14.1	21.5
DO (mg/L)	2.29	0.82	2.01	0.78
Chl-*a* (μg/L)	15.2	-	0.3	-

-：not measured

Table 5. Some environmental factors measured in *Eichhornia crassipes* stand and open water of Lake Sabuah.

	Eichhornia crassipes		Open water	
Parameter	Surface	Bottom（3.8m)	Surface	Bottom (7.5m)
Transparency (cm)	-	-	48	-
PH	5.07	4.59	4.88	4.38
Temperature (°C)	30.5	27.0	32.7	26.9
Conductivity (mS/m)	1.9	2	2	1.8
Turbidity (NTU)	37.4	34.8	20.9	33
DO (mg/L)	2.3	0.54	1.88	1.03

-：not measured

Table 6. Some environmental factors measured in Salvinia sp. stand and open water of canal at University of Palangka Raya.

	Surface water	
Parameter	*Salvinia* sp.	Open water
pH	3.88	3.94
Temperature (°C)	29.9	30.0
Conductivity (mS/m)	5.1	5.1
Turbidity (NTU)	5.3	5.5
DO (mg/L)	1.0	1.1
Chl-*a* (μg/L)	19.6	1.0

Table 7. Some environmental factors measured in open water of L. Bunter and L. Batu.

	L. Bunter		L.Batu	
Parameter	Surface	Bottom（3.2m)	Surface	Bottom（7.1m)
Transparancy (cm)	-	-	38	-
pH	5.14	4.98	4.45	4.05
Temperature (°C)	30.9	29.3	32.8	26.3
Conductivity (mS/m)	2.6	2.6	1.8	2
Turbidity (NTU)	140	134	13	17.8
DO (mg/L)	3.48	3.07	2.71	0.72

Composition and abundance of interrhizon invertebrates

Thirty-one taxa belonging to 3 groups of invertebrates, Arachnida, Insecta and Isopoda, were found in the interrhizon communities from root systems of three kinds of macrophytes in Lake Tundai (Table 8). Among them, insects were the most abundant in every macrophyte stand. The insects consisted of 29 taxa in 7 orders, of which odonates, coleopterans and chironomids were common to occur in three vegetational stands examined. Fewer number of interrhizon taxa were found in *Polygonum* stand (14) than in Graminae and *Eichhornia* stands (20). In addition to invertebrates, many juvenile fish were observed in every vegetational stand studied.

Highest density and/or biomass of many interrhizon invertebrates were found in Graminae stand, in that acarines, coenagrionids (Odonata), belostomatids and naucorids

(Hemiptera), lepidopterans, helodids (Coleoptera), chironomines and tanypodines (Chironomidae), and culicids (Diptera) were distinctly abundant there. Mean biomass of interrhizon invertebrates in Graminae stand was 55 times and 5 times higher than those in *Polygonum* and *Eichhornia* stands, respectively. On the other hand, *Eichhornia* stand was characterized by having abundant polycentropodid trichopterans which was not found from

Table 8. Mean density and (biomass) of interrhizon invertebrates in three macrophyte stands in L. Tundai. Numeral indicates number or (g) per square meter of submerged part of respective macrophyte.

Taxon		*Polygonum* stand	Graminae stand	*Eichhornia* stand
Acarina	Acari gen. spp.	– (+)	22.2 (+)	1.3 (0.003)
Insecta	Ephemeroptera			
	Cloeon sp.	– (0.031)		6.0 (0.009)
	Baetidae gen. sp.			4.0 (0.007)
	Caenidae gen. sp.			4.0 (0.001)
	Odonata			
	Coenagrionidae gen. sp.	7.4 (0.023)	44.4 (0.211)	2.0 (0.092)
	Libellulidae gen. sp.		22.2 (1.040)	22.2 (1.089)
	Hemiptera			
	Belostomatidae gen. sp.		3.7 (2.741)	
	Naucoridae gen. sp.		7.4 (0.080)	4.0 (0.048)
	Micronecta sp. (larva and imago)	– (0.033)	3.7 (0.001)	
	Pleidae gen sp.	– (0.003)	3.7 (0.003)	
	Hydrometridae gen. sp.			1.3 (+)
	Trichoptera			
	Hydroptilidae gen. sp.		3.7 (+)	
	Polycentropodidae gen. sp.			96.0 (0.280)
	Lepidoptera			
	Lepidoptera non det. (larva)		7.4 (0.093)	1.3 (+)
	Coleoptera			
	Hydrophilidae gen. sp.	– (0.007)		
	Ditiscidae gen. sp. (imago)	– (0.002)		
	Ditiscidae gen. sp. (larva)	– (+)	3.7 (0.048)	
	Helodidae gen. sp. (imago)		– (+)	– (0.003)
	Helodidae gen. sp. (larvae)	– (0.005)	114.8 (0.159)	4.0 (0.034)
	Coleoptera non det. (imago)	– (0.001)	33.3 (0.075)	8.0 (0.007)
	Coleoptera non det. (larva)			4.0 (0.011)
	Coleoptera non det. (pupa)		3.7 (0.069)	
	Coleoptera non det. (imago, terrestrial?)		3.7 (0.004)	
	Diptera			
	Tipulidae gen. sp.			– (0.001)
	Chironominae gen. spp.	– (0.050)	459.3 (3.091)	– (0.008)
	Orthocladiinae gen.spp.	– (+)	– (+)	– (+)
	Tanypodiinae gen. sp.	– (0.003)	129.6 (0.045)	(0.173)
	Ceratopogonidae gen. sp.	– (0.001)		– (+)
	Culicidae gen. sp.		14.8 (0.009)	1.3 (+)
	Athericidae gen. sp.		3.7 (0.995)	
Isopoda	Isopoda non det.		3.7 (0.012)	
	Number of taxa occurred	14	20	20
	Total (g fresh wt/m^2)	– (0.158)	– (8.672)	– (1.759)
	Total (g fresh wt/1kg submerged part of plant)	– (0.135)	– (0.895)	– (0.129)

-, not counted; +, less than 0.001 g.

other two macrophyte stands. Ephemeropterans were more diverse and abundant in *Eichhornia* stand than in other two macrophyte stands.

Nematodes, oligochaetes, chironomids, coleopterans and trichopterans were found from bottoms in the study sites (Table 9). Among them, nematodes and chironomids were common to occur at both bottoms beneath vegetation and open waters in all macrophyte stands studied (Table 9). Abundant nematodes were found in the bottoms beneath *Eichhornia* stand. Chironomids were the most abundant macrozoobenthos, the densities were always higher in open water bottoms than in macrophyte bottoms at every vegetational stand.

Table 9. Mean density and (biomass) of benthic invertebrates beneath macrophyte stand and at open water off the macrophyte stand in in Lake Tundai.
Numeral indicates number or (g) per square meter of bottom.

Taxon	*Polygonum* stand		Graminae stand		*Eichhornia* stand	
	macrophyte	open water	macrophyte	open water	macrophyte	open water
Nematoda	15 (+)	15 (+)	59 (+)	45 (+)	622 (+)	30 (+)
Oligochaeta	45 (0.001)			44 (+)		147 (+)
Chironomidae	134 (0.002)	1438 (0.083)	193 (0.009)	341 (0.017)	194 (0.006)	400 (0.008)
Coleoptera	15 (+)					
Trichoptera		15 (+)				

+, less than 0.001 g

Eleven invertebrate taxa were found among root system of *Salvinia* sp. in the canal of University of Palangka Raya (Table 10), of which insects were the most common as in all macrophyte stands of L. Tundai. The *Salvinia* sp. stand harbored *Centroptilum* sp. (Ephemeroptera), Leptoceridae sp. (Trichoptera) and Decapoda, all of which were not recorded from L. Tundai.

Table 10. A list of interrhizon animals in the Salvinia sp. stand in UNPAR canal.

Class	Order	Species
Acarina		Acari gen. sp.
Insecta	Ephemeroptera	*Centroptilum* sp.
		Caenidae gen. sp.
	Odonata	Coenagrionidae gen. sp.
		Anisoptera gen. sp.
	Hemiptera	*Micronecta* sp.
		Hemiptera non det.
	Trichoptera	Leptoceridae gen. sp.
	Coleoptera	Coleoptera non det.
	Diptera	Ceratopogonidae gen. sp.
Crustacea	Decapoda	Natantia non det.
Pisces		Pisces non det.

Discussion

The habitat of interrhizon has generally possibility to provide food, oxygen, and concealment for many species inhabiting there (Heckman, 1996). As for food, higher concentrations of chlorophyll-*a* in water of plant stands (Tables 2, 3, 4 and 6) seem to show that planktonic and sessile algae grow intensively in the rhizoid sphere. Heckman (1998) listed up above 130 typical species of algae from interrhizon of Pantanal of Pocone. A lot of detritus for food sources will be produced from submerged parts of macrophytes. The food chain around rhizoid system starting from primary production will increase diversity of interrhizon community. In the present study in L. Tundai, chlorophyll-*a* concentrations in surface waters were much higher in Graminae and *Eichhornia* stands than in open waters near vegetations. It is expected, therefore, that these two stands harbor more diverse and abundant interrhizon animals. Graminae stand actually had abundant invertebrates, however, it is not true in *Eichhornia* stand.

Lake water had inclination to show shortage of oxygen (Tables 2-6), which is essential for all aquatic organisms, especially invertebrates and fishes. The rhizoid system of macrophytes has high possibility to supply oxygen to these organisms, because the roots of some macrophytes transport atmospheric oxygen through the aerenchyme tissue. Oxygen passes through plant tissues to supply cells and some diffuse into the surrounding water. Jedick *et al*. (1989) experimentally presented the evidences that *Eichhornia crassipes* and *Pistia stratiotes* sampled from Amazon supplied O_2 to water beneath their stands. Slightly higher concentrations of oxygen in water of *Polygonum* sp. and *Eichhornia crassipes* stands were determined in Lake Tundai (Tables 2 and 4), however, interrhizon invertebrates in these stands were less abundant than in Graminae stand where oxygen were rather slightly lower than in open water. These suggest that some factors other than algal abundance or oxygen concentration can affect diversity and abundance of interrhizon community.

Complex rhizoid systems of macrophytes must serve as a shelter from many species of predators. Even if small piranhas, *Serrasalmus spilopleura*, used the roots of *Eichhornia crassipes*, as shelter place as well as a rich foraging place (Sazima and Zamprogno, 1985). Many interrhizon organisms must use rhizoids as concealment, though it is difficult to distinguish their causes of staying in rhizosphere from a comfortable place for oxygen condition, a rich food or a shelter. Comparing the composition with zoobenthos, the invertebrate assemblages found in root systems of aquatic macrophytes in Lake Tundai were characterized by having diverse insects. However, in the present study it is still unclear that how many species are represented in interrhizon, and how respective species uses rhizoid system. As well as taxonomical details, careful studies are needed for ecological aspects of interrhizon to evaluate the root system for aquatic organisms precisely.

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Description of a freshwater oligochaete worm *Slavina appendiculata* from Saguling Reservoir

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Introduction

Saguling Reservoir is one of the cascade reservoirs located in West Java. The reservoir has some functions such as hydroelectric power supply for Java and Bali area, and fisheries using floating net pens. Recently, the reservoir has been suffering from some problems such as: sedimentation caused by erosion, degradation of water quality, and corrosion of turbine, etc. Degradation of water quality may cause decrease of abundance of benthic macroinvertebrates and alter community composition. Oligochaeta is one of the benthic macroinvertebrates that constitute important component of the food web in the reservoir ecosystem. Identification of freshwater Oligochaeta in Indonesia is still problematic and impeding bioassessment programs because of the small sizes of the organisms and the lack of taxonomist. Hence a training program for taxonomy of the fauna is especially necessary for Indonesian taxonomist to improve their ability to identify the fauna. Existence of JSPS Core University Program is beneficial for this purpose. One species from Saguling reservoir was described in the present report as *Slavina appendiculata* (d'Udekem, 1855). This species is living abundantly on the aquatic root of water hyacinth (*Eichhornia crassipes*) but is not yet well known to Indonesian researchers. If a short description of the species is available, it can improve knowledge on the diversity of oligochaetes in tropical waters and implement bioassessment programs.

Material and Methods

The specimens were collected using sieving (0.3mm mesh opening) from the root of water hyacinth (*Eichhornia crassipes*) and preserved in a 100-ml plastic bottle containig 5% formalin solution. In the laboratory of Department of Natural Science, Hirosaki Univesity, the sample was rinsed with tap water and was sorted under a stereoscopis microscope with magnification of 60×. Species determination was performed after slide mounting with CMCP-10 solution as mounting medium. The specimen was taken from the bottle with forceps and was placed on a microscope glass. CMCP-10 solution was added on the object and covered with a cover glass slip. The microscopic glass was heated on a hotplate at a temperature of 60°C for 1 day. The specimen was examined under a microscope at magnifications of 100-1000× and was identified using guidebooks by Brinkhurst and Jamieson (1971) and Kathmann and Brinkhurst (1999).

Results

Description of *Slavina appendiculata* worm was as follows: Body 3.4 mm long. Body wall papillate, adhering foreign material can be seen at magnification of 400×. Dorsal setal bundle beginning in VI, composed of smooth hairs and needles. Hair setae always one per bundle; those in VI 640 µm long, much longer than those in the following segments. Hair setae in the following segments 209 - 248µm long. Dorsal needles one per bundle, about 50 µm long, with tapering and distended distal end. Ventral setae in II –V 3 per bundle, 90 µm long, thinner and straighter than those in the following segments, with upper tooth much longer as thick as lower tooth. Ventral setae in the following segments 2-3 per bundles, 70 - 100 µm long, with upper tooth as long as and thinner than lower tooth.

From the above description, the worm still fulfills the criterion which is described by Brinkhurst and Jamieson (1971) and Kathmann and Brinkhurst (1999) such as: length 2-20mm, eyes present, dorsal setae bundles from VI, consisting of 1-2 stout hairs (in VI 1-3 per bundle, strongly elongate), and 1-2 straight needles with distal part effilated, and tip often slightly distended, ventral setae 2-5 per bundle, in II – V thinner, and in II slightly longer than the rest, all with proximal nodulus, an angular proximal bend, and upper tooth thinner and slightly longer than lower. Dorsal satae beginning in IV or VI, non serrated hairs and fine, bifid or simple needles, slightly curved distally. Elongate hair setae on VI, 1-2 or 3 hairs and needles. Body wall encrusted with foreign matter.

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Data report - chlorophyll concentration in lakes according to size fraction

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Method

Water samples were collected from Lake Batu, L. Hurung, L. Tehang, and L. Tundai, on August 2003. Location and characteristics of the lakes are described in other report of this volume (Bathymetric survey of oxbow lakes, Central Kalimantan; Ishikawa et al.) In Lake Tundai, water was collected in three points; near inlet (I), center (C), and near outlet (O). The sample was taken directly into pre-washed plastic bottle from surface of lake. In laboratory, the sample waters were fractionated through nylon mesh net (NY-41HC, 41μm; NY-20HC, 20μm; NY-10HC, 10μm). After fractionation, 50 mL of sample waters were filtered onto precombusted (450°C, 2h) glass-fiber filters (Whatman GF/F, 25mm in diameter). The samples on filters were extracted in 99% methanol, then Chlorophyll *a* and `Phaeopigment concentrations were determined by fluorometric method (Wetzel & Likens2000) using a spectrofluorometer (RF5300PC, Shimadzu, Japan)

Result & Discussion

Table 1 shows the results of measurement of Chlorophyll *a* and Phaeopigment concentrations. Using Chlorophyll *a* + Phaeopigment concentrations, we calculated contribution of each fraction to total concentration (Fig. 1), which indicates high contribution of small-cell phytoplankton to total chlorophyll amount.

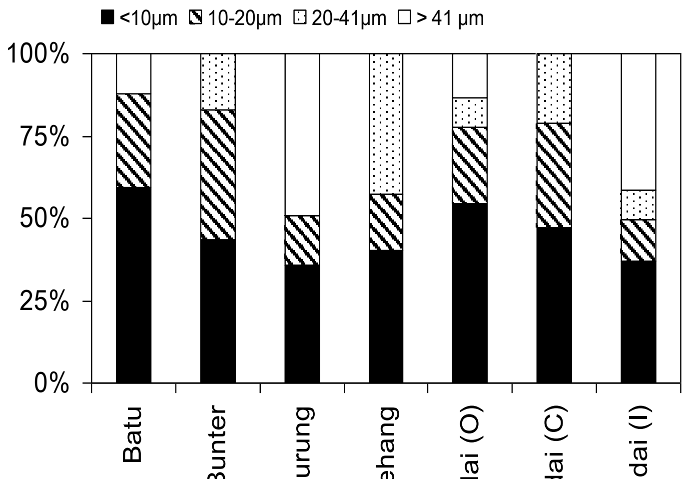

Figure 1 Relative amount of Chlorophyll *a* + Phaeopigment of each size fractions.

Table 1. Size- fractioned Chlorophyll *a* and Phaeopigment concentration of surface water of several lakes in Central Kalimantan.

Date Location		total	<41µm	<20 µm	<10 µm
23 Aug 2003	Chlorophyll *a* (µg/L)	11.3	9.4	10.2	6.6
Lake Batu	Phaeopigment (µg/L)	-0.2	0.2	0.6	0.7
	Chl.*a* +Phaeo. (µg/L)	11.1	9.6	10.7	7.2
23 Aug 2003	Chlorophyll *a* (µg/L)	12.7	12.7	8.8	4.5
Lake Bunter	Phaeopigment (µg/L)	0.6	0.7	2.3	1.3
	Chl.*a* +Phaeo. (µg/L)	13.3	13.4	11.2	5.8
23 Aug 2003	Chlorophyll *a* (µg/L)	36.4	17.7	16.0	4.8
Lake Hurung	Phaeopigment (µg/L)	-4.1	-1.2	0.4	6.9
	Chl.*a* +Phaeo. (µg/L)	32.3	16.5	16.4	11.6
23 Aug 2003	Chlorophyll *a* (µg/L)	7.1	9.8	5.2	2.7
Lake Tehang	Phaeopigment (µg/L)	2.0	2.2	1.6	2.1
	Chl.*a* +Phaeo. (µg/L)	9.1	11.9	6.8	4.8
2 Sep 2003	Chlorophyll *a* (µg/L)	5.4	4.2	3.3	2.0
Lake Tundai	Phaeopigment (µg/L)	1.5	1.7	2.0	1.7
(Near outlet)	Chl.*a* +Phaeo. (µg/L)	6.8	5.9	5.3	3.7
2 Sep 2003	Chlorophyll *a* (µg/L)	17.9	17.4	12.9	7.2
Lake Tundai	Phaeopigment (µg/L)	1.4	2.4	2.6	2.1
(Center)	Chl.*a* +Phaeo. (µg/L)	19.3	19.8	15.6	9.3
2 Sep 2003	Chlorophyll *a* (µg/L)	68.9	37.6	30.4	20.5
Lake Tundai	Phaeopigment (µg/L)	-6.1	-0.8	0.8	2.7
(Near outlet)	Chl.*a* +Phaeo. (µg/L)	62.8	36.8	31.2	23.2

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1. HABITAT CLASSIFICATION OF LAKE LOA KANG FLOODPLAIN SYSTEM

By

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ABSTRACT

*Mahakam River is one of the longest river in Indonesia (920 km). It is located in East Kalimantan Province and receives water from its 77,700 km^2 catchments area. Irrawady Dolphin (Orcaella brevirostris) is one of the mammals that live in freshwater ecosystem, Pesut is the local name of this dolphin. Habitat classification is important data for conservation and restoration of Pesut Habitat***.** *Based on Geological map, Lake Loa Kang floodplain located in Kutai Basin, the widest and deepest basin in Indonesia. The habitat classification of Lake Loa Kang floodplain system was done based on the analysis of geomorphological, hydrological processes and the sedimentation as the features of ecological landscape. Classification was also done using remote sensing technique. The results of image processing indicate that the water body area of Lake Loa Kang Fishery Reserve are 604686 m^2 and 410965 m^2 in rainy and dry season respectively. Geomorphological analysis by satellite image processing and ground check methods revealed that there are seven habitat types in Lake Loa Kang floodplain system that includes backswamp deposit lakes, connecting channels, ephemeral ponds, canal fills, spring, junction of main and tributary rivers and natural levees. In the dry season, the highest sedimentation velocity was observed in Lake Balikpapan but in the wet season it was observed in Lake Loa Kang.*

Key words: *Mahakam, habitat classification, Loa Kang, floodplain, geomorphology.*

INTRODUCTION

Freshwater Dolphin (*Orcaella brevirostris*) is one of the mammals that live in freshwater ecosystem. *Pesut* is the local name of Irrawady Dolphin who lives in River Mahakam. Area of distribution of Pesut Mahakam is range from Mahakam River around Muara Kaman to Long Iram, which stretches ± 250 km (Krebs, 1999). Habitat classification is important data for conservation and restoration of Pesut Habitat. There are many aspects of habitat requirement of Pesut, primarily the depth aspect, which indicated that the Pesut required the water column deeper than 5 meters in floodplains lakes or river segment. Feeding habitat of freshwater dolphin must provide food organism, especially the *whitefish* as the food for Pesut Mahakam (Riyanto, 1995). Hartoto (1997) reported that Lake Loa Kang Fishery Reserve; one of the River Mahakam floodplain system; function as the feeding habitat for Pesut.

Topography and geomorphology of East Kalimantan is mainly built of mountainous part in western portion, which rises between 450 – 1500 m above sea level, hilly area in the central part and flat area that can only be found along river basin and along the coast. Generally the drainage has a dentritic pattern that is provided by several tributaries (Husen& Suradi, 1973). The topography of the study area, according to the topographic map (1:50.000), is relatively undulating; the average slope is 8-30 percent

Table 1.1. Classification of lakes in the middle region of R. Mahakam watershed.

Classification	Lakes	Area range (Ha)
Very big lakes	*Jempang*	10,875 – 15,000
	Semayang	8,937 – 13,000
	Melintang	7,062 – 11,000
Big lakes	*Siran*	1,678
	Kedang	372
	Murung	744 – 812
	Wis	750 – 2,098
	Perian	186
	Merayag	
Medium lakes	*Belibis*	97
	Tempatung	47 – 1,300
	Loa Kang	48.4 – 750
	Berambai	61
	Polong	19
	Klanyangan	18.5
	Katung	17.2
	Nanga	88
	Batu Bumbun	21.4 – 450
	Balikpapan	25.6
	Tawar	10.3
	Tanah liat	25

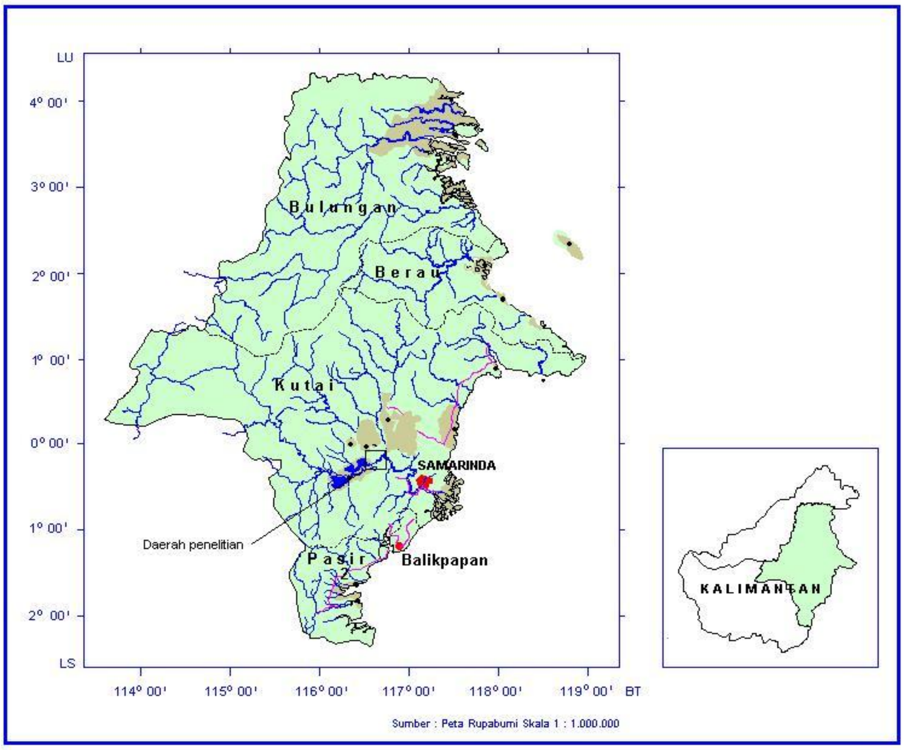
The remaining lakes ar less than 10 hectares in area.

and the elevation is between 50 and 150 meters asl.

River Mahakam is one of the longest rivers in Indonesia (920 km). It is located in East Kalimantan Province and receives water from its 77,700 km^2 catchments area. The catchments area consists of seven sub-catchments (Fakhruddin, 1998), that are Mahakam Ulu (22.539 km^2), Kedang Pahu (7.520 km^2), Seberang Muara Pahu (4.980 km^2), Melintang-Semayang Lakes (2.430 km^2), Belayan (10.350 km^2) and Mahakam Hilir (6.910 km^2).

Surrounding the Middle Mahakam region, there are at least 32 of total 76 freshwater lakes (Bappeda I Kaltim, 1992) that can be detected from the map of scale 1: 50,000. Their sizes of the lakes range from the smallest that was around 1.2 ha up to the biggest (15,000 ha), such as Lake Jempang. Based on their surface area, these Mahakam lakes can be categorized as large lakes, big lakes, medium lakes, small lakes and very small lakes. Detailed classification of the lakes in this area is presented in Table 1.1.Based on Geological Map, Lake Loa Kang floodplain located in Kutai Basin, the widest and deepest basin in Indonesia. Kutai Basin is a prograding delta, where a lot of delta sedimentation types could be found in this basin (Endarto & Bachtiar, 1993).

Preliminary interpretation of satellite image showed that the development of Jempang-Semayang-Melintang Lakes complex; which also include Lake Loa Kang floodplain, is through tectonic activity. Fluvial action (erosion, transport, deposition) is the predominant agent of landscape evolution and also constitutes the natural disturbance regime primarily responsible for sustaining a high level of landscape diversity in river corridors. Although individual landscape features may exhibit high turnover; largely as a function of the interactions between fluvial dynamics and succession phenomenon; their relative abundance in the river corridor tends to remain constant over ecological time (Wasson, 1992).



Sumber : Peta Rupabumi Skala 1 : 1.000.000

Figure 1.1. Study area map

This study is aimed to divulge the habitat classification of Lake Loakang floodplain system based on the geomorphological, hydrological processes and the sedimentation analyses as a feature of ecological landscape. The results of the study will be utilized for developing the protocols for Pesut Habitat conservation and restoration.

MATERIALS AND METHODS

Study area

Lake Loa Kang Fishery Reserve located at 116° 32’ 30” – 116^{o} 35’ 30” E and 0^{o} 15’ 45” – 0^{o} 13’ 15’ N with the altitude about 4 – -0.25 m asl. This fishery reserve lies at about nine kilometers from Kotabangun City (Fig. 1.1).

Geomorphological Analysis

Watershed area were delineated using ArcView 3.1 GIS software from a topography map of 1:1,000 scale. The image used on the interpretation were preprocessed to eliminate radiometric errors. By application of Ermapper 5.5 Program, the geometric correction of the image was done using vector map. The results of analysis of geomorphological features was classified according to available classification (Thornbury 1954; Sampurno, 1982). The classification of land cover and distribution of vegetation is conducted based on Landsat TM satellite images (path/row 116/60, Acquisition date August 26th 2000), each pixel represent a 30 x 30 m area on the ground.

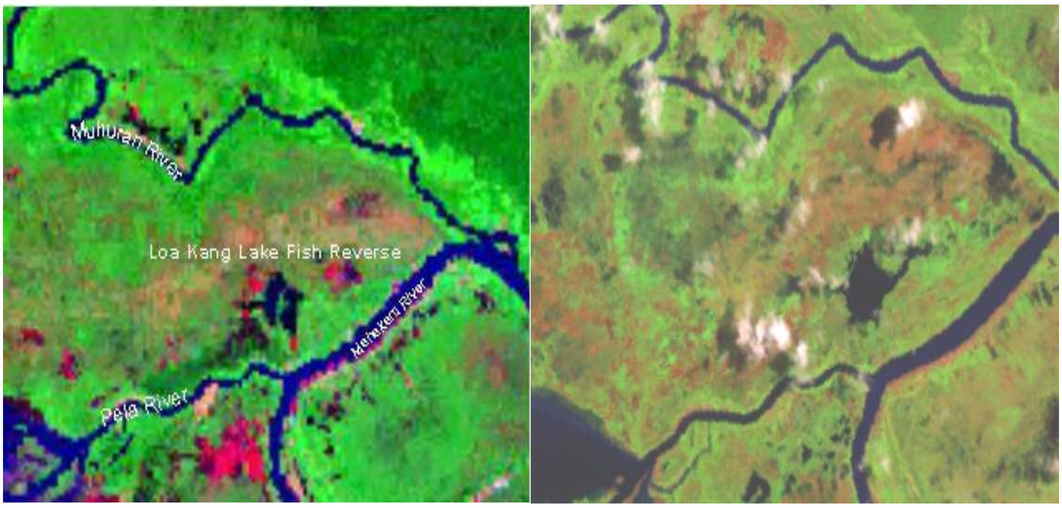
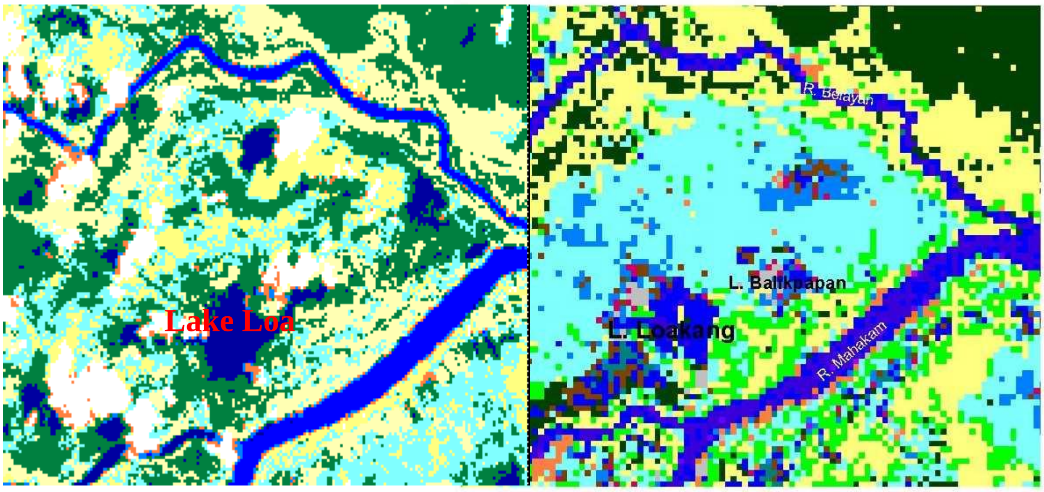


Figure 1.2. Landsat TM Satellite Image with composite RGB band 542 taken on (left) and on May 23th, 2000 (right).



Wet season

Dry season

Figure 1.3. Classification of satellite image on Lake Loa Kang Fishery Reserve. The different color in the image show several habitat types such as water body (blue), forest (green), brush or scrub (yellow) and grassland (light green)

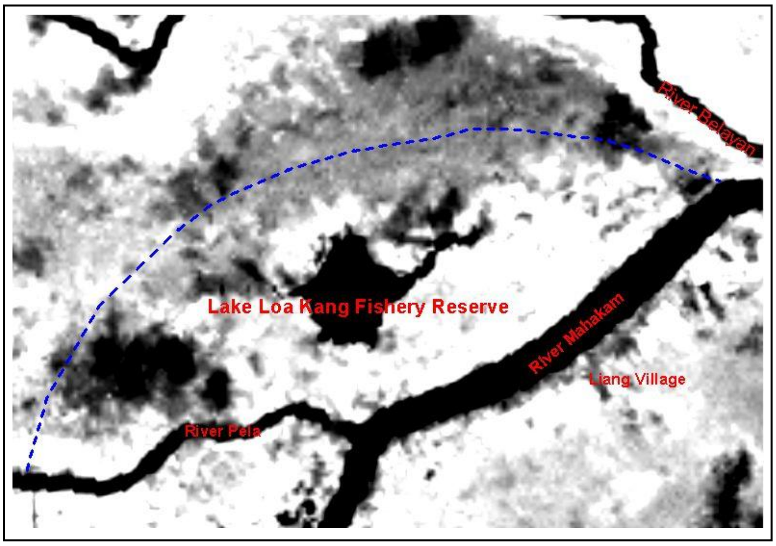


Figure 1.4. The distribution of NDVI values in Lake Loa Kang Fishery Reserve (dark color is indicating water body)

Prior to using automatic classifications technique, the data was processed using Ermapper 5.5 Software. Unsupervised classification method was used to aggregate the 15 land cover classes and was ground check in the field using GPS navigation. The change of land cover and vegetation between 1989 to 2000 is also analyzed using the image shown in Fig. 1.2. Image processing technique was also used to determine the differences between the vegetation and water body of the lake. Area of water body and vegetation around the lake was detected by superimposing two images of difference seasons (dry and rainy).

The Number Differential Vegetation Index (NDVI) was used to distinguished the differences between water body and other terrestrials landscape during the analyses of satellite image The application of NDVI method will show the striking differences between vegetation and non-vegetation coveted area, where NDVI values for the vegetation will be high, while for lake, and river and cloud will show a negative value. The NDVI values for road and bare soil will be around zero. The detailed description of NDVI Techniques is presented in *Arc View Image Analyst* Extension (Erdas & ESRI, 1999).

Settling velocity and Sediment Distribution

Sediment samples that have already been dried in the oven (30 minutes, at 60 ^{o}C) was shook on the sieve of with the mesh sizes of 45 μm, 63 μm, 125 μm, 250 μm, 500 μm, and 1,18 mm. After one hour gyration time; the fractionated sampled was weighed up to the nearest 0.001 g. The geometric size (D_i) then was calculated using the following the formula of Graf (1984) as follows = (boundary [of] under range x boundary of top range)$^{0.5}$ The mean of sediment particle (item) group diameter (D_m) was calculated using the following formula:

Table 1.2 Settling velocity of sediment particle in some habitat of Lake Loa Kang floodplain system.

Station	Months					
	June		August		September	
	Mean granular (mm)	Settling velocity (cm.sec^{-1})	Mean granular (mm)	Settling velocity (cm.sec^{-1})	Mean granular (mm)	Settling velocity (cm.sec^{-1})
R. Loa Kang	0.733	11.295	0.150	0.476	0.149	0.470
L. Loa Kang (Hakang)	0.731	11.233	0.217	0.994	0.214	0.961
Tunjung Spring	0.797	13.380	0.152	0.485	0.213	0.952
L. Balikpapan	0.872	16.011	0.209	0.916	0.141	0.416
Ephemeral ponds	0.686	9.906	0.284	1.695	0.195	0.803

$$D_m = \frac{\Sigma A_i D_i}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where, A_i is the percentage of grain size.

Settling velocity (W_s) was calculated using the *Stoke's Law* formula, that is:

$$Ws = \frac{((\rho_s - \rho)g)}{(18\eta)} \,.\, D_m^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(2)}$$

Where, W_s : settling velocity (cm.sec^{-1})
$(\rho_s - \rho)$: density difference between particle and fluid
g : gravity (9.8 g.s^{-1})
η : dynamic viscosity, (poice)
D_m : Particle diameter (mm)

RESULTS AND DISCUSSION

Image processing

Classification of habitat using satellite image showed that in the dry season, the area of Lake Loa Kang Fishery Reserve was dominated with grass, but in the wet season the water body becoming wide (Fig 1.3). This phenomenon probably happened due to the flat slope of the area (0–10%) and the floodplain system characterized by high water level fluctuation between the dry and wet season.

The techniques of NDVI only can be applied only for the image taken in the wet season, because complete band for the dry season image was not available (lack of Band 6). The analyses of satellite image for the dry season only capable to delineated the boundaries of habitat types (using composite Band 542). The results of image processing (Fig 1.4) indicate that the water body area of Lake Loa Kang Fishery Reserve are 604686 m^2 and 410965 m^2, for the wet and the dry season respectively. This calculation may be not so accurate because some of the area cover by quite thick cloud.

The granularimetric analysis usually was done to know the compiler materials of sedimented particles on the floodplain. The sedimented particle deposited in Lake Loa Kang showed different granular and physical characteristic. The granular geometric of

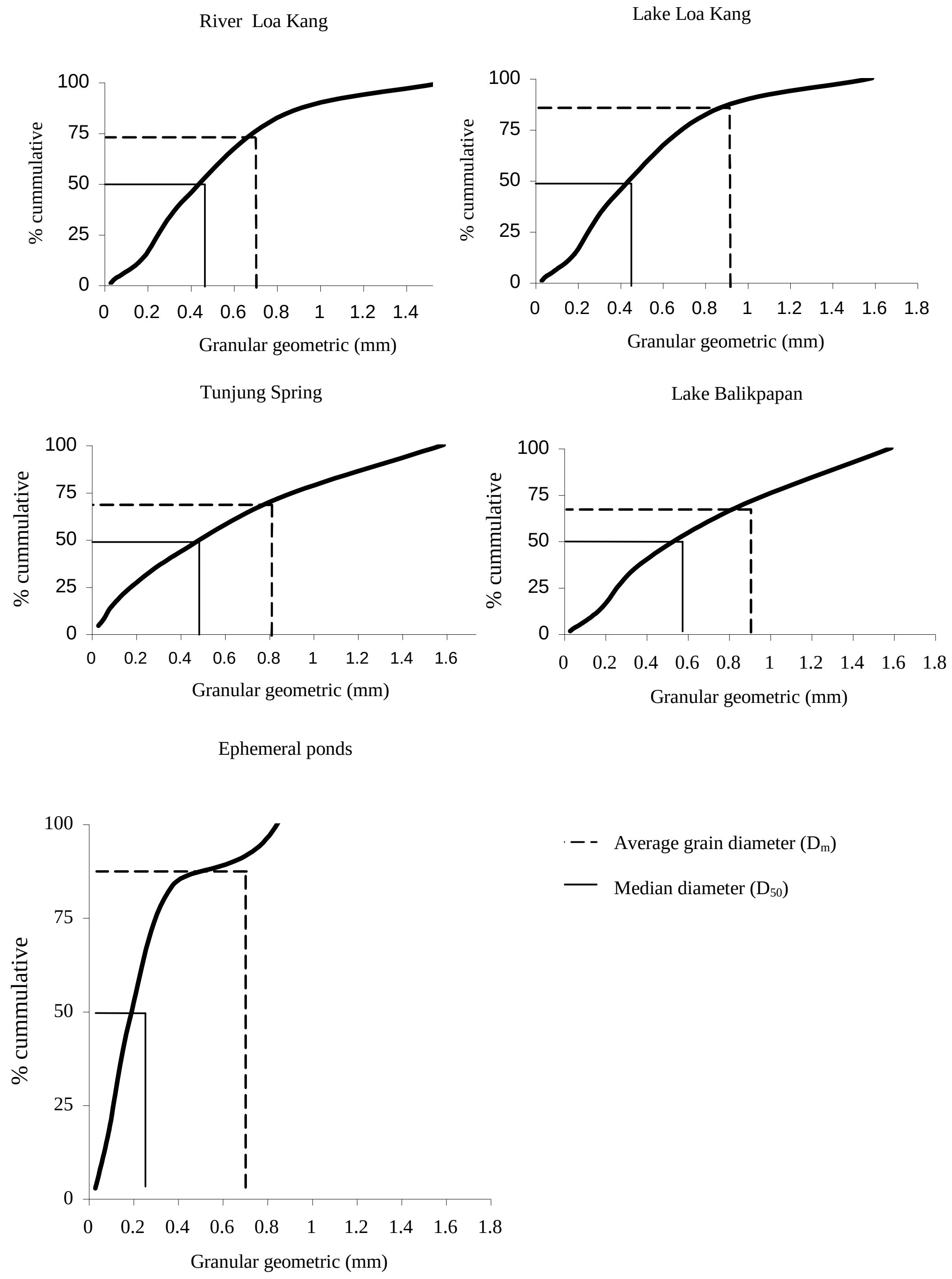


Figure 1.5. The granular geometric and percent cumulative of sediment in Lake Loa Kang Fishery Reserve, June 2003 (dry season)

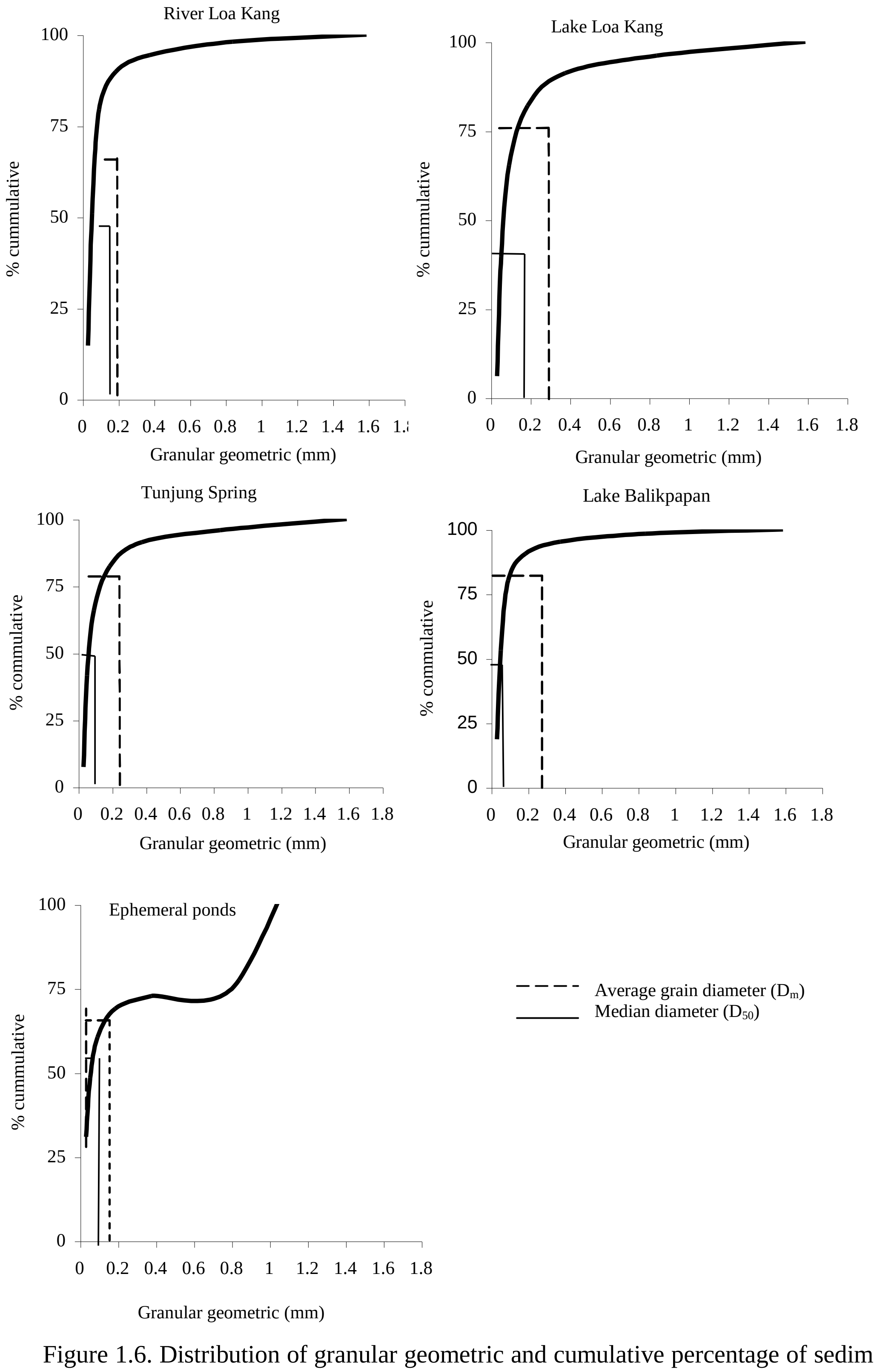


Figure 1.6. Distribution of granular geometric and cumulative percentage of sediment particle in Loa Kang Fishery Reserve, September, 2003 (wet season).

Table 1.3. Description of Habitat type and geomorphological class in the area of Lake Loa Kang Fishery Reserve (LLFR).

Station	Location, habitat type	Geomorphology Types	Coordinates	
			South	East
1	L. Loa Kang, a floodplain lake in LLFR	Backswamp deposit	S 0° 13' 42.0"	E 116° 33' 53.4"
2	R. Loa Kang, connecting channel between L.Loa Kang and L. Balikpapan	Canal fill	S 0° 13' 53.6"	E 116° 33' 57.8"
3	Tunjung Springs, a spring in the LLFR	Spring	S 0° 13' 26.5"	E 116° 33' 54.5"
4	*Hakang*, large size ephemeral pond in LLFR	Backswamp deposit	S 0° 13’ 40.6"	E 116° 33' 45.4"
5	L. Balikpapan, a floodplain lake in LLFR	Backswamp deposit	S 0° 13' 26.1"	E 116° 34' 34.5"
6	R. Balikpapan, a floodplain river (a small tributary of R. Mahakam) in LLFR.	Canal fill	S 0° 13' 32.0"	E 116° 34' 43.8"
7	Mouth of R. Balikpapan, junction of R. Balikpapan and R. Mahakam	Connecting channel between backswamp deposit lake and main river	S 0° 13' 23.9"	E 116° 34' 17.3"
8	Mouth of R. Pela, junction of R. Pela and R. Mahakam	Junction of main and tributary river	S 0° 14' 11.1"	E 116° 34' 4.6"
9	*Lopak*, small size ephemeral pond in LLFR	Backswamp deposit	S 0° 14' 12.7"	E 116° 35' 21.1"
10	*Maling* Canal.	Man made canal that connect L. Loa Kang with R. Mahakam	S 0° 14' 45.8"	E 116° 34' 56.0"
11	Natural levee	Natural levee		

sediment precipitated in Lake Loa Kang floodplain system is showed in Fig 1.5. and Fig 1.6.

Sediment sampling at June 2003 showed the results of sedimentation at the dry season, when coarser particle settling down during rainy season, and sampling at September 2003 as the representation of sedimentation along dry season. While sedimentation in ephemeral ponds seem to differ in the sedimentation pattern, probably because the effect of the fish taking refuge. Settling velocity resulted from calculation using *Stoke Law*s that was done at three different sampling time is presented in Table 1.2.

In the dry season in Lake Balikpapan, higher diameter and settling velocity of sediment (16.01 cm.sec^{-1}) were observed. This pattern probably because bigger grain size is deposited in advance in Lake Balikpapan before the water flows to Lake Loa Kang and to its connecting channel, R. Muhuran and R. Loa Kang, This pattern probably because River Balikpapan is the only channel still connected to both rivers during this season. The lower value was also observed in ephemeral pond, which mean that the water circulation begin from R. Mahakam and than flow pass through R. Balikpapan. On the wet season, the water flows not only from River Balikpapan, but also from River Loa Kang, *Maling* Channel and River Muhuran. This situation made sedimentation on Hakang is higher than other habitat types, and two river of them flow to *Hakang* area. Geomorphological analysis by satellite image processing and ground check revealed that there are several habitat types in Lake Loa Kang floodplain system. Those habitat types showing different geomorphological characters (Table 1.3.)

CONCLUSION

Satellite image analysis showed the area of Lake Loa Kang floodplain system that was managed as fishery reserve. The analyses using NDVI method revealed the difference between vegetation and non-vegetation area of Lake Loa Kang floodplain system in wet (604686 m^2) and the dry season (410965 m^2). In the dry season, higher diameter and settling velocity of sediment (16.01 $cm.sec^{-1}$), in Lake Balikpapan was observed. This pattern probably because bigger grain size is deposited in advance before the water flowed to Lake Loa Kang and to its connecting channel, R. Muhuran and R. Loa Kang. The lower value was observed in ephemeral pond. Geomorphological analysis by satellite image processing and ground check revealed that there are eleven habitat types in Lake Loa Kang floodplain system.

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Ecological Integrity of A Mahakam Floodplain System:12-25.

2. THE DYNAMICS OF WATER QUALITY PARAMETERS IN LAKE LOA KANG FISHERY RESERVE

By

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ABSTRACT

*Lake Loa Kang Fishery Reserve (LLFR) is a floodplain lake system located in Kutai Kertanegara Regency, East Kalimantan Province. It is also well known that River Mahakam floodplain systems provide fishes as food for the indigeneous Irrawady Dolphin (*Orcaella brevirostris*) locally refer as Pesut. Unfortunately, the condition of LLFR and other Pesut habitats tend to be deteriorated and therefore can not sustain sufficient white fish as food , that in its turn also threatened the size of Pesut population. In order to restore LLFR and to supply adequate fish for Pesut and fish stock for local fishers, it is necessary to evaluate the water quality of LLFR as the foundation for its restoration. The objective of the study is to reveal the spatio-temporal distribution of water quality parameters in various habitat types of Lake Loa Kang floodplain system. The samplings were conducted three times in 2003 at ten sampling sites. Temperature, pH, conductivity, turbidity and dissolved oxygen were measured randomly 12 times using Horiba WQC U-10. Water samples were taken compositely from each station and the samples were analyzed for nitrite, nitrate, ammonia, Total Nitrogen, Total Phosphor, Suspended solid, chlorophyll a, Total Organic Matter,* BOD_5*, dissolved organic carbon (DOC) and orthophosphate. Analyses of water samples were conducted following the methods described in Standard Methods (18th edition). The data indicated the concentration of ammonia is higher than the set points value for fisheries almost in all station, possibly as the impacts of decomposition product originated from mass fish kill occur in the dry season and the decomposition of inundated vegetation in rainy season. In spite of high sedimentation rate, concentration of suspended solid is relative low, probably because of high density of sediment particle. Very low concentration of dissolved inorganic phosphorus indicate the existence of nutrient deficiency for plankton. Although the value of the parameters change in time and space, in general, most of the studied water quality parameters still meet the requirement for fishes except for ammonia.*

Key words: *water quality, floodplain, Loa Kang*

INTRODUCTION

Lake Loa Kang Fishery Reserve (LLFR) is a floodplain lakes system located in Kutai Kertanegara Regency, East Kalimantan Province. Until 1970-ies, Lake Loa Kang floodplain system was manage as a fishery reserve, in order to supply natural fish brood stock and fingerling to sustain capture fishery in adjacent waters (Hartoto, 2000). The management of LLFR was performed by local people and its condition was still good until that period. Water levels in this floodplain are influenced by River Mahakam. It is well known that an indigeneous species of Irrawady Dolphin (*Orcaella brevirostris*) lives in River Mahakam and its floodplain. This mammals refer by local people as *Pesut.*

Table 2.1. Description of sampling stations in the area of Lake Loa Kang Fishery Reserve.

Station	Location, habitat type	Coordinates	
		South	East
1	R. Loa Kang, a channel connecting L. Loa Kang with R. Pela	S 0° 13' 53.1"	E 116° 33' 55.6"
2	Connecting channel between L. Loa Kang and L. Balikpapan.	S 0° 13' 30.5"	E 116° 34' 22.6"
3	Tunjung Springs, a spring in the LLFR	S 0° 13' 26.0"	E 116° 33' 54.0"
4	Lake Loa Kang *(Hakang),* a backswamp deposit lake	S 0° 13' 39.9"	E 116° 33' 42.9"
5	Lake Balikpapan, a back swamp deposit lake in LLFR	S 0° 13' 28.3"	E 116° 34' 35.6"
6	River Balikpapan, a connecting channel between backswamp deposit lake with R. Mahakam.	S 0° 13' 32.5"	E 116° 34' 46.1"
7	Mouth of River Balikpapan, junction of R. Balikpapan and R. Mahakam	S 0° 13' 25.0"	E 116° 35' 16.5"
8	Mouth of River Pela, junction of R. Pela and R. Mahakam	S 0° 14' 14.0"	E 116° 34' 0.9"
9	*Lopak,* small size ephemeral pond in LLFR	S 00° 13' 20.7"	E 116° 35' 16.4"
10	Maling Canal, a segment of man made channel that connect L. Loa Kang with River Mahakam	S 00° 13' 45.0"	E 116° 34' 5.0"

Table 2.2. Classification of Ecological Habitat Types in Lake Loa Kang floodplain system

No.	Habitat Types	Location
1.	*Hakang or* Lebung, a depression/deposit lak in floodplain system	L. Loa Kang (St.4) and L. Balikpapan (St.5)
2.	Connecting channel between floodplain lakes	Connecting channel between L. Loa Kang and L. Balikpapan (St.2)
3.	Connecting channel between the floodplain depression lake and main river	R. Loa Kang (St.1) and R. Balikpapan (St.6)
4.	Junction of tributary and main river	Mouth of R. Pela (St.8)
5.	Mouth of connecting channel between the floodplain depression lake and main river	Mouth of R. Balikpapan. (St.7)
6.	A spring in floodplain system	Tunjung Springs (St.3)
7.	Ephemeral ponds	Lopak (St.9)
8.	A segment of man made channel that connect L. Loa Kang with R. Mahakam	*Maling* Canal (St.10)

Pesut is an aquatic mammal that always feed upon white-water fish and the feeding ground of this animal are the floodplain lakes of River Mahakam system. Unfortunately, the condition of floodplain system is threatening to the population size of *Pesut.* Therefore, it has been considered to restore the LLFR. The main objective of this study is to provide data of spatio-temporal distribution of water quality parameter of several habitats in Lake Loa Kang floodplain system. The results of the study is expected to be utilize as the base for its restoration. In the near future, the LLFR is expected to supply adequate fish for Pesut and fish stock for local fishers.

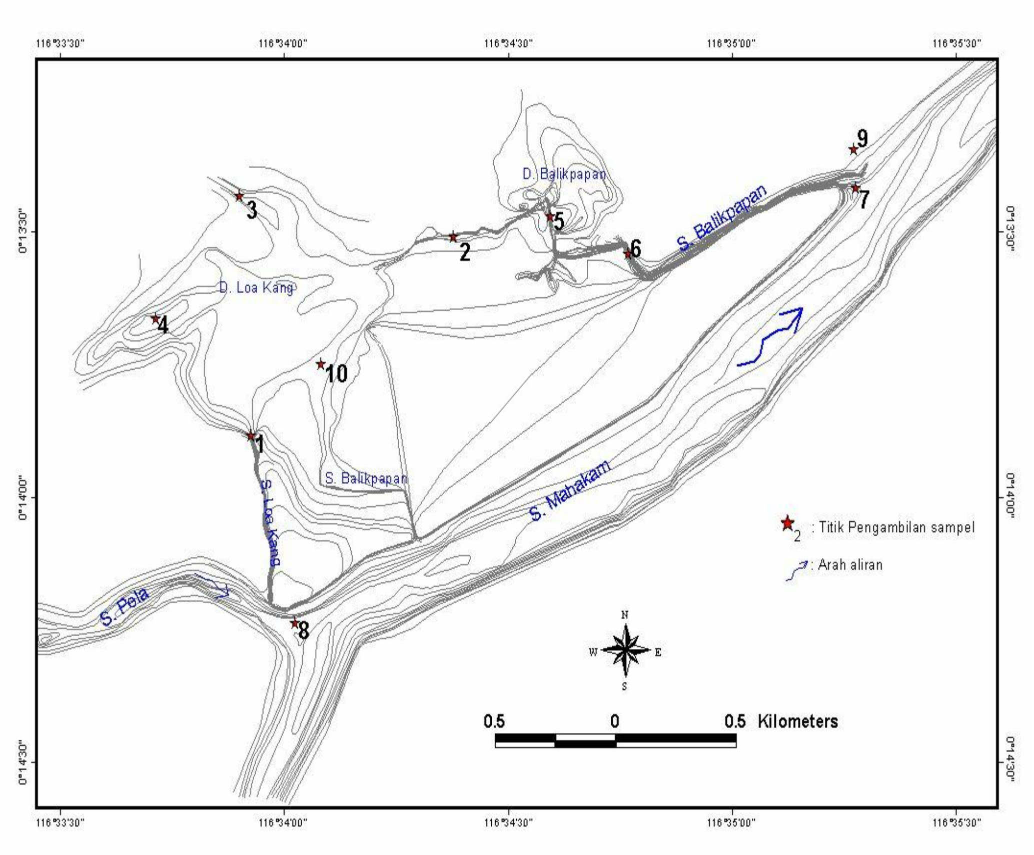


Figure 2.1. Location of sampling station at Lake Loa Kang Fishery Reserve

MATERIALS AND METHODS

Study area

Lake Loa Kang Fishery Reserve is a floodplain system of River Mahakam with total area of 930.27 ha (Hartoto *et al.* 2002). LLFR consists of several habitat types; among the others; are two backswamp deposit lakes or *Hakang*. *Hakang* is a habitat of floodplain system where the water is always available at all Hakang is the terminology for backswamp lakes that is similar to *Lebun*g in the floodplain system of River Musi, South Sumatra (Hartoto, 1992). The *Hakang that* was found in Lake Loa Kang floodplain system are Lake Loa Kang and Lake Balikpapan (Hartoto *et al.* 2002). In addition, there are three rivers that supply water to the floodplain system, those rivers are River Loa Kang, River Balikpapan and River Muhuran (Fig. 2.1).

Sampling and analysis methods

The samplings were conducted three times in June, August and September 2003, that was regarded to represent the dry, transitional and rainy season respectively. Sampling were done at ten sampling stations (Table 2.1), that represents eight ecological habitat types (Table 2.2). Some stations were not sampled during dry season because there is no water due to prolonged drought. At each sampling stations, water quality

Table 2.3. The methods of analysis of water quality parameters

No.	Parameters	Methods
1.	N-Nitrite	Sulphanilamide method, spectrophotometry
2.	N-Nitrate	Brucine methods, spectrophotometry
3.	N-Ammonia	Phenate method, spectrophotometry
4.	Total-N	Brucine method with $K_2S_2O_8$ oxidation, spectrophotometer
5.	Chlorophyll-a	Extraction method by acetone
6.	Dissolved Inorganic Phosphorus	Ascorbic acid method
7.	Dissolved Oxygen	Titrimetry
8.	BOD_5	Titrimetry
9.	Suspended Solid	Gravimetric
10.	Total Organic Matter (TOM)	$KMnO_4$ redox titration
11.	Humic Acid	UV-Spectrophotometer

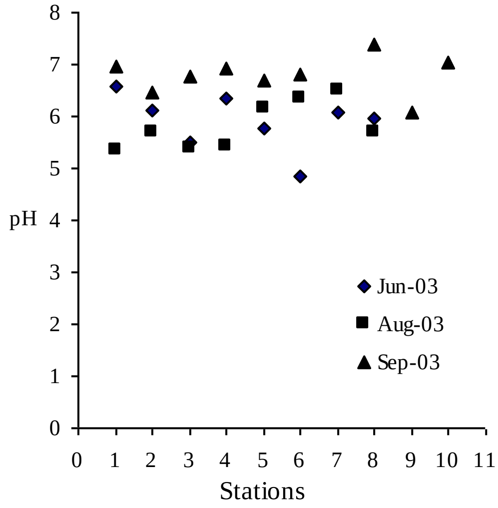


Figure 2.2. The spatio-temporal distribution of pH at ten stations in Lake Loa Kang Fishery Reserve

parameters such as temperature, pH, conductivity, turbidity and dissolved oxygen (DO) were directly measured randomly 12 times using Horiba WQC U-10. Water samples were taken from each stations compositely from the bottom and surface layers and the samples were analyzed for N-nitrite (N-NO_2), N-nitrate (N-NO_3), N-ammonia (N-NH_3), Total-Nitrogen (T-N), Total Phosphor (T-P), Suspended solid, chlorophyll-a, Total Organic Matter (TOM), Biological Oxygen Demand (BOD_5) and Dissolved Organic Carbon (DOC). Dissolved Organic Carbon (DOC) was analyzed using the Shimadzu TOC-5000-A analyzer. All samples preservation and analysis; as shown in Table 2.3; are done according to the methods described in Standard Methods for Water and Wastewater Analysis 18th edition (APHA-AWWA, 2000)

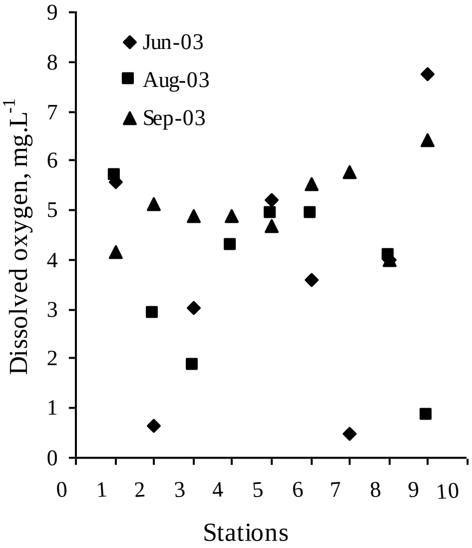


Figure 2.3. Dissolved oxygen at several habitat of Lake Loa Kang floodplain system

Data analyses

The data was analyzed pictorially using Microsoft Excell Program 1998.

RESULTS AND DISCUSSION

The data were taken three times in June, August and September 2003 at ten sampling stations that represented eight habitat types. The results of direct water quality parameter measurement was shown in Table 2.4. The data resulted from analysis of water samples in the laboratory were presented in Table 2.5 to Table 2.7.

Temperature, pH, conductivity, turbidity and dissolved oxygen were measured in the field using Horiba WQC U-10. During sampling, water temperature were high, the highest temperature (26.9-35.8 ^{o}C) was observed in the dry season (June 2003) and the backswamp deposit lake (Lake Loa Kang, St. 4) was completely dried at this time. In August and September 2003, the water temperature were range 24.9-29.0 ^{o}C and 27.2-30.8 ^{o}C respectively. According to Boyd (1990), in tropic area, optimum temperature for fish growing are in the range of 25-32 ^{o}C. In Lake Loa Kang floodplain system, the maximum water temperature was observed in June during early dry season.

Figure 2.2 showed that the pH in LLFR is within the range of 5.4 -7.4, the highest pH was observed in the September 2003 at the junction of tributary and main river (St. 8) when the water level was high. The lowest pH was observed in August at connecting channel between the floodplain depression lake and main river (St. 6). In some stations where the pH was lower than pH 6, quite number of fish population were still observed.

Boyd (1990) stated the range of dissolved oxygen level for living requirement of fish is > 3 mg.L$^{-1.}$ Dissolved oxygen in most station in LLFR are still meeting the requirement for fish life, except in *Lopak* (St 9) in the middle of dry season where the concentration was near zero, but when the water level increasing, the concentration of

Table 2.4. Basic water quality parameter of Lake Loa Kang floodplain system in 2003

a. June 2003 (dry season)

Station	pH	Cond. mS.cm^{-1}	Turb. NTU	DO mg.L^{-1}	Temp. ^{o}C	Secchi Depth (cm)	Note
1	6.12	0.107	343	0.63	28.7		Z_{max}= 30 cm
2	-	-	-	-	-	-	Dried up
3	5.50	0.036	116	3.02	35.8	The bottom was seen	Shallow, 30 cm
4	6.56	0.027	150	5.56	31,1	The bottom was seen	Z_{max}= 30 cm
5	6.35	0.038	179	5.20	34.23		
6	5.78	0.032	123	3.58	35.8		
8	4.86	0.042	11	0.50	26.9		
7	-	-	-	-	-	-	-
9	6.07	0.043	62	4.01	30.3	17.3	
10	5.96	0.026	324	7.74	33.3		

b. August 2003 (transitional season)

Station	pH	Cond. mS.cm^{-1}	Turb. NTU	DO mg.L^{-1}	Temp. ^{o}C	Secchi Depth (cm)
1.	5.36	0.055	120	5,68	24.9	No data, very shallow, Z_{max}= < 10 cm
2.	5.68	0.097	119	2,92	26.0	Similar as above
3.	5.37	0.045	102,6	1,87	25.3	Similar as above
4.	5.43	0.047	104,6	4,29	27.0	Similar as above
5.	5.92	0.055	110	4.11	28.3	Similar as above
6	6.15	0.050	118	4.93	29.0	Similar as above
7	6.35	0.057	135	4.93	28.9	Similar as above
8.	6.49	0.051	308	4,06	28.9	Similar as above
9.	5.71	0.078	124	0.86	26.9	Similar as above
10.	-	-	-	-	-	-

- : the data is missing

c. September 2003 (rainy season)

Station	pH	Cond mS.cm^{-1}	Turb. NTU	DO mg.L^{-1}	Temp. ^{o}C	Secchi Depth (cm)
1.	6.98	0.033	63.7	4.16	27.5	33.5
2.	6.46	0.032	74.4	5.41	29.4	29.0
3.	6.76	0.030	106.7	4.89	30.7	16.7
4.	6.93	0.031	98.6	4.87	30.8	17.5
5.	6.70	0.031	89.7	4.69	27.8	25
6.	6.80	0.031	109	5.51	27.4	20.3
7.	-	-	-	-	-	-
8	7.38	0.032	89	5.77	27.2	25.5
9.	6.07	0.043	62.3	4.01	30.3	17.3
10.	7.05	0.031	140.7	6.43	29.9	No data, very shallow, Z_{max}= <10

dissolved oxygen in this habitat type also raising (Fig 2.3)**.** In early dry season (June), dissolved oxygen level in connecting channel between depression lakes (St 2) and at the mouth of connecting channel (St 7) were near zero, supposed as the impact of decomposition process of dead fish and inundated plants. In August, we observed that there are a lot of dead fishes stranded on the littoral part of several habitat types in Lake Loa Kang Fishery Reserve. For fisheries and agriculture activities, concentration of dissolved oxygen was suggested should be higher than 3 mg.L^{-1} (Anonymous, 2001).

Nitrogen is always present in aquatic ecosystem and most abundantly as gas. Relatively small quantities exist in the combined forms of ammonia (N-NH_4^+), nitrate N-NO_3^-), nitrite (N-NO_2-), urea ($CO[NH_2]_2$) and dissolved organics compounds. Nitrogen is

Table 2.5. The data of water quality parameter at sampling stations of Lake Loa Kang floodplain system in June 2003

Sta-tion	Parameters									
	N-NO$_2$ mg.L^{-1}	N-NO$_3$ mg.L^{-1}	N-NH$_4$ mg.L^{-1}	T-N mg.L^{-1}	BOD$_5$ mg.L^{-1}	TOM mg.L^{-1}	SS mg.L^{-1}	Chlo-a mg.m-^{3}	TOC mg.L^{-1}	DOC mg.L^{-1}
1	0.016	0.219	0.132	1.353	4.148	73.312	57.0	17.936	26.725	26.390
2	0.038	0.188	0.040	1.389	3.420	31.600	297.0	56.046	36.190	11.750
3	0.011	0.183	0.136	1.459	2.362	9.356	93.5	18.510	28.910	15.270
4	0.025	0.269	0.042	1.669	1.299	61.304	209.7	18.798	55.220	33.300
5	0.143	0.454	0.098	1.575	4.965	64.464	49.5	9.650	27.350	20.510
6	0.026	0.433	0.235	1.573	0.666	20.856	83.0	37.762	108.400	13.240
7	0.005	0.038	0.051	0.564	2.543	55.260	26.7	41.913	25.520	7.170
8	0.031	0.289	0.108	1.548	1.160	69.520	49.5	33.717	62.940	22.710
9	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	

Chlo-a: Chlorophyl -a

Table 2.6. The data of water quality parameter at sampling stations of Lake Loa Kang floodplain system in August 2003.

Sta-tion	Parameters									
	N-NO$_2$ mg.L^{-1}	N-NO$_3$ mg.L^{-1}	N-NH$_4$ mg.L^{-1}	TN mg.L^{-1}	BOD$_5$ mg.L^{-1}	TOM mg.L^{-1}	SS mg.L^{-1}	TOC mg.L^{-1}	DOC mg.L^{-1}	S^{2-} mg.L^{-1}
1	0.087	0.571	0.028	1.352	7.086	139.66	46.5	32.690	11.910	0.093
2	0.137	0.592	0.038	6.792	5.594	76..60	80.5	9.020	4.580	0.482
3	0.015	0.162	0.020	3.908	2.285	130.18	0.0	14.370	11.360	0.762
4	0.058	0.295	0.029	4.144	0.665	139.66	127.3	19.830	11.270	0.640
5	0.081	0.734	0.016	2.536	3.529	814.38	47.5	11.430	4.820	0.762
6	0.018	0.234	0.034	1.474	2.372	59.08	39.5	5.130	3.480	0.032
7	0.035	0.186	0.123	5.584	3.676	59.08	134.0			0.640
8	0.042	0.172	0.019	1.233	2.749	87.52	122.5	20.830	14.310	0.397
9	0.015	0.304	0.047	5.016	3.015	119.12	67.0	16.240	14.580	0.883
10	0.622	0.827	0.065	1.768	4.801	153.88	886.0	36.730	22.960	1.248

often present in quantities that can limit plant growth. The concentration of most nitrogen compounds in lakes and streams tends to follow regular seasonal pattern Natural changes in the vegetation of the drainage basin caused by fires, flood or artificial clearing usually resulted in the increased of nitrate in stream (Goldman & Horne 1983). Ammonia differs from nitrate in toxicity and is retained by most soil. The toxicity of ammonia to aquatic animals and plants is of great practical importance (Goldman & Horne, 1983). The concentration of nitrate in August, probably related to the abundant of ammonia resulted from of decomposition process (Fig 2.4). The high concentration of The high concentration of ammonia probably as the consequence of decomposition of fish observed during mass fish kill in the early dry season (June) and also due to the decomposition of inundated vegetation in rainy season (September).

NO$_2$-N is generally present only in trace quantities in water exposed to oxygen, where it is transformed to nitrate. Nitrite is converted to ammonia in anoxic waters (Goldman & Horne, 1983). In LLFR, the highest concentration of nitrite was observed at connecting channel (St. 7) in August (Fig. 2.5a). This pattern is suggested due to the impact of nitrification process that was going on in that time. According to Government

Table 2.7. The data of water quality parameter at sampling stations of Lake Loa Kang floodplain system in September 2003.

Station	Parameter								
	$N\text{-}NO_2$ $mg.L^{-1}$	$N\text{-}NO_3$ $mg.L^{-1}$	$N\text{-}NH_4$ $mg.L^{-1}$	T-N $mg.L^{-1}$	TOM $mg.L^{-1}$	BOD_5 $mg.L^{-1}$	SS $mg.L^{-1}$	Chloro phyll-a $mg.L^{-1}$	S^{2-} $mg.L^{-1}$
1	0.024	0.261	0.191	5.036	15.455	2.316	11.0	1.508	0.006
2	0.021	0.175		9.453	14.823	1.122	16. 7	0.466	0.179
3	0.052	0.126	0.456	6.963	23.671	3.928	43.3	2.792	0.410
4	0.025	0.149	0.265	0.719	20.511	3.157	33.3	2.327	0.525
5	0.004	0.151	0.187	0.882	14.823	2.147	32.0	0.000	0.237
6	0.005	0.051	0.181	0.652	14.191	8.418	38. 7	0.000	1.446
8	0.008	0.328	0.141	7.126	11.677	1.123	92.0	0.000	0.375
9	0.008	1.548	0.430		42.013		572.0	0.000	1.158
10	0.007	0.220	0.212	6.058	11.999	0.782	56. 7	2.538	0.294

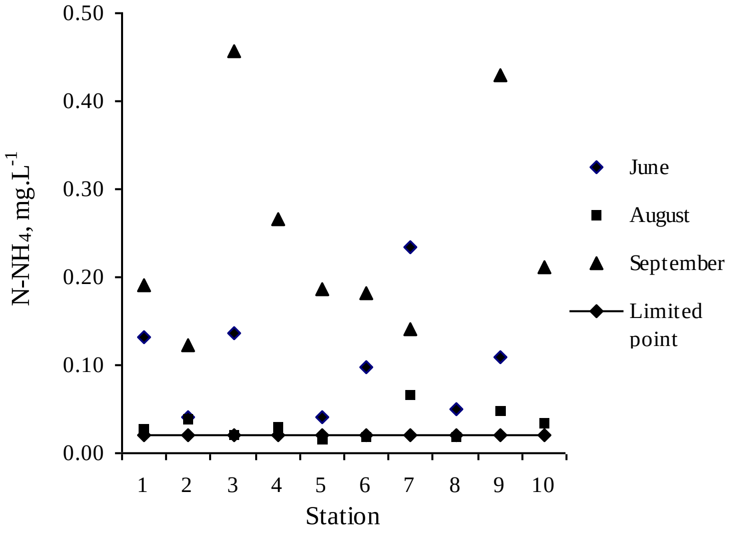
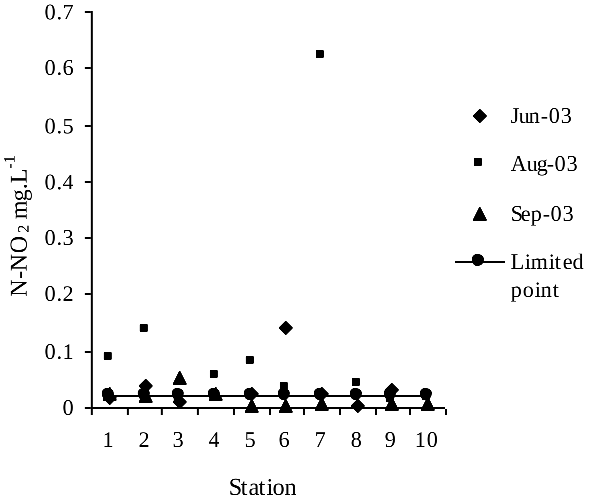


Figure 2.4. Distribution of ammonia concentration at several habitat of Lake Loa Kang floodplain system

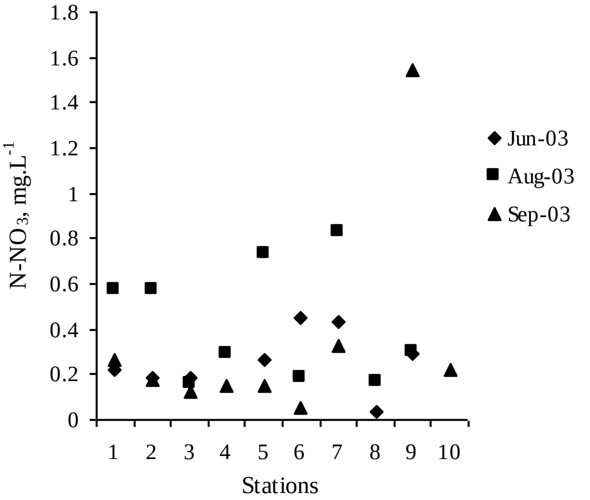
Regulation No. 82, 2001 on water quality criteria for fisheries ($N\text{-}NO_2$ concentration in LKFR was higher than the set points values, that indicate that the condition is threatening for fisheries.

In LLFR, $N\text{-}NO_3$ concentration in August was higher than other season, probably because of released nutrient from inundated plants at the beginning of flood season (Fig. 2.5.b). In that time, the highest concentration of nitrate was observed in the junction of R. Balikpapan and R. Mahakam (St. 7) where many died plant got stranded in the mouth of River Balikpapan.

In spite of high sedimentation rate (Ridwansyah, 2004), concentration of suspended solid is relative low. According to Government Regulation No. 82/ 2001 for



a. N- NO_2



b. N-NO_3

Figure 2.5. Concentration of N-nitrite (a) and N-nitrate (b) in water column of Lake Loa Kang floodplain system

fishery, maximum concentration of suspended solid is 1000 mg.L^{-1} whereasconcentration of suspended solid in eight habitat types is within the range 11.00-886.00 mg.L^{-1} (Fig 2.6), which means that from the point of view the condition of this parameter the condition of LLFR is still suitable for fishery.

The concentration of organic matter in natural body of water resulted from an interplay of net productivity, exudation of organic substances by phytoplankton, and import and export (inflow, outflow, dissolution, sedimentation, etc) of organic matter. Productive lakes have a gross primary production of organic matter on order of a few g

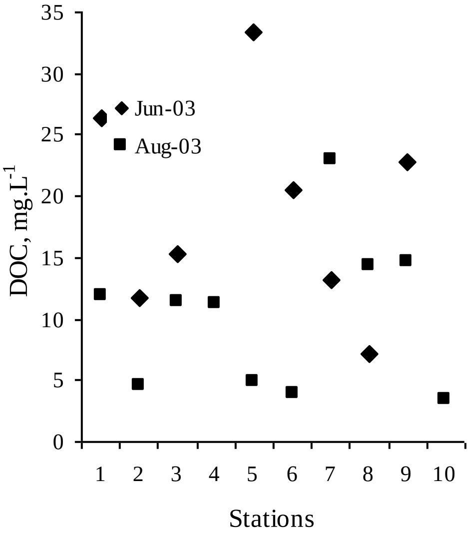


Figure 2.6. Suspended solid in several habitat of Lake Loa Kang floodplain system

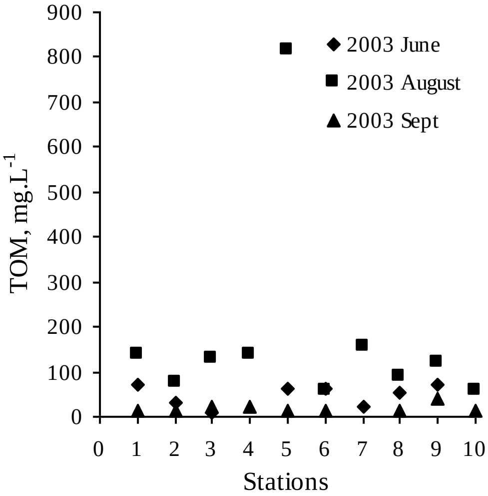


Figure 2.7. Concentration of Total Organic Matter (TOM) in several habitat of Lake Loa Kang floodplain system.

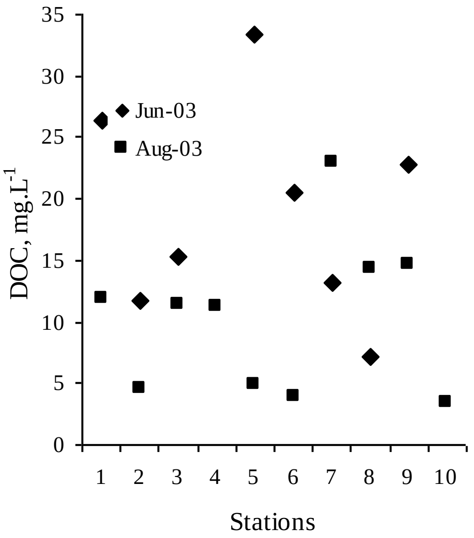


Figure 2.8. Concentration of DOC in several habitat of Lake Loa Kang floodplain system

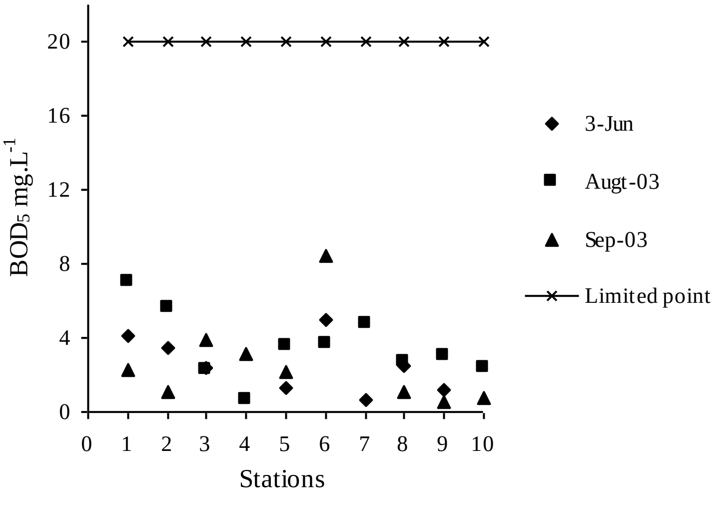


Figure 2.9. The level of BOD_5 in several habitat of Lake Loa Kang floodplain system

m^{-2}. day^{-1}. Production in flowing waters is usually very high (Stumm and Morgan, 1981). From the data that taken during three times sampling (Fig 2.7), the highest TOM average (177.902 mg.L^{-1}) was observed in transitional season (August 2003), especially in Lake Balikpapan, (St 5) is 814.38 mg.L$^{-1.}$ This phenomenon presumably related to seasonal change of climatic condition because August 2003 is beginning of rainy season therefore input of organic matter is increasing as well as allochthonous or autochthonous.

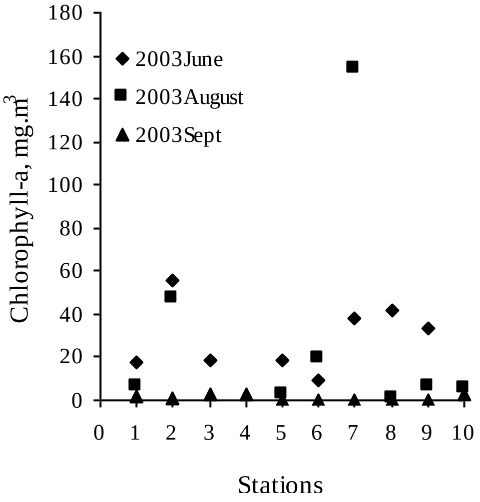


Figure 2.10. Concentration of chlorophyll-a in several habitat of Lake Loa Kang floodplain system

The concentration and flux of dissolved organic carbon (DOC) are important characteristics of aquatic ecosystem, with its important effect on light and ultraviolet (UV)-B attenuation, ecosystem respiration, nutrient availability, metal toxicity and the global carbon balance (Mulholland, 2003). The data of DOC from Lake Loa Kang floodplain system was shown in Fig. 2.8. DOC concentration in eight habitats were in the range 3.48-33.30 mg.L^{-1}. The highest concentration was observed in St. 5, in June (dry season) and the lowest concentration was observed at St. 10 in August (monsoon). DOC concentration appear to be influence primarily by climate (precipitation) and habitat types.

Biological oxygen demand (BOD$_5$) refers to the amount of oxygen consumed when the organic matter in a given volume of water is biodegradable. BOD is an indicator of the potential for a water body to become depleted in oxygen and possibly become anaerobic because of biodegradation. BOD$_5$ is measured as the decrease in dissolved oxygen (in mg.L^{-1}) after 5 days of incubation (Weiner, 2000). Generally BOD$_5$ level in eight habitat types (Fig. 2.9) are ranged between 0.590-8.418 mg.L^{-1} are lower than the maximum set point (20 mg.L^{-1}) for fishery according to Government Regulation No 82/2001 on Water quality. It could be means that the degradation process of organic matter by microorganism in Lake Loa Kang system do not consume much dissolved oxygen, therefore probably the aquatic life in this lake still running in its natural process.

Chlorophyll-a is the primary photosynthetic pigment that present in all algae and cyanobacteria and photosynthetic organism other than the photosynthetic sulfur bacteria. Chlorophyll-a has two in vitro absorption band, in the red light region at 660-665 nm and at lower wave length near 430 nm (Wetzel, 2001) and the water samples was measured by Spectrophotometer UV-VIS 120.Concentration of chlorophyll-a in LLFR is shown in Fig. 2.10. The data indicated that generally the highest concentration was observed in June 2003 (dry season), similar phenomenon also observed by Hartoto (1997). The pattern of chlorophyll-a distribution in eight habitat types of LLFR is not seen clearly, Boyd (1990) reported that when macrophyte algae were abundant, there was little phytoplankton and low chlorophyll *a* concentration. In Station 3 (a spring in floodplain system) where many *Nelumbo sp* (Local name:*Tunjung*) growing, concentration of chlorophyll-*a* is not significantly different. The averaged concentration in June, August and September were 52.07, 30.39 and 0.96 µg.L^{-1} respectively. This value indicated that LLFR is an unfertilized lake according to Hepher(1962) in his study in Israel observed chlorophyll *a* concentration in unfertilized pond were between 8.8 and 115.5 µg.L^{-1}

CONCLUSION

The data indicated that the concentration of ammonia is higher than the set point for fisheries (Regulation No. 20, 1990) almost in all stations. This phenomenon possibly due to the impacts of decomposition product originated from mass fish kill occur in the dry season and the decomposition of inundated vegetation in rainy season. In spite of high sedimentation rate, concentration of suspended is relative low, probably because of high density of sediment particle. Although the value of the water quality parameters change with time and space, in general, most of the studied parameters still meet the requirement for fishes except for ammonia.

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3. DISTRIBUTION OF HETEROTROPHIC BACTERIA AS ORGANIC MATTER DECOMPOSER IN LAKE LOA KANG FLOODPLAIN SYSTEM

By

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ABSTRACT

Lake Loa Kang Fishery Reserve (LLFR) is one of floodplain systems where the fluctuation of its water level is influenced by the changes in the discharge of water in River Mahakam. River Mahakam exchanges water that carry organic and inorganic matter with its floodplain and this phenomenon influenced the ecological balance of the system. Active bacteria community function in the degradation and assimilation of organic matter, carbon, nitrogen and other nutrient. Heterotrophic Bacteria (HB) in aquatic system is strongly related to organic matter decomposition processes. The objective of this study is to predict spatial and temporal distribution of heterotrophic bacteria and its relationship to Total Organic Matter (TOM) concentration. Samplings were done four times in June, August, September 2003 and June 2004 at seven sampling stations that represent five habitat types of the floodplain. The number of HB was determined by Total Plate Count method with spread plate techniques at 10^{-1} to 10^{-8} dilution, while the TOM concentration was determined using Permanganate Titration methods. The results showed that spatially, the highest number of HB (11.1 x 10^{8} cells.mL^{-1}) was found at connecting channel between depression lake and river segment (St 6) and the lowest (37.7 x 10^{6} cells.mL^{-1}) was found at connecting channel between depression lakes (St 2). This pattern was in coincidence with the pattern for TOM concentration that are 240.010 mg.L^{-1} and 29.532 mg.L^{-1} for St.6 and St. 2 respectively. Temporally, the highest average of HB number and TOM concentration were found in August 2003, each are 94.3 x 10^{7} cel.mL^{-1} and 217.88 mg.L^{-1}. The lowest average were found in September 2003 that are 10.2 x 10^{7} cells.mL^{-1} and 16.783 mg.L^{-1} for HB number and TOM concentration in that order. Statistical test showed that there is a significant correlation between Heterotrophic Bacteria and TOM (r = 0.966, P<0.05).

Key words: *Loa Kang, floodplain, heterotrophic bacteria, organic matter .*

INTRODUCTION

Mahakam floodplains are complex system that consists of several lakes and rivers. Water fluctuation and water quality of floodplain lakes system is strongly influenced by the main river. Study on Mahakam floodplain lakes had been already conducted several years, i.e. study on limnology of Lake Semayang, Lake Melintang, Lake Jempang *(*Lukman & Gunawan, 1998; Gunawan, 1998, Hartoto *et al.* 1998)*)* and limnology of Lake Loa Kang Fishery Reserve (Hartoto, 1997). These lakes function as an important feeding ground for indigenous large aquatic mammal, Irrawady Dolphine (*Orcaella brevirostris*) or locally refer as the *Pesut* (Hartoto *et al.* 2002).

Lake Loa Kang Fishery Reserve (LLFR) is a floodplain system located near Liang Village, Kotabangun District. Kutai Kertanegara Regency, East Kalimantan. It consists of several habitat types, among the others, two backswamp depression lakes

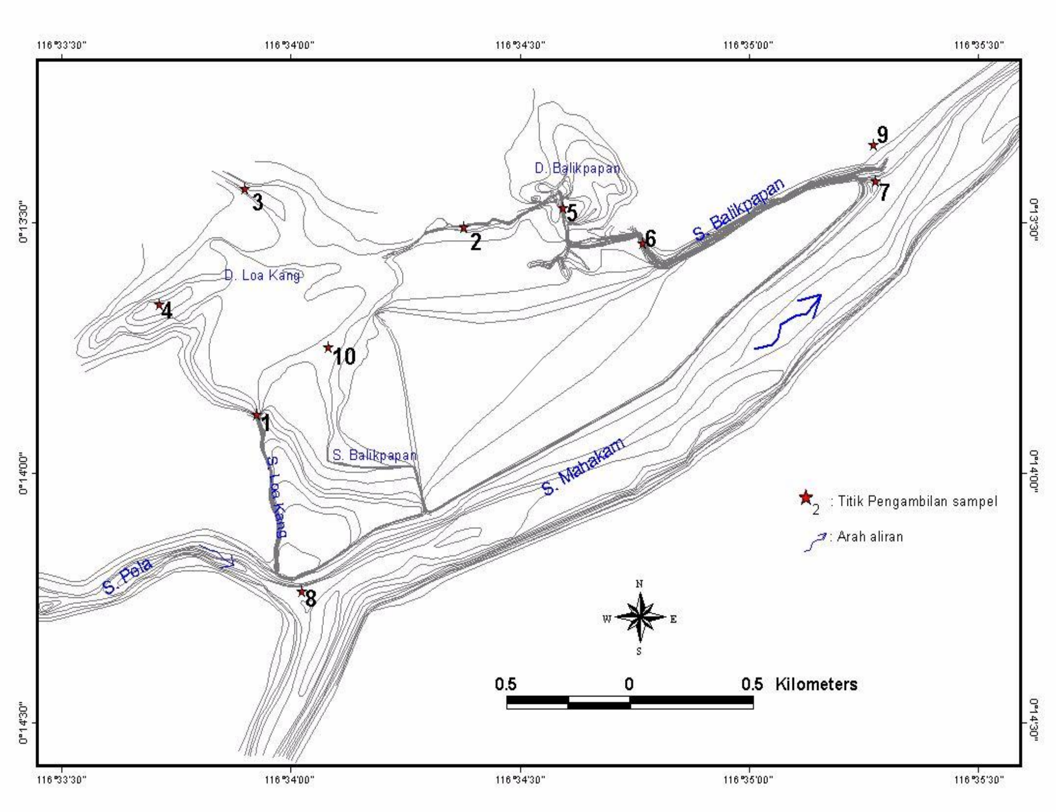

Figure 3.1. Location of sampling stations in Lake Loa Kang Fishery Reserve

Table 3.1. Classification of Ecological Habitat Types in Lake Loa Kang Fishery Reserve.

No.	Habitat Types	Location
1.	*Hakang or* Lebung, a depression lake in floodplain system	L. Loa Kang (St.4) and L Balikpapan (St. 5)
2.	Connecting channel between floodplain lakes	Connecting channel between L. Loa Kang and L. Balikpapan (St. 2)
3.	Connecting channel between the floodplain depression lake and main river	R. Loa Kang (St.1) and R. Balikpapan (St.6)
4.	Junction of tributary and main river	Mouth of R. Pela (St.8)
6.	A spring in floodplain system	Tunjung Springs (St.3)

that refer as Lake Loa Kang and Lake Balikpapan. The depths of these two lakes are influenced by the fluctuation of water level of River Mahakam. River Mahakam exchanges water; which carry organic and inorganic matter; with its floodplain and this phenomenon influenced the ecological balance of the system. Disruption of natural purification capacity decreased water quality of the lake (Hartoto *et al*. 2002).

In lake system, bacteria is an active microorganism that function in degradation and assimilation of organic matter such as carbon, nitrogen, phosphor and other nutrients (Badjoeri *et al*. 2001). Heterotrophic Bacteria (HB) in aquatic system is strongly related to organic matter decomposition process. Therefore, the increase of organic matter content is usually followed by increasing abundance of HB population. The study was aimed to predict spatial and temporal distribution of heterotrophic bacteria and its relationship with the changing of organic matter content.

MATERIALS AND METHODS

Sampling methods

The survey was conducted three times in 2003 and once time in 2004, those are at June 2003, August 2003, September 2003 and July 2004. Sampling was done at seven stations that represent five habitat type (Fig. 3.1 and Table 3.1). Water samples were taken on surface layer by Snatch Bottle Sampler and collected in sterilized bottle sample and saved in the cool box. For HB analysis, samples were analyzed in the field laboratory whereas Total Organic Matter (TOM) data is refer to Yustiawati *et al.* (2004, this monograph).

Sample analysis methods

Analysis of heterotrophic Bacteria was conducted by Total Plate Count (TPC) Method with Spread Plate Technique. Media that was used to grow the heterotrophic bacteria is Nutrient Agar or NA (48 g in 1000 ml sterilized water). Water sample was taken 100 µL from each sampling stations and than diluted gradually until 10^{-8}. The solution then inoculated into NA media and incubated at 37 ^{o}C for 24 hours. The samples from each sampling stations was analyzed in three replicates. The number of heterotrophic bacteria in the sample calculated by the formula described by Cappucino & Sherman (1983).

$$P = \frac{1000 \text{ x } (\Sigma \text{ colony x dilution})}{\text{Volume of inoculated sample } (\mu\text{L})}$$

Where P = number of heterotrophic bacteria cells in one ml sample

Total Organic Matter concentration was analyzed using permanganate method that was described by Putra. *et al*. (1992), whereas the other parameter such as Nitrogen, Phosphorus, BOD_5 and Suspended Solid refer to report of Yustiawati *et al.* (this monograph). Direct measurement of water quality parameter, such as pH, temperature, conductivity and dissolved oxygen were conducted using Horiba Water Quality Checker U-10.

Data analysis methods

Data analysis was conducted by Statistica Version 5 and MS. Excell 98 software.Regression analyses was done according to the Methods described by Zar (1999)

RESULTS AND DISCUSSION

The results of laboratory analysis (Table 3.2) showed that the number of heterotrophic bacteria were varied for each habitat types. This pattern quite similar to the spatial and temporal distribution pattern of Total Organic Matter concentration (Table

Table 3.2. Number of Heterotrophic Bacteria during four observations

Station	Heterotrophic Bacteria (cells.mL^{-1})				
	June 2003	Aug. 2003	Sept. 2003	July 2004	Average
1	ND	14.5 x 10^7	ND	14.5 x 10^7	14.5 x 10^7
2	ND	ND	31.0 x 10^6	44.3 x 10^6	37.7 x 10^6
3	ND	38.7 x 10^7	33.0 x 10^6	50.7 x 10^6	15.6 x 10^7
4	42.0 x 10^6	38.0 x 10^7	27.0 x 10^6	12.8 x 10^7	14.4 x 10^7
5	18.0 x 10^7	83.3 x 10^7	71.0 x 10^6	12.1 x 10^5	27.1 x 10^7
6	35.4 x 10^7	36.7 x 10^8	41.1 x 10^7	20.0 x 10^5	11.1 x 10^8
8	12.1 x 10^7	24.7 x 10^7	36.0 x 10^6	46.2 x 10^7	21.7 x 10^7
Average	17.4 x 10^7	94.3 x 10^7	10.2 x 10^7	11.9 x 10^7	33.9 x 10^7

ND= no data

Table 3.3. Concentration of Total Organic Matter (TOM) during four observations

Station	Total Organic Matter (mg.L^{-1})				
	June 2003	Aug. 2003	Sept. 2003	July 2004	Average
1	ND	59.080	ND	51.192	55.136
2	ND	ND	14.823	44.240	29.532
3	ND	130.180	21.511	52.456	68.049
4	20.856	139.66	11.677	44.872	54.266
5	61.304	76.46	14.823	52.456	51.261
6	73.312	814.38	23.671	48.664	240.010
8	64.464	87.52	14.191	29.704	48.970
Average	54.984	217.88	16.783	46.655	84.848

ND= no data

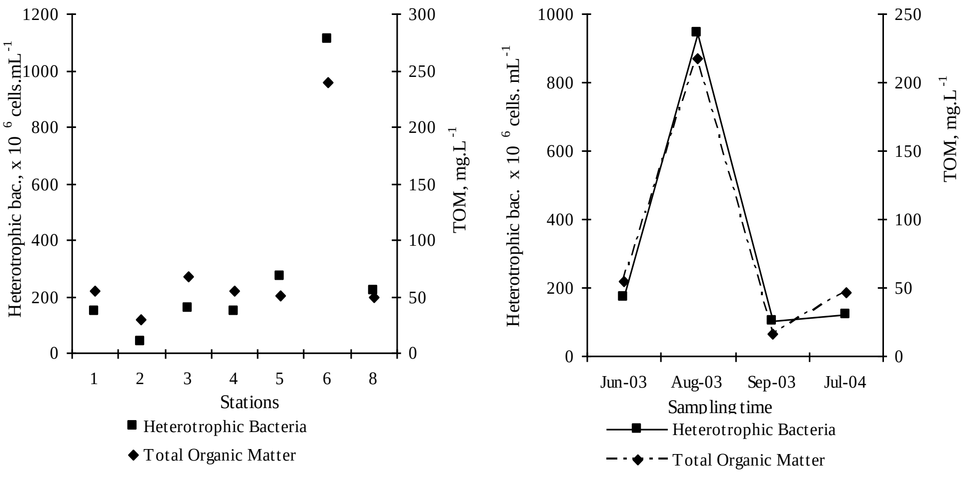

Figure 3.2. Spatial and temporal distribution of HB and TOM

3.3).

Spatially, Fig. 3.2 showed that the highest average of heterotrophic bacteria number (11.1 x 10^8 cells.mL^{-1}) was found at connecting channel between floodplain lakes and the main river (St.6) and the lowest was found at St. 2 (37.7 x 10^6 cells.mL^{-1}). This pattern was in coincidence with the pattern for TOM concentration that are 240.010 mg.L^{-1} and 29.532 mg.L^{-1} for St. 6 and St. 2 respectively.

The abundant organic matter at St. 6 could be originated from domestic waste

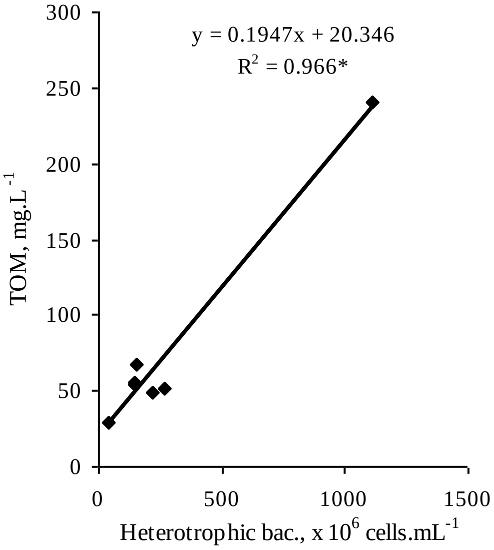

Figure 3.3 Correlation between the number of heterotrophic bacteria cells and TOM

Table 3.4. Physico-chemical water quality parameter of several stations at Lake Loa Kang Fishery Reserve

Station	Parameter							
	pH	Cond. mS.cm-1	DO mg.L-1	Temp. ^{o}C	T-N mg.L-1	T-P mg.L-1	SS mg.L-1	BOD$_5$ mg.L-1
1	5.36	0,055	5.68	24.9	6.92	0.238	80.50	5.594
2	6.46	0,032	5.41	29.4	9.453	0.069	16.67	1.122
3	6.07	0.038	3.38	28.0	5.436	0.266	43.33	3.107
4	6.31	0.035	3.24	29.6	2.072	0.254	72.55	2.657
5	6.32	0.041	4.67	26.8	1.696	0.263	96.3	3.068
6	6.14	0.039	4.13	30.6	2.604	0.139	74.01	5.686
8	6.79	0.042	4.61	30.8	3.311	0.380	99.17	1.513

Source : Yustiawati *et al.* 2004

and the waste of transportation vehicles such as the boats that pass by the River Mahakam. Temporally, Fig. 3.2 showed that number of HB and TOM on each sampling time were varied. The highest (9.43 x 10^8 cells.mL^{-1} and 217.88 mg.L^{-1}) and lowest average (10.1 x 10^8 cells.mL^{-1} and 16.62 mg.L^{-1}) of HB number and Total Organic Matter concentration were found on August and September 2003 respectively. This condition probably caused by differences in season. The month of August is transitional season when the surface runoff carried organic matters from soil and adjacent dry swamp to LLFR area. On September 2003, when the water flow is increasing, the water level is rising and removed the organic matter from the soil.

Fig 3.3 showed that there is a significant correlation between the number of Heterotrophic Bacteria and Total Organic Matter concentration. Widiyanto (1998) descriptively indicated that the abundant number of Heterotrophic Bacteria in inland water was sustained by the environment that was represented by physico-chemical characteristics such as Total Phosphor (T-P) and Total Nitrogen (T-N), Suspended Solid (SS), Dissolved Oxygen and others. According to Goldman and Horne (1983) the Heterotrophic Bacteria need an amount of oxygen to decompose the organic matter that represented by Biological Oxygen Demand (BOD_5). The results of analysis of those parameter in this study was presented in Table 3.4. According to statistical analysis, TOM is significantly correlated with Heterotrophic Bacteria number ($r = 0.966$) but no significant correlation was observed for the other parameters.

Average Heterotrophic Bacteria number in all habitat of LLFR is 33.9 x 10^7 cells.mL^{-1}. Generally, this value is higher compared to the HB number of other types of inland water in Indonesia such as in Ranu Grati (Widiyanto, 1998) and L. Maninjau (Badjoeri, *200*1) that is always less than 10 x 10^7 cells.$mL^{-1.}$ The pattern probably due to the water in LLFR has higher content of humic acid resulted from assimilation of organic matter in soil and water. This condition also indicated that all habitats in LLFR is progressing toward a eutrophic aquatic system. Rheinheimer (1980) reported that an aquatic system is classified as a eutrophic when it has the number of Heterotrophic Bacteria between 2.2–12.3 x 10^5 cells.$mL^{-1.}$ In naturally functioned aquatic system, the number of Heterotrophic Bacteria is around the magnitude of 10 x 10^4 cells.mL^{-1} (Anonymous, 1988).

CONCLUSION

Spatially, the number of heterotrophic bacteria on each ecological habitat types in LLFR were varied. Temporally, the number of heterotrophic bacteria on each sampling time were varied, according to season. The number of heterotrophic bacteria is significantly correlated with Total Organic Matter. Generally, the number of HB in LLFR is higher than in several habitat in Indonesian inland water such as L. Ranu Grati and L. Maninjau. This case probably because the inland water system in LLFR has higher content of organic matter in soil and water.

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4. SPATIAL DISTRIBUTION OF NITRIFYING BACTERIA IN LAKE LOA KANG FLOODPLAIN

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ABSTRACT

Lake Loa Kang is a fishery reserve located in a floodplain system of River Mahakam. This floodplain consists of several habitat types, such as backswamp deposit lakes represented by Lake Loa Kang and Lake Balikpapan. This two floodplain lakes exchange water with River Mahakam and one of its tributary, the River Pela. Nitrification is one key of microbiological process of nitrogen cycle in inland water. The nitrifying bacteria functional group that mediated the process can be detected and identified by the technique of enrichment culture. This study was aimed to reveal the features of nitrification process in several floodplain habitat types of Lake Loa Kang Fishery Reserve (LLFR) system with emphasize on the spatial and temporal distribution pattern of nitrifying bacteria. The information gather from the study will be utilized as limnological data base for development of conservation and restoration measure of floodplain habitat. Water samplings are conducted for three times in 2003, those were in dry (June), transitional (August) and the rainy season (September). The results of the study showed that the number of nitrifying bacteria is highest in connecting channel between floodplain lakes and tributary river (R. Loa Kang) and the lowest in floodplain deposit lakes (L Balikpapan). Ex situ simulation of this biogeochemical cycle indicate a duration of 13 - 21 days to complete the nitrification process. The number of nitritation and nitratation bacteria in Lake of Loa Kang in the dry season is smaller compared to the number in rainy season. The duration of nitrification process in LLFR suspected to be influenced by the number of bacteria, organic material and season.

Key words: *Nitrifying bacteria, Loa Kang, floodplain*

INTRODUCTION

The Mahakam floodplain system is a vast complex of inland water, which are interconnected one to another and finally to River Mahakam. These inland waters include the bigger floodplain lakes such as Lake Semayang (13,000 ha), Melintang (10,000 ha) and Jempang (15,000 ha) and smaller lakes such as Lake Siran, Batu Bumbun, Loa Kang, Kahol Pongkol and Balikpapan (Lukman and Gunawan, 1998). These floodplains for many decades has functions as a very important fishing ground for inland water fishers.

Suwelo in 1984 as cited in Lukman (1997) reported that there are seven fishery reserves in the centre of Mahakam watershed. Hartoto *et al*. (2002) cited that there are eleven fishery reserves in Mahakam floodplain. These fishery reserves are Lake Batu Bumbun, Lake Ngayan, Lake Loa Kang, Lake Padam Api, Lake Tanah Liat, Lake Gab, Batangan Muntai River, Jantur Malang River and several bays in L. Semayang, such as Berduit, Selimau and Kademba Bays.

Lake Loa Kang is a fishery reserve system (Hartoto *et al*. 2002) that consist, among the others, of two floodplain lakes, refer as Lake Loa Kang and Lake Balikpapan.

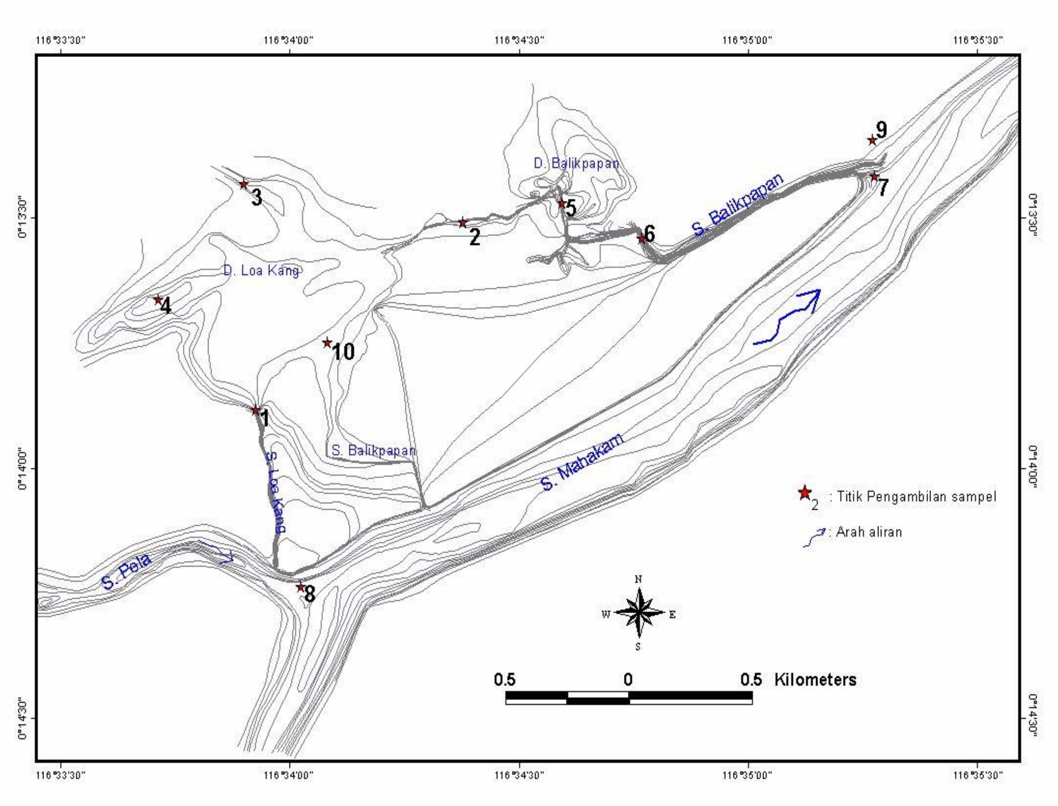

Figure 4.1. Location of sampling stations in Lake Loa Kang Fishery Reserve

The two lakes exchange water with and ecologically connected to River Mahakam and one of its tributary, the River Pela. Lake Loa Kang is already designated as a fish sanctuary since about 500 years BP during the authority of Moslem Kutai Kertanegara Kingdom, but the appropriate protection of fishery reserve ceased to exist after 1970-ies.

Although information on the role of Kutai Kingdom in conservation of indigeneous Irrawady Dolphin (*Orcaella brevirostris* or *Pesut Mahakam*) was not available, recent observations indicate that location of fishery reserve is related to the feeding area of the aquatic mammal. In spite of extensive of poaching in the lake, it is recorded that there are habitat characterized as spawning, rearing, feeding, roaming and refuge site for freshwater fishes in Lake Loa Kang (Hartoto, 1997).

Bacteria and another microorganism play a decisive role in the cycling of material in aquatic system. The role of bacteria in the primary production of organic material is small but they re-mineralize it on a large scale under the appropriate conditions. They are able to break down virtually all of natural organic compounds into the components from which they originated (Rheinheimer, 1985; Rodina, 1983). Nitrogen, as a constituent of protein, is a vital element for every type of living organism. It is taken up by green plants mainly in the form of ammonia or nitrate. These compounds, however, occur in most waters in only very small quantities, so that the nitrogen is the limiting factor for plant life in rivers, lakes and the sea (Rheinheimer, 1985). Nitrification is a key microbiological process of nitrogen cycle in inland water.The dynamic interaction of microbiological reactions within the nitrogen cycle renders the analysis of different processes very difficult (Hastings *et al.*, 1998).

Table 4.1. Description of sampling stations in Lake Loa Kang Fishery Reserve

Station	Location, habitat type	Coordinates	
		South	East
1.	River Loa Kang, a connecting channel between the floodplain depression lake and main river	S. 0° 13’ 53.1”	E. 116° 33’ 55.6’’
2.	Connecting channel between floodplain lakes. L. Loa Kang, and Lake Balikpapan.	S. 0° 13’ 30.5”	E. 116° 34’ 22.7”
3.	Tunjung Springs, A spring in floodplain system	S. 0° 13’ 26.0”	E. 116° 33’ 54.0”
4.	L. Loa Kang (*Hakang) or* Lebung, a backswamp deposit lake in a floodplain system	S. 0° 13’ 39.9”	E. 116° 33’ 42.9”
5.	L. Balikpapan *or Lebung* a backswamp depression lake in floodplain system	S. 0° 13’ 28.3”	E. 116° 34’ 35.6”
6.	R. Balikpapan, a connecting channel between the floodplain depression lake and main river. A floodplain river (a small tributary of R. Mahakam)	S. 0° 13’ 32.5”	E. 116° 34’ 46.1”
7.	Mouth of River Balikpapan, Junction of R. Balikpapan and R. Mahakam	S. 0° 13’ 25.0”	E. 116° 35’ 16.5”
8.	Mouth of River Pela. Junction of R. Pela and R. Mahakam	S. 0° 14’ 14.0”	E. 116° 34’ 0.9”
9.	*Lopak,* small size ephemeral pond in LLFR	S. 0° 13’ 20.7”	E. 116° 35’ 16.4”
10.	Maling canal, a segment of man made canal that connect L. Loa Kang with R. Mahakam	S .0° 13’ 45.8”	E. 116° 34’ 5.0”

Nitrification as an important process in nitrogen cycle defined as the oxidation of ammonia into nitrites and then into nitrates. The nitrates are further converted to organic nitrogen compounds in the microbial cells (Rodina, 1972). Ammonia that is liberated during the ammonification process seldom accumulates to any appreciable extent in the soil. In an aerobic environment, it undergoes bacterial oxidation to nitrates by two-step process by primarily the chemoautotrophic soil microorganism that is *Nitrosomonas* and *Nitrobacter* (Cappucinno & Sherman, 1983; Rheinheimer, 1985). The two-steps process is as below:

$$NH_4^+ + 1\tfrac{1}{2}\ O_2 \xrightarrow{\qquad\qquad} NO_2^- + H_2O + 2\ H^+ + 76\ \text{kcal}$$

$$NO_2^- + \tfrac{1}{2}\ O_2 \xrightarrow{\qquad\qquad} NO_3^- + 24\ \text{kcal}$$

Nitrifying bacteria cannot be directly enumerated on agar plates and information on their occurrence and distribution in freshwater lakes is derived from most-probable-number (MPN) determinations based on measurements of nitrite formation in vitro. The method was reported by Rowe *et al.* in 1977 and by Hall in 1986 as cited in Hasting *et al.* (1998). MPN determinations can be augmented by specific nitrification rate measurements. The nitrifying bacteria species that mediate the process can be detected and identified by enrichment culture. This study was aimed to reveal some features of nitrification process in several floodplain habitat types of Lake Loa Kang Fishery Reserve system, with emphasize on the spatial distribution pattern of nitrifying bacteria. The results of the study will be utilized as limnological data base for development of conservation and

Table 4.2. The description of the test media composition for nitrifying bacteria

Preparation	Composition of test medium	Methods
Nitrite Formation	Sulphate broth medium 1. $(NH_4)_2$ SO_4 2 g 2. K_2HPO_4 1 g 3. $MgSO_4$ 7 H_2O 0,5 g 4. $FeSO_4$ 7 H_2O 0,4 g 4. $CaCO_3$ 5 g 5. Distilled water 1000 ml 6. pH medium 7,4	1. MPN (Most Probable Number) method with 3 test tube series 2. Not sterilization 3. Incubation : 21 days in temperature 28 ℃ 4. NEDD and Sulphanilamide reagent for detection of nitrite or Trommsdorf's reagent and sulphuric acid.
Nitrate Formation	Nitrite broth medium 1. Na NO_3 1g 2. Na_2CO_3 1g 3. NaCl 0,5 g 4. K_2HPO_4 0,5 g 5. $MgSO_4$ 7 H_2O 0,3 g 6. $FeSO_4$ 7 H_2O 0,3 g 7. Distilled water 1000 ml	1. MPN (Most Probable Number) method with 3 test tube series 2. Reagent : Diphenylamine, sulphuric acid 3. Sterilization 121℃, 1 atm, 20 minutes 5. Incubation : 21 days in temperature 28 ℃ 6. Brucine (5%) reagent for detection of nitrate

Table 4.3. The criteria and methods to evaluate the nitrification process

No.	Reagent	Determinations
1.	NEDD and Sulphanilamide	Test for the presence of nitrate is using NEDD and Sulphanilamide reagent. A pink colour indicate that nitrate was oxidized to nitrite.
2.	Trommsdorf's	Test for the presence of nitrite is using Trommsdorf's reagent and sulphuric acid. The presence of a blue-black colour is and indicator of the presence of nitrite and No colour changes is indicative of the absence of nitrite or that nitrates have not been formed.
3.	Brucine	Test for presence of nitrate by use Brucine reagent (5%). The presence of pink colour is indicative of the presence nitrates, and presence of yellow colour changes is indicative of presence nitrate.

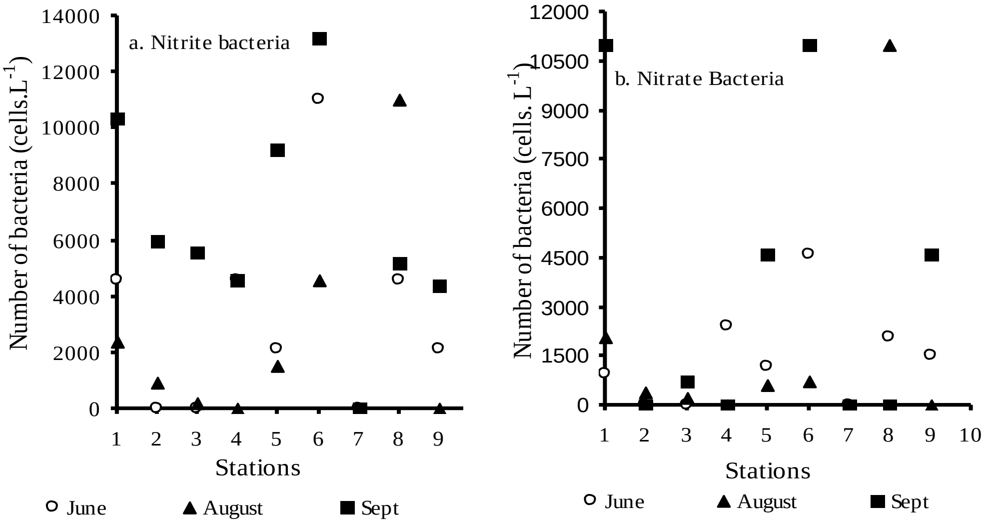

Figure 4.2. Spatial and temporal distribution of nitrite (a) and nitrate (b) bacteria of LLFR .

restoration measures of *Pesut* habitat.

MATERIALS AND METHODS

Lake Loa Kang Fishery Reserve (LLFR) lies at Kota Bangun District, Kutai Kertanegara Regency, East Kalimantan. Water samplings are conducted for three times, the first is in dry season (June 2003), second in the transitional season (August 2003) and the third (September 2003) in the dry season. The water samples were collected compositely from the water-sediment interface layer, middle and to surface layers for each sampling stations. Water samples and parameters measurement are taken at eight sampling stations. The sampling stations in LLFR was presented in Fig. 4.1. A tiny amount of the samples were inoculated to the appropriate medium. The medium for each analyzes is prepared according to Cappuccino and Sherman (1983) and Rodina (1972). The description of sampling stations in the area of LLFR and the habitat type they represented were shown in Table 4.1.

The analysis of nitrifying bacteria is conducted according to Most Probable Number (MPN) Method using three test tubes series (Cappuccino & Sherman, 1983; Rodina 1972). The description of the composition of the test media for nitrifying bacteria is presented in Table 4.2. The criteria and methods to evaluate the process is shown in Table 4.3. To evaluate the relationship between natural environment condition and the nitrification process, water quality data such as Total Nitrogen (T-N), ammonia-N and nitrite-N are refer to data presented by Yustiawati *et al.* (2004. this Monograph).

RESULTS AND DISCUSSION

As shown in Fig. 4.2., the spatial distribution of nitrite bacteria in LLFR indicate the highest number was observed in connecting channel between the floodplain depression lake and main river (R. Loa Kang, St.1) and the lowest was observed in small size (*Lopak,* St.9). As for the nitrate bacteria, the highest number was found in the floodplain river (R. Balikpapan, St.6) and the lowest was recorded in the connecting channel between the two floodplain lakes (St. 2). The number of nitritation bacteria in the dry season range from 2100–11000 cells.L^{-1}, which is higher compared to the number in transitional season that range 210 - 11000 cells. L^{-1}. In rainy season, when the water level is increasing, the number of nitrite bacteria is the highest (11000 – 24000 cells. L^{-1}). The temporal distribution of nitrifying bacteria in LLFR at dry season its the lowest compared to the number of this bacteria in rainy season.

The temporal distribution of nitrifying bacteria in LLFR showed that the number of bacteria in the dry season is the lowest compared to rainy season (Fig. 4.2). The spatial distribution of nitrate bacteria in LLFR showed the pattern where the highest number of bacteria was found in River Balikpapan (St.6) and the lowest in connecting channel between floodplain lakes (St. 2). The number of nitratation bacteria in the dry season range from 930 to 4600 cells. L^{-1}. On the other hand, the nitratation bacteria in transitional season is increasing and range from 230 to 11000 cells. L^{-1} and in rainy season is increasing further up to 750 - 11000 cells.L^{-1} (Fig. 4.2).

The number of nitrifying bacteria is the summation of the number of nitritation and nitratation bacteria. Comparison between the two types of nitrifying bacteria always showed that the number of nitritation bacteria is always higher than the nitratation bacteria in all habitat types (Fig 4.3). This pattern is also reported by Rheinheimer (1985)

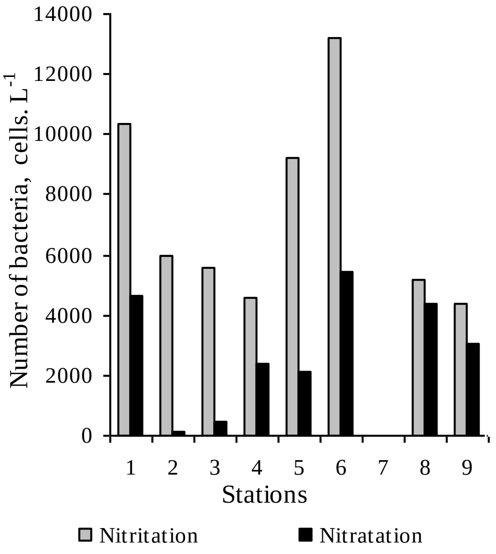

Figure 4.3. Comparison of the number of nitritation and nitratation bacteria in each station of LLFR

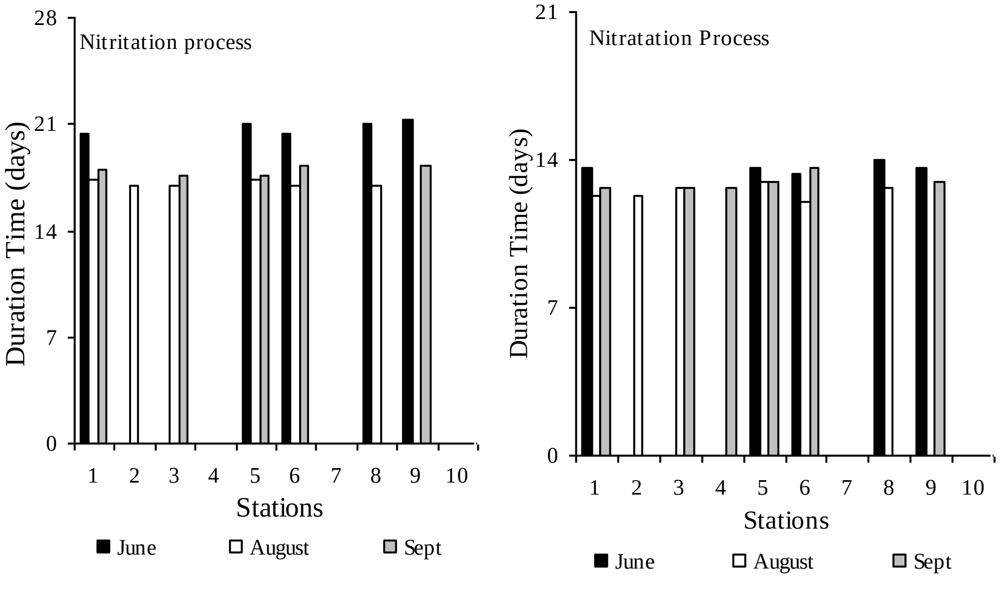

Figure 4.4. The time duration required to complete nitrification process in several habitat types of LLFR

and Hartoto *et al.* (1998) who described that the ratio of nitritation to nitratation bacteria in water is 13:1, while in sediment the ratio is 28:1. Lowest of amount of nitratation bacteria was observed either in water and sediment because this bacteria are

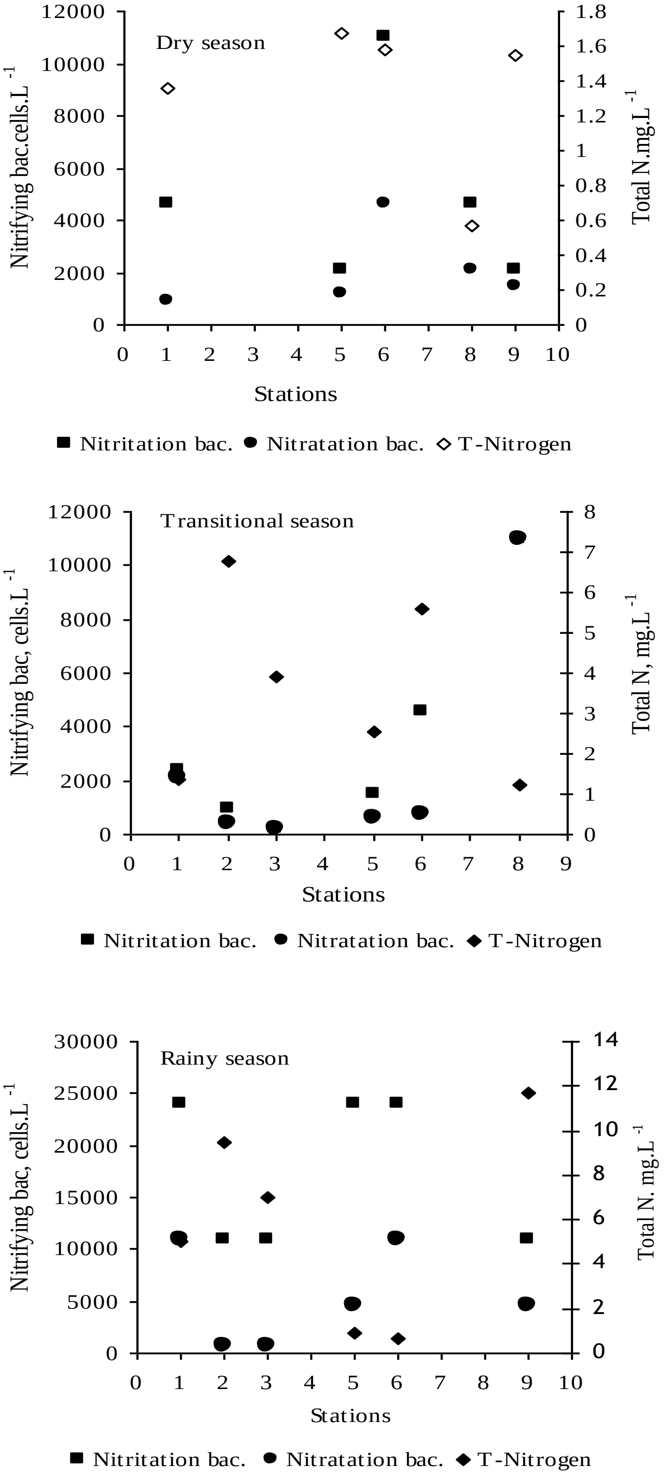

Figure 4.5a.The concentration of Total-N and the biomass of nitrifying bacteria in the dry, transitional and rainy seasons at LLFR.

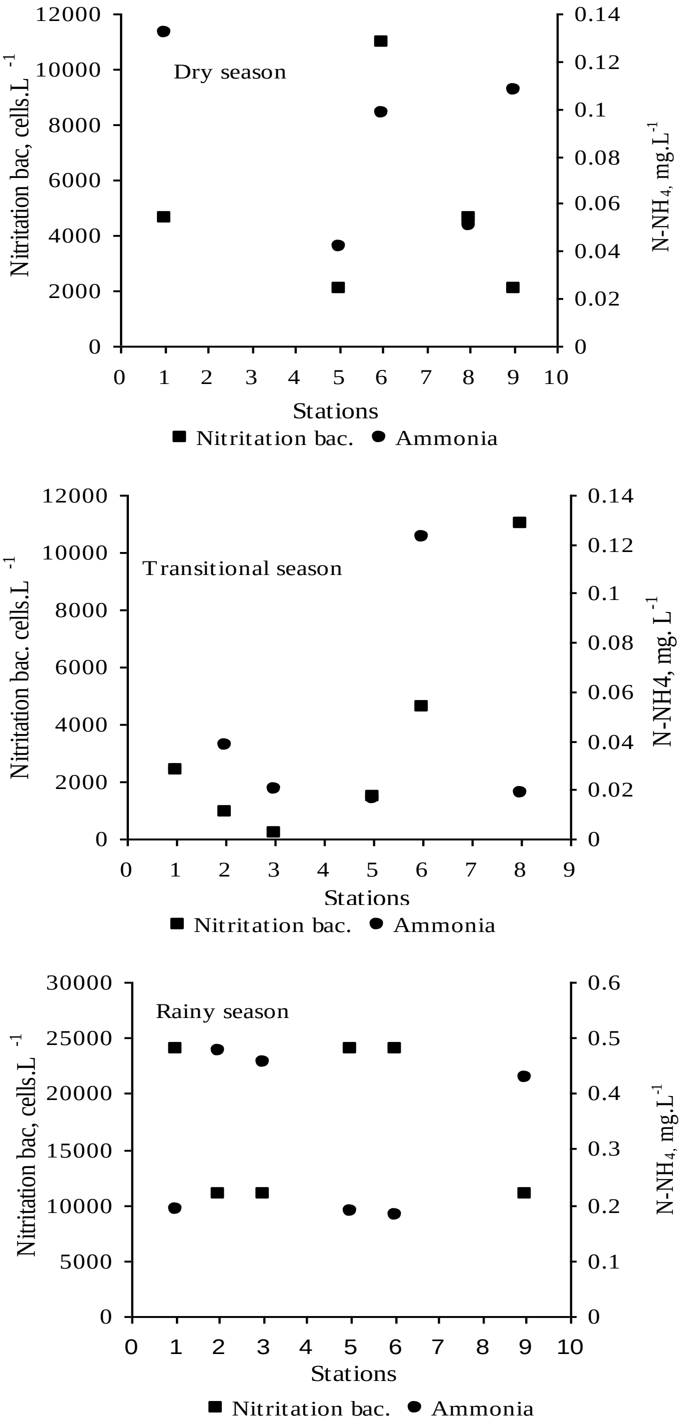

Figure 4.5b. The concentration of ammonia and the biomass of nitritation bacteria in the dry, transitional and rainy seasons at LLFR.

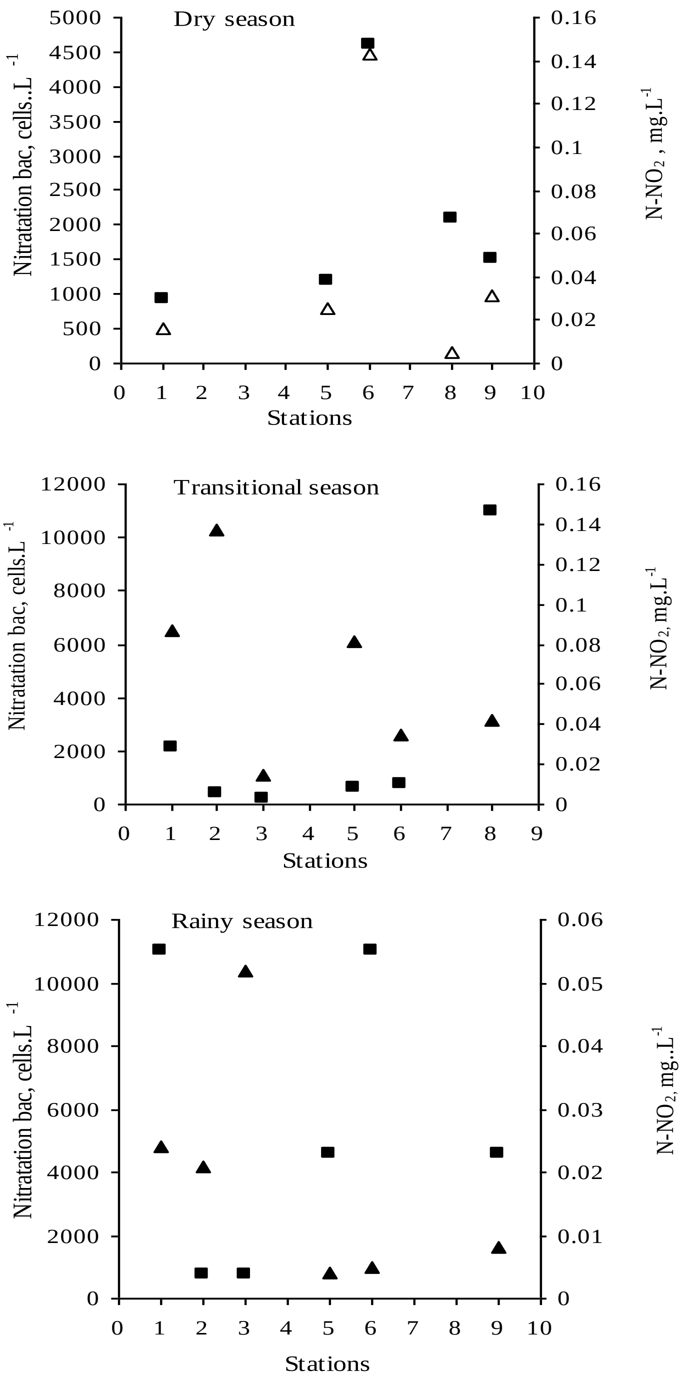

Figure 4.5c. The nitrite concentration and the biomass of nitratation bacteria at LLFR

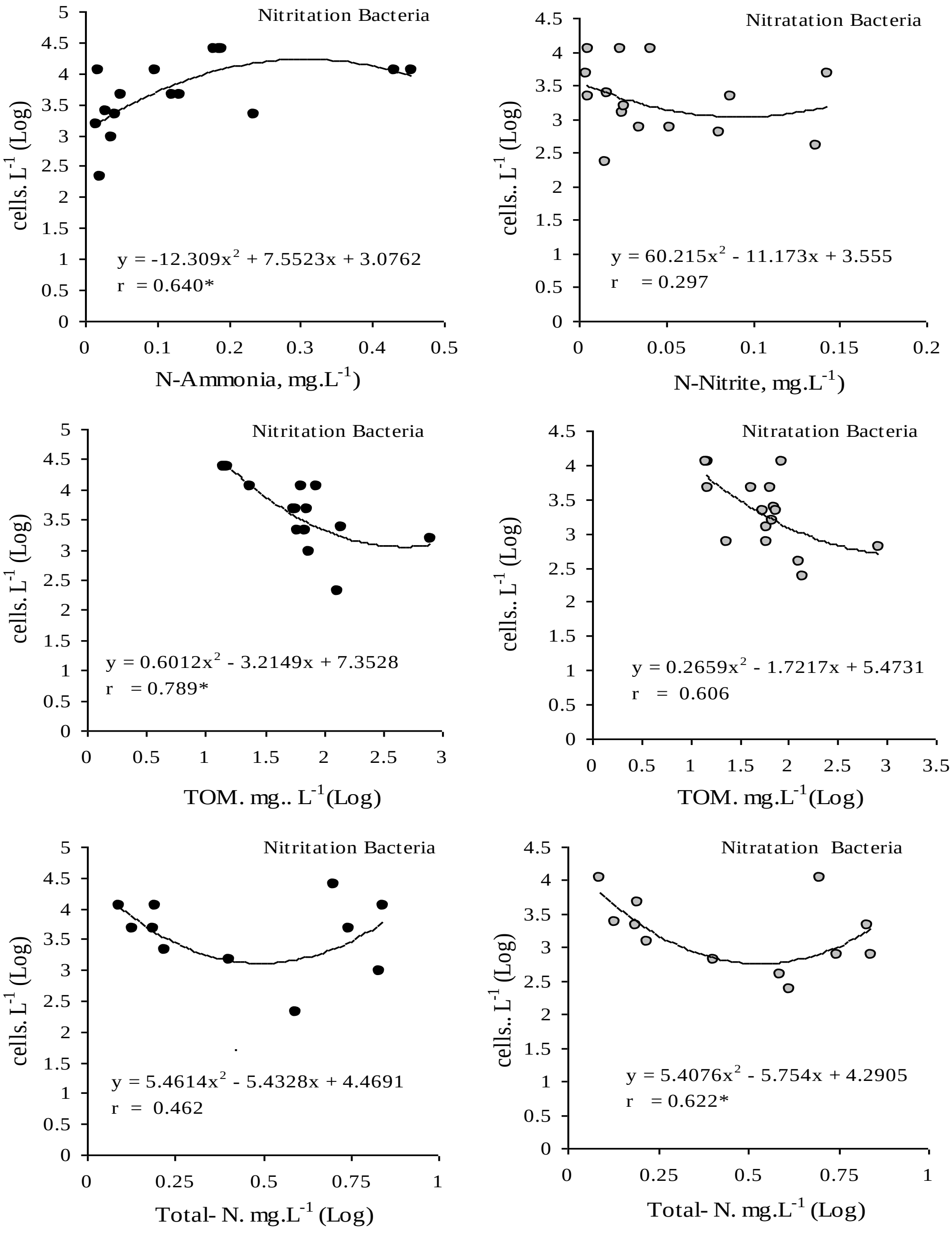

Figure 4.6. The correlation analysis between nitritation and nitratation bacteria with the levels ammonia, nitrite, TOM and Total-N in LLFR.

more sensitive to oxygen content under its optimal growing condition. This pattern was also observed in Lake Maninjau, West Sumatra (Badjoeri, 2002). The number of nitritatation bacteria (1.34 – 2.96 x 10 ^{3} cells. mL^{-1}) is higher than nitratation bacteria (1.08 – 2.70 x 10 ^{3} cells. mL^{-1}).

Based on the time required by the samples to complete the nitrate formation, the results of the study also showed that nitrification in LLFR is still running in its natural condition. The duration required to complete nitrification process (*ex situ*) in the medium is range 13–21 days (Fig. 4.4). The duration of nitrification process for bacteria from Lake Bojongsari, a small tropical floodplain lake in the vicinity of Bogor (West Java), is around 19.7–22 days (Meutia and Hartoto, 1990), deep vulcano-tectonic lake in West Sumatra, the time required for nitrification is range 12-22 days and in Semayang-Melintang is 30 days (Badjoeri, 1996).

Nitrification process in most habitat types of Lake Loa Kang Fishery Reserve was influenced by number of bacteria, organic material and season. Increased number of nitrifiying bacteria in the rainy season in R. Balikpapan probably caused by the flushing of allochthonous organic material from adjacent area. In the rainy season, the number of and as for the case of Lake Maninjau, a nitrifying bacteria in backswamp depression lake (Lake Loa Kang) is increasing probably because the lake is receiving water that carried a lot of inundated organic debris from R. Mahakam (through the mouth of R. Balikpapan, St 7) and from segment of R. Pela (through R. Loa Kang). Increasing availability of organic matter, probably trigger the growth of nitrifying bacteria, that started to increased in number at early rainy season (in August) and at the middle of rainy season (September) the decomposition of organic materials is significantly started to occur. This pattern is also supported by increasing concentration of total nitrogen, ammonia and nitrite of June to August and September (Fig. 4.5 a, b and c).

The results of correlation analysis (Fig. 4.6, $r_{\text{table P= 0.05; v=13}} = 0.608$) between the number of nitrification bacteria showed that there are significant correlation between the number of nitritation bacteria with ammonia and Total Organic Matter (TOM), but there is no significant correlation with Total Nitrogen (TN). On the other hand, for nitratation bacteria, the number of cells only significantly correlated with Total Nitrogen (T-N).The cause of this pattern is subject for further studies.

CONCLUSION

The spatial distribution of nitrifying bacteria in Lake Loa Kang Fishery Reserve indicated that at the dry season the number of cells is at its lowest compared to other season. Nitrification process in Lake Loa Kang Fishery Reserve influenced by number of bacteria, organic material and season. The nitrification process can be completely finished in the duration of 21 days. There is a correlation between the number nitrifying bacteria with ammonia, total organic material and total nitrogen.

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Ecological Integrity of A Mahakam Floodplain System: 45-53

5. SPATIAL DISTRIBUTION OF SULFIDE IN WATER COLUMN OF SEVERAL HABITAT TYPES OF LAKE LOA KANG FLOODPLAIN

By
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ABSTRACT

*The deteriorated condition of Lake Loa Kang Fishery Reserve (LLFR) probably could not anymore sustain the life of white water fishes that function as the food for the indigeneous Irrawady Dolphin or Pesut (*Orcaella brevirostris*) that lives in River Mahakam. The LLFR introduced as a fish sanctuary that functions to supply natural brood stock and fingerlings for local capture fishery since 500 years ago. The study of sulphurous compound, especially sulfide is one of the important foundations in designing habitat conservation measures for the sustainability of fish production and maintaining good water quality. The aim of the study is to reveal the spatial distribution pattern of the sulfide in several habitats of LLFR. Measurement and water sampling were done three times in June, August and September 2003 at 10 sampling stations represent eight habitat types within the floodplain system. The sulfide, Total Organic Matter (TOM) and* BOD_5 *were analyzed according to the method described in Standard Methods 18th edition. The results showed that concentration of sulfide tends to decrease from June to September. The highest concentration (2.611* $mg.L^{-1}$*) was found at the Mouth of River Pela (junction of main river and its tributaries) in June at dry season. Meanwhile River Loa Kang; that represents connecting channel between back swamp deposit lake and tributary river; has the lowest concentration (0.006* $mg.L^{-1}$*) in rainy season (September). The results shown that sulfide concentration in LLFR sometimes higher than recommended concentration in Government Regulation No. 20/1990 for water of Class B for fisheries (0.1* $mg.L^{-1}$*), but the concentration is less than the sulfide concentration in oxbow lakes of Central Kalimantan and Lake Maninjau, West Sumatra.*

Key words: *spatial, distribution, sulfide, Lake Loa Kang.*

INTRODUCTION

Since many years ago**,** floodplain system of Mahakam River known as the habitat for white water fishes that function as the food for indigenous Irrawady Dolphin (*Orcaella brevirostris*) or *Pesut* (Hartoto, 1998). One of the floodplain system is Lake Loa Kang that already designated as fishery reserves. As reported by Hartoto *et al.* (2002), the condition of the Lake Loa Kang Fishery Reserve (LLFR) has become deteriorated because of lack in management input and ecologically, probably already can not sustain a significant size of ichthyofauna anymore. The function as the harvest reserve to sustain capture fishery production is questionable since there are frequent poaching using electric fishing, poison and others illegal fishing methods. In the dry season when the water level declining, sedimentation occurred in many parts of the lakes. Human activities also damaged some of the floodplain habitats, such as the floodplain depression lakes, swamp forest and inundated grassland and altered the natural water exchange pattern. Important limnological factors for the data base to revitalize floodplain system are habitat typology, water quality, the intactness of food chains, the nature of biogeochemical processes and ecological connectivity of the system.

One of the factors that affected the quality of lake waters is toxic agent such as sulfur. There are so many forms of the sulfur but in natural waters, most are in the form of sulphate. Sulphate is reduced to sulfhydril (-SH) groups in protein synthesis, with a concomitant production of oxygen that is utilized in oxidative metabolic reactions (Wetzel, 2001). The existence of many of sulfur forms interrelated with each other in one cycle called the sulfur cycle. One of the sulfur forms is sulfide that often present in natural water including lakes. It is common present from the decomposition of organic matter, sometimes from industrial wastes, but mostly from the bacterial reduction of sulphate (APHA-AWWA, 1992). By decomposition of organic matter, sulfur releases as hydrogen sulfide (H_2S) that under aerobic conditions is rapidly oxidized to sulphate (Jorgensen, 1980). The redox mechanism of sulfide existence is as below

Oxidation reaction:

$$(CH_2O) + SO_4^{2-} \longrightarrow 2\,CO_2 + 2\,OH^- + H_2S$$

$$H_2SO_4 + 4\,H_2 \longrightarrow 4\,H_2O + H_2S$$

Reduction reaction:

$$S^{2-} + 2\,O_2 \longrightarrow SO_4^{2-}$$

Hydrogen sulfide is toxic and considerably deteriorates the organoleptic properties of water. Water bodies used for sanitary and hygienic purposes and fisheries should be rigidly regulated for hydrogen sulfur content (UNESCO and WHO, 1978). According to Jorgensen (1980), even though the average of sulfur compounds in the aquatic system was 0,2 %, it hardly makes it a limiting nutrient. However, sometime when it is considered as a significant element in management content, it is because it plays significant role in the mobilisation of phosphate. Reduction of Fe (III) that binds phosphate to Fe (II) occurred under anoxic condition. Transformation of iron (II) phosphate to Fe_2S under release of phosphate takes place due to the low solubility of iron disulfide (FeS_2).

Organic matter containing sulfur compounds was degraded in the water column by sulfur reducing bacteria. The product of degradation is the dominant form of sulphurous compound that is sulphate, which then reduced to H_2S. The sulfur sources could be in the form of organic sulfur compound (ester sulphates and protein sulfur) and the remainder as pyritic sulfur, acid volatile sulphides, sulfide dissolved in interstitial water, elemental sulfur and dissolved sulphates (Wetzel, 2001). The sulphate reducing bacteria need carbon in the form of organic compounds (Vamos & Tasnadi, 1975). But rapid mineralization of organic matter prevented sulphate depletion in the water column (Urban *et al.* 2001).

Lake Loa Kang as the location of the study function as the habitat of food for freshwater dolphin in Mahakam River should be under good condition and free from the toxic agent. Results of the study on sulphurous compounds including sulfide in water column is one of the important foundation in designing habitat conservation measures for the sustainability of fishery production and Pesut life and for maintaining good water quality. The aim of this study is to reveal the spatial distribution of the sulfide in several habitats of Lake Loa Kang Fishery Reserve system. This study is one of the first step in revealing the sulfide formation process in the lake and the factor that affected the process.

MATERIALS AND METHODS

Sampling station and sampling methods.

The study in the LLFR is conducted in ten sampling stations (Table 5.1 and Fig. 5.1). The LLFR was sampled in June, August and September 2003. Water samples are taken compositely from surface, Secchi Depth and bottom water layers using Snatch Bottle Sampler. Some water quality parameter, such as pH, dissolved oxygen, temperature and conductivity are measured 12 times randomly at each sampling stations using HORIBA WQC U-10.

Analytical Methods

The water samples were analyzed for sulfide, Total Organic Matter (TOM) and Biological Oxygen Demand (BOD_5), according to procedures described in Standard Methods of Water and Wastewater 18th Eds (APHA-AWWA, 1992). Analysis of sulfide directly done in the field using iodometric methods. A portion of water sample is reacted with excessive iodine solution. The sulfide contained in the sample will give a yellow colour after sample acidification with HCl solution. Iodine reacts with sulfide, oxidizing it to sulfur and the remnant of excessive iodine then titrated with thiosulfate solution. The difference between the amount of iodine added to the sample and the remain amount of iodine that reacted with thiosulfate is the iodine represent the amount of sulfide contained in the sample. Analyses of Total Organic Matter and BOD_5 were done using the Permanganate and iodometric methods respectively (Yustiawati *et al.* 2004)

Data analysis

The data available was analyzed pictorially using Microsoft Excell Program

Table 5.1. Description of sampling stations in the area of Lake Loa Kang Fishery Reserve (LLFR).

Station	Location, habitat type	Coordinates	
		South	East
1	R. Loa Kang, a channel connecting L. Loa Kang with River Pela	S 0° 13' 53.1"	E 116° 33' 55.6"
2	Connecting channel between L. Loa Kang and L. Balikpapan.	S 0° 13' 30.5"	E 116° 34' 22.6"
3	Tunjung Springs, a spring in the LLFR	S 0° 13' 26.0"	E 116° 33' 54.0"
4	Lake Loa Kang *(Hakang),* a back swamp depression lake	S 0° 13' 39.9"	E 116° 33' 42.9"
5	Lake Balikpapan, a back swamp depression in LLFR	S 0° 13' 28.3"	E 116° 34' 35.6"
6	River Balikpapan, a floodplain river (a small tributary of R. Mahakam) in LLFR.	S 0° 13' 32.5"	E 116° 34' 46.1"
7	Mouth of River Balikpapan, junction of R. Balikpapan and R. Mahakam	S 0° 13' 25.0"	E 116° 35' 16.5"
8	Mouth of River Pela, junction of R. Pela and R. Mahakam	S 0° 14' 14.0"	E 116° 34' 0.9"
9	*Lopak,* small size ephemeral pond in LLFR	S 0° 13' 20.7"	E 116° 35' 16.4"
10	Maling Canal, a segment of man made channel that connect L. Loa Kang with River Mahakam	S 0° 13' 45.0"	E 116° 34' 5.0"

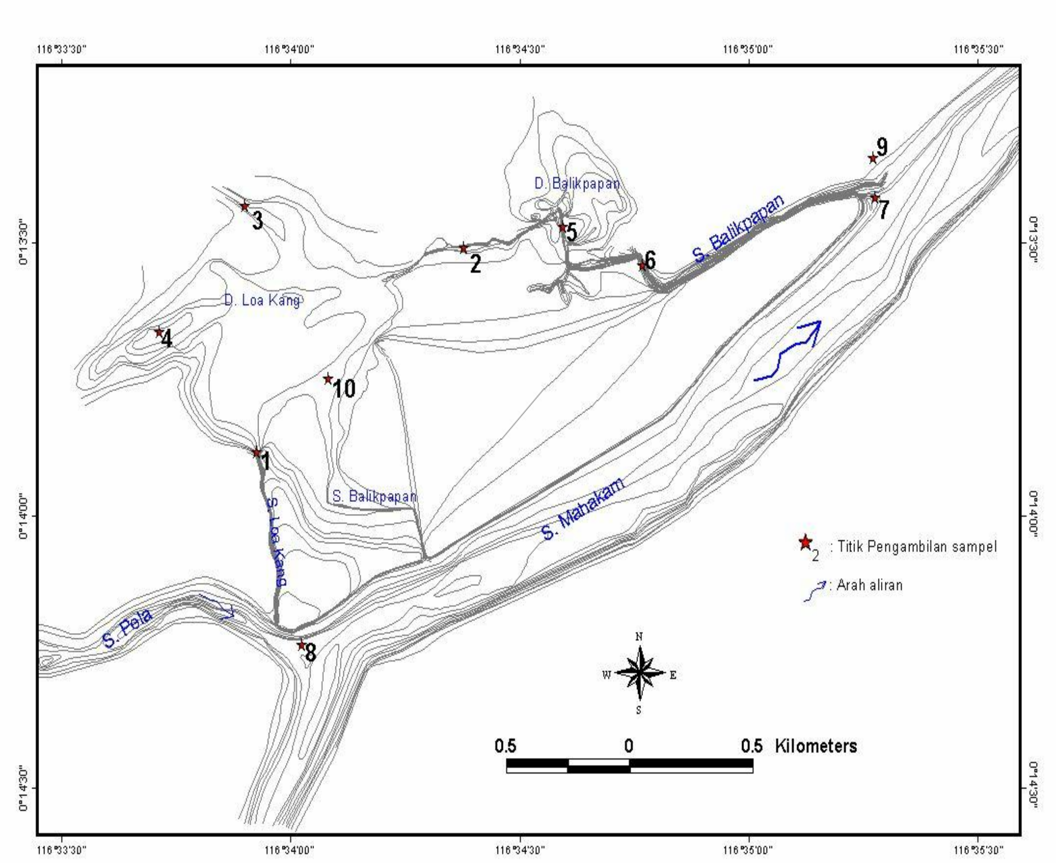

Figure 5.1. Sampling station in Lake Loa Kang floodplain system that was managed as fishery reserve

Table 5.2. Classification of Ecological Habitat Types in Lake Loa Kang Fishery Reserve

No.	Habitat Types	Location
1.	*Hakang or* Lebung, a depression lake in floodplain system	L. Loa Kang (St.4) and L. Balikpapan (St.5)
2.	Connecting channel between floodplain lakes	Connecting channel between L. Loa Kang and L. Balikpapan (St.2)
3.	Connecting channel between the floodplain deposit lake and main river	R. Loa Kang (St.1) and R. Balikpapan (St.6)
4.	Junction of tributary and main river	Mouth of R. Pela (St.8)
5.	Mouth of connecting channel between the floodplain depression lake and main river	Mouth of R. Balikpapan. (St.7)
6.	A spring in floodplain system	*Tunjung* Springs (St.3)
7.	Ephemeral ponds	*Lopak* (St.9)
8.	A segment of man made channel that connect L. Loa Kang with River Mahakam	*Maling* Canal (St.10)

RESULTS AND DISCUSSION

There are ten sampling stations in LLFR. Based on ecological connectivity, those stations proposed to be classified into several habitat types (Table 5.2), such as floodplain lakes (St.4 Lake Loa Kang & St. 5 Lake Balikpapan), connecting channel between floodplain lakes (St. 2), connecting channel between the floodplain lake and

Table 5.3. Results of analysis of sulfide in water column in Lake Loa Kang Fishery Reserve

Station	S^{2-}, mg.L^{-1}			Average
	June 2003	August 2003	September 2003	
1	2.318	0.482	0.006	0.935
2			0.179	0.179
3	2.172	0.762	0.410	1.115
4	1.952	0.640	0.525	1.039
5	1.733	0.762	0.237	0.911
6	1.733	0.640	1.446	1.273
7		1.248		1.248
8	2.611	0.397	0.375	1.128
9	2.465	0.883	1.158	1.502
10	2.026	0,032	0.294	0.784
Average	2.126	0.650	0.514	1.011

main river (St 1 R. Loa Kang & St6 River Balikpapan), junction of tributary and main river (St 8, Mouth River Pela), mouth of connecting channel between the lake and main river (St 7), a spring in floodplain system (St3, Tunjung springs), an ephemeral pond (St 9, Lopak) and a segment of man made channel that connect L. Loa Kang with River Mahakam (St. 10, *Maling* Canal). The number of sampling stations in June and September 2003 was nine but in August the number was ten, depend on the condition of LLFR. Prolonged dry season dried up several sampling stations.

The sulfide concentration in several stations of LLFR tend to decreased from June to September 2003, as shown in Table 5.3 and Fig. 5.2. The average concentration in June from eight sampling stations, in August (10 stations) and September (9 stations) were 2.126 mg.L^{-1}, 0.650 mg.L^{-1} and 0.514 mg.L^{-1} respectively. It happened due to increasing water level because in August and September 2003 were the periods of transitional and rainy seasons, when the higher amount of water diluted the sulfide in water column.

The highest of sulfide concentration (2.611 mg.L^{-1}) was observed in the junction of main and tributary rivers (St. 8, Mouth of River Pela) in June, but it was drastically decreased to 0.397 mg.L^{-1} and 0.375 mg.L^{-1} in August and September respectively. The highest sulfide concentration found in June probably because that time was the period of the dry season when the water level in River Mahakam was low and it contained higher level of organic matter. Organic matter could be originated from domestically waste and added with the waste from transportation vehicle such as the boats that pass by the junction of River Mahakam and River Pela. The lowest sulfide concentration (0.006 mg.L^{-1}) was found in connecting channel between tributary and back swamp deposit lakes (St 1, River Loa Kang) in rainy season (September) because of dilution of organic matter in water column.

The organic matter concentrations in LLFR tend to decreased from June to September 2003. The organic matter concentration in this case is represented by the levels of TOM and BOD_5 as shown in Table 5.4 and Fig. 5.3 -5.4. On the other hand, according to statistical analysis, sulfide is not significantly correlated with organic matter as shown by coefficient correlation values that were 0.042 and 0.470 for TOM and BOD_5 correspondingly.H_2S was dissociated weakly to HS^{-v} and S^{2-} and the process is determined by several factors as pH and redox condition. The range of pH in LLFR was

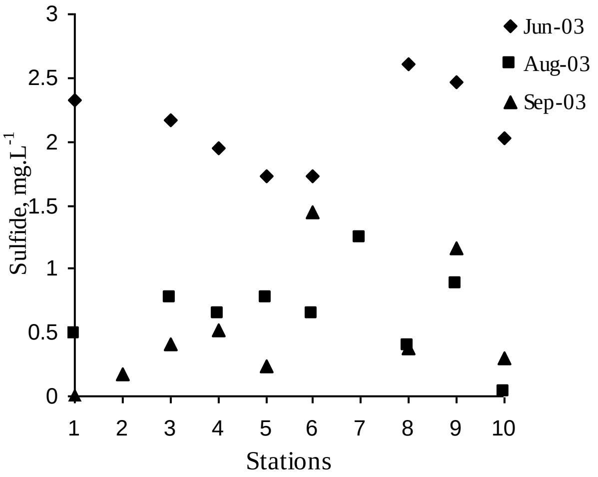

Figure 5.2. Spatial and temporal distribution of sulfide (S^{2-}) in Lake Loa Kang Fishery Reserve

Table 5.4. Results of analysis of TOM and BOD_5 in Lake Loa Kang Fishery Reserve

Station	Parameter	Concentration , mg.L^{-1}			Average
		June 2003	Aug. 2003	Sept. 2003	
1	TOM	31.600	76.460	15.455	41.172
	BOD_5	3.420	5.594	2.316	3.777
2	TOM			14.823	14.823
	BOD_5			1.122	1.122
3	TOM	9.356	130.180	23.671	54.402
	BOD_5	2.362	2.285	3.928	2.858
4	TOM	73.312	139.660	20.511	77.828
	BOD_5	4.148	0.665	3.157	2.657
5	TOM	61.304	814.380	14.823	296.836
	BOD_5	1.299	3.529	2.147	2.325
6	TOM	64.464	59.080	14.191	45.912
	BOD_5	4.965	2.372	8.418	5.252
7	TOM		59.080		59.080
	BOD_5		3.676		3.676
8	TOM	20.856	87.520	11.677	40.018
	BOD_5	0.666	2.749	1.123	1.513
9	TOM	55.260	119.120	42.013	72.131
	BOD_5	2.543	3.015	0.590	2.049
10	TOM	69.520	153.880	11.993	78.464
	BOD_5	1.160	4.801	0.782	2.248
Average		48.209	182.151	18.795	

Source : Yustiawati *et al.* 2004

SULFIDE IN WATER

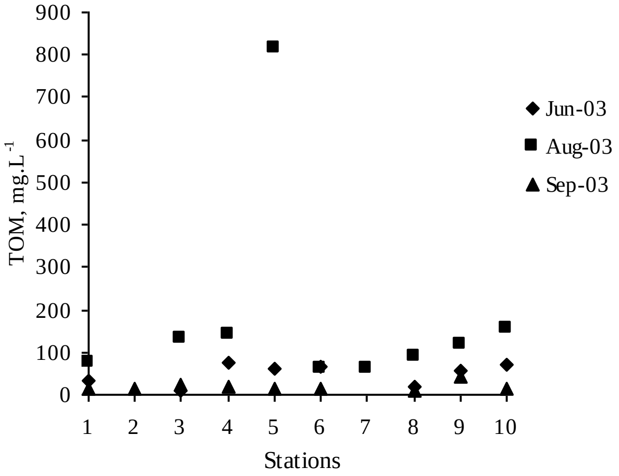

Figure 5.3. Distribution of Total Organic Matter in Lake Loa Kang Fishery Reserve

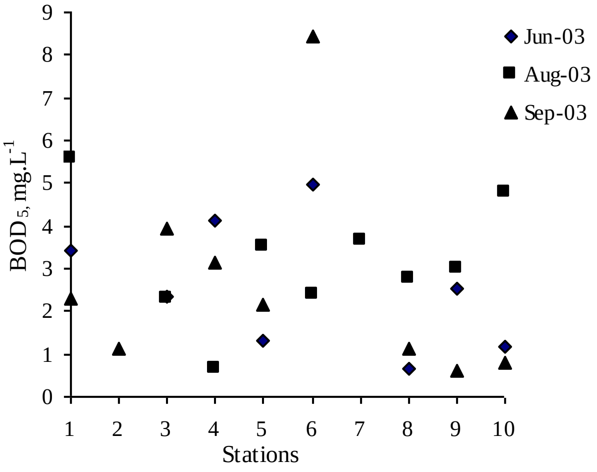

Figure 5.4. Spatial and temporal distribution of BOD_5 in Lake Loa Kang Fishery Reserve

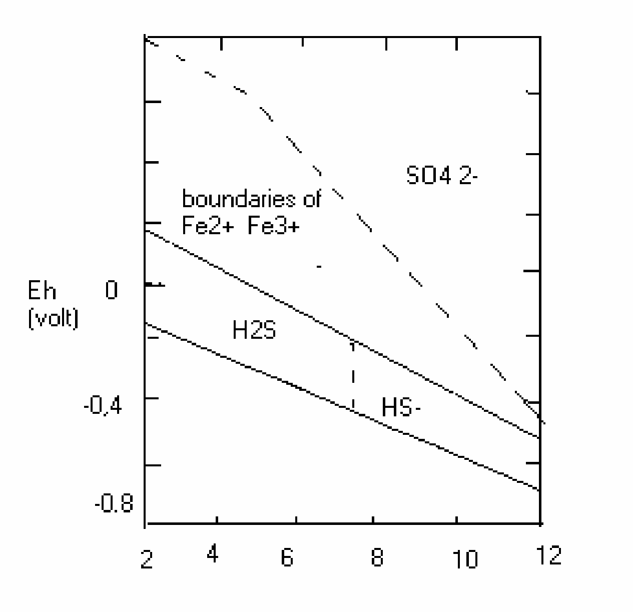

Figure 5.5. Stability of sulfur form (Jorgensen, 1980)

4.86-7.38, so the sulfur form was dominated by sulphate (SO_4^{2-}) and gaseous H_2S (Jorgensen. 1980). That explained why the concentration of sulfide in LLFR was low.

Compared to other inland water of Indonesia. the concentration of sulfide in LLFR was lower than Lake Maninjau, West Sumatra (Hartoto *et al.* 2001) and oxbow lakes in Central Kalimantan (Hartoto *pers. comm.*). The sulfide concentration in Lake Maninjau range 0.6-14 mg.L^{-1} in 2001. Lake Maninjau is a deep volcano tectonic lake, which water already multi-used for capture fishery, cage aquaculture, aquatic ecotourism and hydroelectric power generation. Concentration of sulfide in Lake Maninjau was higher than the concentration in LLFR because there were plenty organic material originally from fish feed debris accumulated in the bottom of the lake and released H_2S from the sediment to the water column. Anoxic sediments rich in organic matter release gaseous hydrogen sulfide (H_2S) to produce the familiar rotten-egg smell of decaying vegetation. In lake, this H_2S is oxidized to SO_4^{2-} at the mud of water interface as long as there is reduced by bacterial respiration and Chemical Oxygen Demand. H_2S is released into the air or overlying water (Goldman and Horne, 1983).

Sulfide concentration in LLFR is lower than sulfide concentration in several oxbow lakes in Central Kalimantan (Lake Tabiri, Lake Rengas, and Lake Takapan, data of Hartoto & Sugiarti) with the range of sulfide in water column was 0.776-5.792 mg.$L^{-1.}$ Because organic matter in LLFR lower than in oxbow lake in Central Kalimantan represented in Humic acid concentration. As reported by Yustiawati *et al.* (2004b), concentration Humic acid in LLFR is just a few mg/L lower than Humic Acid lakes in Central Kalimantan.

According to Government Regulation No.20/1990, the recommended sulfide concentration is 0.1 mg.L^{-1} for water of Class B for fisheries. The results shown that sometimes concentration of sulfide in LLFR are much higher and is not good to sustain the good condition for fishes life as the food for Pesut. Several way must be taken to revitalized ecological condition of LLFR to return back its function as the feeding ground for *Pesut.*

CONCLUSION

Sulfide concentration in several sampling points in Fishery Reserve of Lake Loa Kang and Lake Balikpapan consist of Lake Loa Kang ,River Loa Kang (connecting channel of Lake Balikpapan and Lake Loa Kang), Tunjung Springs, Hakang, Lake Balikpapan, River Balikpapan, Mouth of River Balikpapan, Lopak, Mouth of River Pela and Maling Canal segment decreased from June to August and September. The highest concentration was 2.611 mg.L^{-1} in the Mouth of River Pela in June and the lowest concentration was 0.006 mg.L^{-1} in River Loa Kang in September 2003. The average concentration of sulfide ion were 2.126 mg.l^{-1}, 0.650 mg.L^{-1} and 0.514 mg.L^{-1} in June, August and September respectively The results showed that sulfide concentration in LLFR sometimes higher than recommended concentration in Government Regulation No. 20/1990 for water of Class B for fisheries (0.1 mg.L^{-1}), but the concentration is less than the sulfide concentration in oxbow lakes in Central Kalimantan and Lake Maninjau, West Sumatra.

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6. PHOSPHOROUS NUTRIENT FINGER PRINTS IN SEVERAL HABITATS OF LAKE LOA KANG FISHERY RESERVE

By

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ABSTRACT

A study on phosphorous (P) fractions in several habitats of a floodplain system that was managed as Lake Loa Kang Fishery Reserve at Kutai Kertanegara Regency, East Kalimantan was conducted in June, August and September 2003. The objective of this study is to reveal the spatial distribution of various P- fractions in the system. Water samples were taken from eight stations and P fractions were analyzed according to Standard Methods 20th Edition. The sampling stations represented six habitat types such as back swamp deposit lake (St.4 & St. 5), connecting channels between deposit lake and main river (St 1 and St 6), junction of tributary and main river (St. 8), a spring (St. 3), ephemeral pond (St. 9) and man made channel that connect floodplain and main river (St. 10). The results showed that the lowest and highest average concentration of Total Phosphorus (TP) was observed in St.6 (0.139 mg/L) and St. 10 (0.524 mg/L) respectively. T-P concentration indicate a hyper-eutrophic condition in all stations. The average dissolved organic-P (DOP) and Particulate Organic-P (POP) is higher than the Particulate Inorganic-P (PIP) and Dissolved Inorganic-P (DIP), except in St. 8, probably because the DOP is originated from detritus that was carried by water from terrestrial origin. The material input indicator showed that Particulate Phosphorus was higher than Total Dissolved Phosphorus in all stations, except in St..4, where those fractions are nearly equal. The trophic indicator, indicate a condition where the Total Organic Phosphorus (TOP) was dominant, followed by Total Acid Hydrolyzable Phosphorus (TAHP) and Total Inorganic Phosphorus (TIP) in all stations, except in St.1 where the TAHP fraction was dominant. In St. 8 the TIP were higher than TAHP, in St. 4 and St. 9 the TAHP equal to TIP. The production rate indicator showed the concentration of PIP was higher than DIP in all stations, except in St. 5 where it were nearly equal. Detritus dependency indicator showed the percentage Particulate Acid Hydrolyzable Phosphorus, (PAHP) was higher than the Dissolved Acid Hydrolyzable Phosphorus (DAHP) in all station except in St.6 where it were nearly equal. Except in St.1 and St. 4 the organic material indicator shows that the system was characterized by higher concentration of POP than DOP in most stations.

Keywords*: phosphorus, floodplain, Lake Loa Kang*

INTRODUCTION

Phosphorus is not needed in large quantities for growth, suchlike requirement for major elements such as carbon, oxygen, hydrogen and nitrogen, but it is one of the more common limiting elements on land and in freshwater (Goldman & Horne, 1983). In natural waters and waste waters, phosphorus compound almost solely exists as phosphates. These compounds are classified as orthophosphates, condensed phosphates (pyro-, meta- and other polyphosphates) and organically bound phosphates. They occur in solution, in particles or detritus, or in the bodies of aquatic organisms. (APHA-AWWA-WEF, 1998). No other element in fresh water has been studied as intensively as phosphorus. A great body of quantitative data exists on the seasonal distribution of phosphorus in lakes and loading rates of phosphorus from the surrounding drainage basins. (Wetzel, 2001).

Phosphorus (P) nutrient fingerprints is a method to present information related to the composition of phosphorus fractions, as the configuration of the external function impacts and internal conditions of natural inland water. The phosphorus fingerprints represents material input, trophic, production rates, detritus dependency and organic material indicators. (Yustiawati & Hartoto, 1999).

In operational analytical level, phosphorus species are consisted of Total Phosphorus (T-P), Total Dissolved Phosphorus (TDP), Total Inorganic Phosphorus (TIP), Total Acid Hydrolyzable Phosphorus (TAHP), Total Organic Phosphorus (TOP), Dissolved Inorganic Phosphorus (DIP), Dissolved Acid Hydrolyzable Phosphorus (DAHP) and Dissolved Organic Phosphorus or DOP (APHA-AWWA-WEF, 1998). As proposed by Yustiawati & Hartoto (1999), the other phosphorus fractions that can be calculated from the data above are Particulate Phosphorus (PP = TP-TDP), Particulate Inorganic Phosphorus (PIP = TIP-DIP), Particulate Acid Hydrolyzable Phosphorus (PAHP = TAHP-DAHP) and Particulate Organic Phosphorus (POP= TOP-DOP).

With the study of phosphorus fingerprints, we can features the criteria of ecological integrity and it could be use as a background data for development of water quality set points in inland water conservation and restoration measures. In the above context, the aim of this study is to reveal the phosphorus fingerprints in Lake Loa Kang Fishery Reserve (LLFR) in East Kalimantan for a base line data for restoration of limnological condition in LLFR

MATERIALS AND METHODS

Description of s sampling stations

Since many years ago, floodplain system of Mahakam River known as the habitat for white water fishes that function as the food for The Mahakam Freshwater Dolphin (*Orcaella brevirostris*). One of the floodplain system is Lake Loa Kang that located in the Kota Bangun District, Kutai Kertanegara Regency, East Kalimantan Province. The floodplain system already designated as fishery reserve since 500 years ago and consisted of several habitat types such as; among the others; two back swamp depression lakes refer as Lake Loa Kang and Lake Balikpapan (Hartoto 1997), Lake Loa Kang floodplain system exchange water with River Mahakam and River Pela, one of River Mahakam tributary (Hartoto *et al.* 2002). The study was conducted at eight sampling stations in Lake Loa Kang Fishery Reserve. Detailed description and location of sampling sites was presented in Table 6.1 and Fig. 6 1 and classification of habitat was presented in Table 6.2. Samplings were done in June, August and September 2003.

Sampling methods

Water samples were taken compositely from bottom and surface layers from each sampling stations. With the purpose to collect data on phosphorus fingerprint, the water samples were taken using Snatch Bottle Sampler then preserved and pre-treated

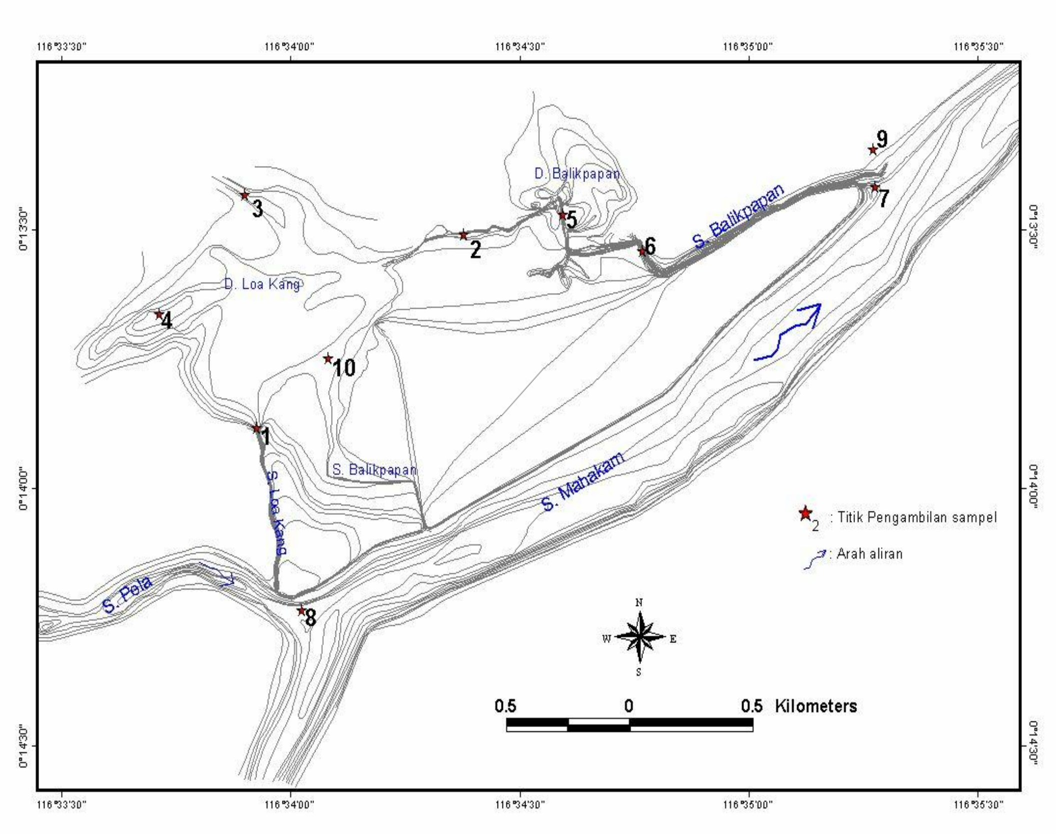

Figure 6.1. Sampling stations in Lake Loa Kang Fishery Reserve

Table 6.1. Description of sampling stations in the area of Lake Loa Kang Fishery Reserve (LLFR*)*.

Stations	Location, habitat type	Coordinates	
		South	East.
1.	R. Loa Kang, a channel connecting L. Loa Kang with River Pela	S 0^{o} 13' 53.1 "	E 116^{o} 33' 55.6"
3.	Tunjung Springs, a spring in the LLFR	S 0^{o} 13' 26.0"	E 116^{o} 33' 54.0"
4.	Lake Loa Kang *(Hakang),* a floodplain lake	S 0^{o} 13' 39.9"	E 116^{o} 33' 42.9"
5.	Lake Balikpapan, a floodplain lake in LLFR	S 0^{o} 13' 28.3"	E 116^{o} 34' 35.6"
6.	River Balikpapan, a floodplain river (a small tributary of R. Mahakam) in LLFR.	S 0^{o} 13' 32.5"	E 116^{o} 34' 46,1"
8.	Mouth of River Pela, junction of R. Pela and R. Mahakam	S 0^{o} 14' 14.0"	E 116^{o} 34' 0.9"
9.	*Lopak,* small size ephemeral pond in LLFR	S 0^{o} 13' 20.7"	E 116^{o} 35' 16.4"
10.	Maling Canal, a segment of man made channel that connect L. Loa Kang with R. Mahakam	S 0^{o} 13' 45.0"	E 116^{o} 34' 5.0"

Table 6.2. Classification of Ecological Habitat Types in Lake Loa Kang Fishery Reserve

No.	Habitat Types	Location
1.	*Hakang or* Lebung, a back swamp deposit or depression lake in floodplain system	Lake Loa Kang (St.4) and Lake Balikpapan (St.5)
2.	Connecting channel between the floodplain depression lake and main river	River Loa Kang (St.1) and River Balikpapan (St.6)
3..	Junction of tributary and main river	Mouth of River Pela (St.8)
4..	A spring in floodplain system	Tunjung Springs (St..3)
5.	Ephemeral ponds	Lopak (St..9)
6.	A segment of man made channel that connect L. Loa Kang with River Mahakam	*Maling* Canal (St..10)

with concentrated sulphuric acid according to the fractionation methods for phosphorus species described by APHA-AWWA-WEF (1998).

Analytical methods

According to APHA-AWWA-WEF (1998), speciation of phosphorus consisted of T-P, TIP, TAHP, TOP, TDP, DIP, DAHP and DOP. Fractionation methods of the above various phosphorus is presented in Fig. 6.2. Analysis of phosphorus fraction was carried out using Ascorbic Acid Method. The basic principle of the analysis is to react orthophosphate complex with ammonium molybdate and potassium antimonyl tartrate in acid medium to form a heteropolyphosphomolybdic acid. The acid then reduced with ascorbic acid to develop intensely colour molybdenum blue. The light absorption of samples then measured using Spectrophotometer UV-VIS in 880 nm wavelength.

RESULTS AND DISCUSSION

The data collected from three sampling times from eight stations in Lake Loa Kang Fishery Reserve was shown in Table 6.3 to Table 6.5. and the average of T-P concentration is presented in Table 6.6. The results showed that the lowest average concentration of TP (0.139 mg.L^{-1}) was observed in connecting channel between the floodplain depression lake and main river (St. 6). This pattern probably due to possibility of the nutrient in connecting channel is already deposited in the sediment or absorbed by the aquatic macrophyte before they were carried away by the water that flow in the connecting channel. The highest average concentration (0.524 mg/L) was found in man made canal (St. 10), which could be explain because the man made canal is the geo morphology feature that carried the water from Mahakam river water at the earliest moment of water level rising.

Wetzel (2001) reported that for eutrophic water, the average value of TP is 0.084 mg/L, and the lake rich in organic matter; such as bogs and bog lakes; tend to exhibit high total phosphorus concentration. Yustiawati *et al.* (2004) reported that the lowest average concentration of Total Organic Matter (TOM) is 40.017 mg/L was observed in the junction of tributary and main river (St. 8) and the highest average concentration is 296.836 mg/L, which was found in *Hakang or* Lebung, a back swamp deposit or depression lake in floodplain system (St. 5). From T-P point of view, it seems that all stations were already in hyper-eutrophic condition (Fig. 6.3). Hartoto *et al.* (2002) in their studies in 2002 reported that the levels of T-P in several stations in LLFR were also already in hyper-eutrophic condition (Table 6.6). On the other hand in 1996-1997, the concentration of TP in several stations of Lake Loa Kang (Hartoto,

Table 6.7. Comparison of T-P concentration in LLFR in 2003, 2002 and 1996/1997

a. In 2003

No.	Habitat types and stations	T-P, $mg.L^{-1}$			
		June (dry)	Aug. (trans.*)	Sept. (rainy)	Average in habitat
1.	*Hakang or* Lebung, a back swamp deposit lake in floodplain system, St 4 & St 5	0.395 0.487	0.218 0.171	0.150 0.132	0.259
2.	Connecting channel between the floodplain depression lake and main river, St 1 & St 6	0.503 0.167	0.238 0.143	0.102 0.108	0.210
3.	Junction of tributary and main river, St.8	0.594	0.449	0.096	0.380
4.	A spring in floodplain system, St.3	0.215	0.092	0.144	0.150
5.	Ephemeral ponds, St.9	0.222	0.087	0.932	0.414
6.	A segment of man made channel that connect L. Loa Kang with R. Mahakam, St.10	0.188	0.169	1.215	0.524

Trans*: transitional

b. In 2002 (Source: Hartoto *et al*. 2002)

No.	Habitat Types	Stations	T-P, $mg.L^{-1}$		
			Aug. (trans*	Nov. (rainy)	Average in habitat
1.	*Hakang or* Lebung, a Backswamp deposit lake in floodplain system	The middle of L. Loa Kang Littoral part of L. Loa Kang L. Balikpapan	0.110 0.113 0.099	0.207 0.434 0.521	0.247
2.	Connecting channel between Floodplain deposit lake and main river	R. Loa Kang	0.103	0.343	0.223
3.	Junction of tributary and main river	Mouth of R. Pela	0.116	0.072	0.094

c. In 1996/1997 (Source: Hartoto, 1997)

No.	Habitat Types	Stations	T-P (mg/L)		
			July 1996 (dry)	Jan. 1997 (rainy)	Average in habitat
1.	*Hakang or* Lebung, a backswamp deposit lake in floodplain system	Deepest part of L. Loa Kang	0.625	0.039	0.332
2.	Connecting channel between floodplain deposit lake and main river	Mouth of R .Loa Kang	0.908	0.036	0.472
3.	Junction of tributary and main river	Related R. Pela segment	0.432	0.043	0.238

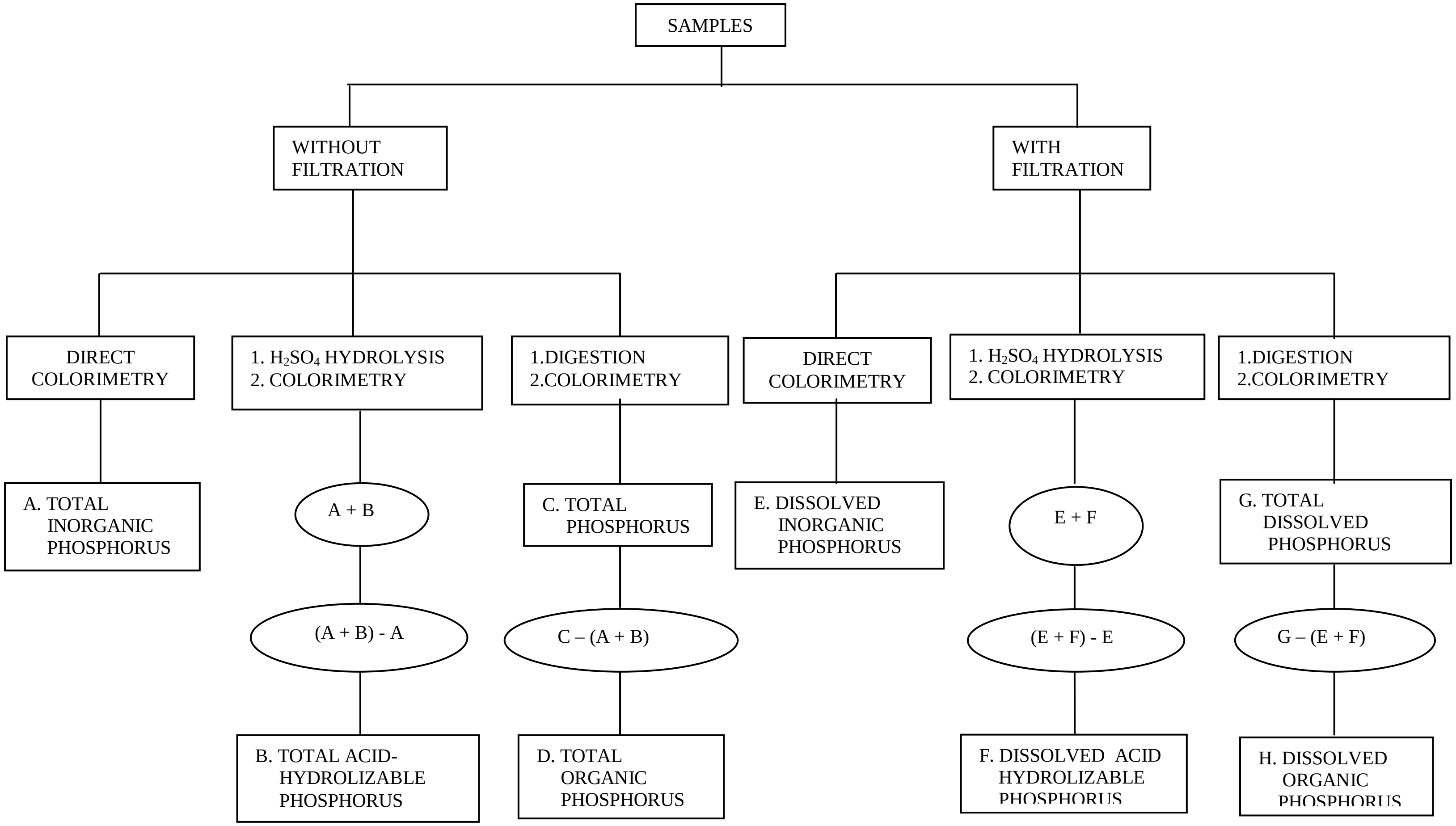

Figure 6.2. Fractionation steps of phosphorus fraction in water (Source: APHA-AWWA-WEF, 1998)

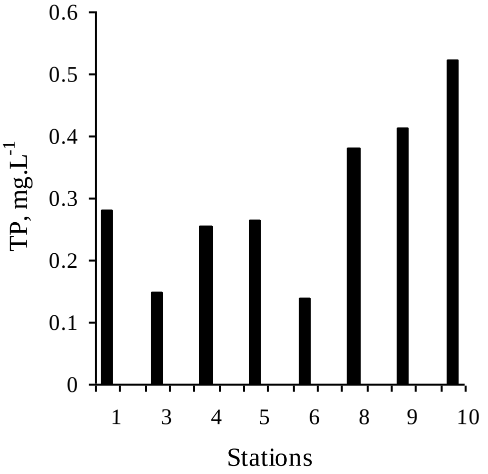

Figure 6.3. The average concentration of sampling stations at LLFR

1997) were alre … eason (July 1996) but the
concentration te … y season (January 1997).
In all st … DOP were higher than the
inorganic phosp … average concentration of
DIP nearly equa … d, a very large proportion;
greater than 90 … s organic phosphates and
cell … and dead
part … d organic
fractions in an appreciable number of lakes indicates that most of total phosphorus is in an organic phase. The DOP originated from detritus in that system was carried by surface runoff from terrestrial origin as reported by Baccini (1985).

Phosphorus finger print can be divided into five types (Hartoto *et al.*1998). The first. type refers to material input indicator, that was represented by the percentage of TDP and PP to TP (Fig 7.4). The result showed that the percentage of PP fraction were higher than TDP fraction in all stations except in St. 4 where the percentage of PP fraction nearly equal to TDP fraction. The higher percentage of PP fraction than the TDP fraction indicates a poor decomposition process occurred in the water. (Hartoto *et al.*1998). Pacini & Gachter (!999) reported that in the Kleine Aa River, particulate P may be as low as 0.003 mg/L during base flow but becomes the predominant form of transported P during intense storm events reaching concentrations of several mg/L. Different pattern was observed in connecting channel between the floodplain depression lake and the main river (St. 1 and St. 6). This pattern was also observed in the junction of tributary and main river (St. 8) where the concentration of PP decrease in rainy season (Table 63 to 6.5). Hartoto (1997) reported in Lake Loa Kang, the percentage of PP fraction was higher than TDP fraction in dry season but in monsoon season the percentage of PP fraction decrease It is likely that some particulate phosphorus solved into dissolved total phosphorus .(Hartoto *et al.*1998). The phenomenon in Lake Semayang nearly same as reported by. Hartoto *et al.*1998 , that the percentage of TDP fraction in the dry season nearly equal to PP fraction but the percentage of TDP fraction

Table 6.3. Concentration of P-fractions and their percentage to T-P in June 2003

Stations	Concentration of P-fraction ($mg.L^{-1}$) and its percentage to T-P											
	Material input indicator			Trophic indicator			Production rate indicator		Detritus dependency indicator		Organic material indicator	
	TP $mg.l^{-1}$ %	TDP $mg.l^{-1}$ %	PP $mg.l^{-1}$ %	TIP $mg.l^{-1}$ %	TAHP $mg.l^{-1}$ %	TOP $mg.l^{-1}$ %	DIP $mg.l^{-1}$ %	PIP $mg.l^{-1}$ %	DAHP $mg.l^{-1}$ %	PAHP $mg.l^{-1}$ %	DOP $mg.l^{-1}$ %	POP $mg.l^{-1}$ %
St. 1	0.503	0.166	0.337	0.072	0.247	0.184	0.020	0.052	0.037	0.210	0.109	0.075
	100.00	33.00	67.00	14.31	49.11	36.58	3.98	10.34	7.36	41.75	21.67	14.91
St. 3	0.215	0.104	0.111	0.009	0.048	0.158	0.000	0.009	0.009	0.039	0.095	0.063
	100.00	48.37	51.63	4.19	22.33	73.49	0.00	4.19	4.19	18.14	44.19	29.30
St. 4	0.395	0.281	0.114	0.060	0.032	0.303	0.030	0.030	0.023	0.009	0.228	0.075
	100.00	71.14	28.86	15.19	8.10	76.71	7.59	7.59	5.82	2.28	57.72	18.99
St. 5	0.487	0.152	0.335	0.053	0.095	0.339	0.030	0.023	0.030	0.065	0.122	0.217
	100.00	31.21	68.79	10.88	19.51	69.61	6.16	4.72	6.16	13.35	25.05	44.56
St..6	0.167	0.100	0.067	0.023	0.070	0.074	0.014	0.009	0.043	0.027	0.043	0.031
	100.00	59.88	40.12	13.77	41.92	44.31	8.38	5.39	25.75	16.17	25.75	18.56
St. 8	0.594	0.045	0.549	0.244	0.120	0.230	0.032	0.212	0.045	0.075	0.013	0.217
	100.00	7.58	92.42	41.08	20.20	38.72	5.39	35.69	7.58	12.63	2.19	36.53
St. 9	0.222	0.047	0.175	0.047	0.062	0.113	0.000	0.047	0.023	0.039	0.023	0.090
	100.00	21.17	78.83	21.17	27.93	50.90	0.00	21.17	10.36	17.57	10.36	40.54
St. 10	0.188	0.109	0.079	0.062	0.055	0.071	0.041	0.021	0.005	0.050	0.063	0.008
	100.00	57.98	42.02	32.98	29.26	37.77	21.81	11.17	2.66	26.60	33.51	4.26

Table 6.4. Concentration of P-fractions and their percentage to T-P in August 2003.

Stations	Concentration of P-fraction ($mg.L^{-1}$) and its percentage to T-P											
	Material input indicator			Trophic indicator			Production rate indicator		Detritus dependency indicator		Organic material indicator	
	TP $mg.l^{-1}$ %	TDP $mg.l^{-1}$ %	PP $mg.l^{-1}$ %	TIP $mg.l^{-1}$ %	TAHP $mg.l^{-1}$ %	TOP $mg.l^{-1}$ %	DIP $mg.l^{-1}$ %	PIP $mg.l^{-1}$ %	DAHP $mg.l^{-1}$ %	PAHP $mg.l^{-1}$ %	DOP $mg.l^{-1}$ %	POP $mg.l^{-1}$ %
St. 1	0.238	0.039	0.199	0.054	0.125	0.059	0.000	0.054	0.033	0.092	0.006	0.053
	100.00	16.39	83.61	22.69	52.52	24.79	0.00	22.69	13.87	38.66	2.52	22.27
St. 3	0.092	0.021	0.071	0.011	0.006	0.075	0.009	0.002	0.006	0.000	0.006	0.069
	100.00	22.83	77.17	11.96	6.52	81.52	9.78	2.17	6.52	0.00	6.52	75.00
St. 4	0.218	0.064	0.154	0.054	0.051	0.113	0.003	0.051	0.032	0.019	0.029	0.084
	100.00	29.36	70.64	24.77	23.39	51.83	1.38	23.39	14.68	8.72	13.30	38.53
St. 5	0.171	0.074	0.097	0.002	0.092	0.077	0.000	0.002	0.046	0.046	0.028	0.049
	100.00	43.27	56.73	1.17	53.80	45.03	0.00	1.17	26.90	26.90	16.37	28.65
St. 6	0.143	0.024	0.119	0.015	0.085	0.043	0.000	0.015	0.024	0.061	0.000	0.043
	100.00	16.78	83.22	10.49	59.44	30.07	0.00	10.49	16.78	42.66	0.00	30.07
St. 8	0.449	0.018	0.431	0.134	0.012	0.303	0.000	0.134	0.008	0.004	0.010	0.293
	100.00	4.01	95.99	29.84	2.67	67.48	0.00	29.84	1.78	0.89	2.23	65.26
St. 9	0.087	0.036	0.051	0.003	0.052	0.032	0.000	0.003	0.022	0.030	0.014	0.018
	100.00	41.38	58.62	3.45	59.77	36.78	0.00	3.45	25.29	34.48	16.09	20.69
St.10	0.169	0.021	0.148	0.027	0.089	0.053	0.000	0.027	0.020	0.069	0.001	0.052
	100.00	12.43	87.57	15.98	52.66	31.36	0.00	15.98	11.83	40.83	0.59	30.77

Table 6.5. Concentration of P-fraction and percentage to T-P in September 2003

Stations	Concentration of P-fraction (mg.L^{-1}) and its percentage to T-P											
	Material input indicator			Trophic indicator			Production rate indicator		Detritus dependency indicator		Organic material indicator	
	TP mg.l^{-1} %	TDP mg.l^{-1} %	PP mg.l^{-1} %	TIP mg.l^{-1} %	TAHP mg.l^{-1} %	TOP mg.l^{-1} %	DIP mg.l^{-1} %	PIP mg.l^{-1} %	DAHP mg.l^{-1} %	PAHP mg.l^{-1} %	DOP mg.l^{-1} %	POP mg.l^{-1} %
St 1	0.102	0.061	0.041	0.016	0.024	0.062	0.000	0.016	0.020	0.004	0.030	0.032
	100.00	59.80	40.20	15.69	23.53	60.78	0.00	15.69	19.61	3.92	29.41	31.37
St 3	0.144	0.039	0.105	0.033	0.077	0.034	0.000	0.033	0.037	0.040	0.002	0.032
	100.00	27.08	72.92	22.92	53.47	23.61	0.00	22.92	25.69	27.78	1.39	22.22
St 4	0.150	0.011	0.139	0.036	0.070	0.044	0.006	0.030	0.008	0.062	0.003	0.041
	100.00	7.33	92.67	24.00	46.67	29.33	4.00	20.00	5.33	41.33	2.00	27.33
St 5	0.132	0.015	0.117	0.010	0.024	0.098	0.000	0.010	0.008	0.016	0.007	0.091
	100.00	11.36	88.64	7.58	18.18	74.24	0.00	7.58	6.06	12.12	5.30	68.94
St6	0.108	0.011	0.097	0.024	0.010	0.074	0.000	0.024	0.009	0.001	0.002	0.072
	100.00	10.19	89.81	22.22	9.26	68.52	0.00	22.22	8.33	0.93	1.85	66.67
St 8	0.096	0.018	0.078	0.019	0.064	0.013	0.000	0.019	0.012	0.052	0.006	0.007
	100.00	18.75	81.25	19.79	66.67	13.54	0.00	19.79	12.50	54.17	6.25	7.29
St 9	0.932	0.036	0.896	0.182	0.123	0.627	0.003	0.179	0.006	0.117	0.027	0.600
	100.00	3.86	96.14	19.53	13.20	67.27	0.32	19.21	0.64	12.55	2.90	64.38
St 10	1.215	0.015	1.200	0.030	0.040	1.145	0.000	0.030	0.005	0.035	0.010	1.135
	100.00	1.23	98.77	2.47	3.29	94.24	0.00	2.47	0.41	2.88	0.82	93.42

Table 6.6. Average concentration of P-fraction and percentage to T-P in each station

Stations	Concentration of P-fraction (mg.L^{-1}) and its percentage to T-P											
	Material input indicator			Trophic indicator			Production rate indicator		Detritus dependency indicator		Organic material indicator	
	TP mg.l^{-1} %	TDP mg.l^{-1} %	PP mg.l^{-1} %	TIP mg.l^{-1} %	TAHP mg.l^{-1} %	TOP mg.l^{-1} %	DIP mg.l^{-1} %	PIP mg.l^{-1} %	DAHP mg.l^{-1} %	PAHP mg.l^{-1} %	DOP mg.l^{-1} %	POP mg.l^{-1} %
St. 1	0.281	0.089	0.192	0.047	0.132	0.102	0.007	0.041	0.030	0.102	0.048	0.053
	100.00	31.55	68.45	16.84	46.98	36.18	2.37	14.47	10.68	36.30	17.20	18.98
St. 3	0.150	0.055	0.096	0.018	0.044	0.089	0.003	0.015	0.017	0.026	0.034	0.055
	100.00	36.36	63.64	11.75	29.05	59.20	2.00	9.76	11.53	17.52	22.84	36.36
St. 4	0.254	0.119	0.136	0.050	0.051	0.153	0.013	0.037	0.021	0.030	0.087	0.067
	100.00	46.66	53.34	19.66	20.05	60.29	5.11	14.55	8.26	11.80	34.08	26.21
St. 5	0.263	0.080	0.183	0.022	0.070	0.171	0.010	0.012	0.028	0.042	0.052	0.119
	100.00	30.51	69.49	8.23	26.71	65.06	3.80	4.43	10.63	16.08	19.87	45.19
St. 6	0.139	0.045	0.094	0.021	0.055	0.064	0.005	0.016	0.025	0.030	0.015	0.049
	100.00	32.30	67.70	14.83	39.47	45.69	3.35	11.48	18.18	21.29	10.77	34.93
St. 6	0.380	0.027	0.353	0.132	0.065	0.182	0.011	0.122	0.022	0.044	0.010	0.172
	100.00	7.11	92.89	34.86	17.21	47.94	2.81	32.05	5.71	11.50	2.55	45.39
St. 8	0.414	0.040	0.374	0.077	0.079	0.257	0.001	0.076	0.017	0.062	0.021	0.236
	100.00	9.59	90.41	18.69	19.10	62.21	0.24	18.45	4.11	14.99	5.16	57.05
St. 10	0.524	0.048	0.476	0.040	0.061	0.423	0.014	0.026	0.010	0.051	0.025	0.398
	100.00	9.22	90.78	7.57	11.70	80.73	2.61	4.96	1.91	9.80	4.71	76.02

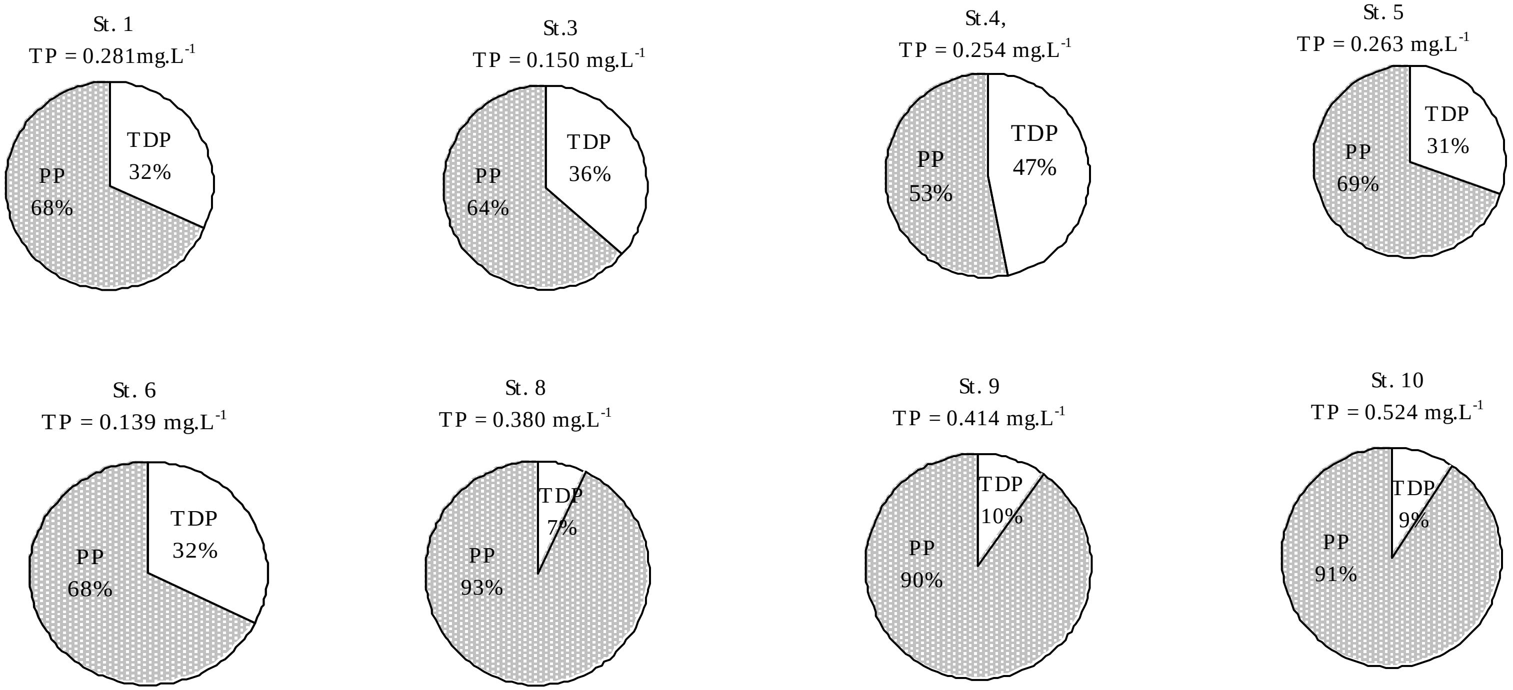

Figure 6.4. Material Input indicator in each stations at Lake Loa Kang Fishery Reserve

significantly increase during rainy season. Lake Semayang tend to change from autochthonous type in the dry season to allochthonous in type lake in monsoon. Other factor that controls the existence of dissolved phosphorus in the redox condition of any water since in aerobic condition phosphate tend to be deposited simultaneously with iron deposition.

The second type of P-finger prints is the trophic indicator, which present the percentage of the TOP, TIP and TAHP fractions to TP (Fig.6.5). In most stations the TOP fraction was dominant followed by TAHP fraction and TIP fraction. In St.1 the TAHP fraction was dominant followed by TOP fraction and TIP fraction. In St. 8, the TIP fraction was higher than TAHP, in St. 4 and St. 9 the TAHP fraction equal to TIP. The dominance of TOP fraction in a system indicating that the system either required sufficient time to produce TIP or it receives a large P-organic input from other sources rather than detritus (Hartoto *et. al.* 1999). Wetzel (2001) report, separation of total phosphorus into inorganic and organic fraction in an appreciable number of lake indicates that most of the total phosphorus is in organic phase. The organic material produced by photosynthesis in the terrestrial water system usually consist. of plant of plant part such as leaves, bark and roots. (Hartoto *et al.* 1999). In the dry season, at Lake Semayang; a major floodplain lake system of River Mahakam that is located very near o lake Loa Kang; the TAHP fraction (65 %) was dominant but in rainy season the percentage of TAHP is decreasing to 34 % and the highest-fraction is found in TOP (46 %). Higher percentage of TAHP indicates that in rainy season there is an input of organic-P to Lake, Semayang possibly originated from detritus carried by surface run off during the rain.(Hartoto *et. al.*1998), and indicate a high concentration of partially break down phosphorus containing organic compounds. This phenomenon is similarly observed in Lake Loa Kang (Hartoto, 1997) where the percentage of TAHP fractions was dominant for both dry (76 %) and in rainy season (53 %).

The third type of P-finger prints refers to the production rate indicator which compare the levels of DIP and PIP fraction to TIP (Fig. 6.6). In all stations, the percentage of PIP fraction were higher than DIP fractions, except St. 5 where the percentage of PIP fraction is nearly equal to DIP fraction. Higher percentage of PIP fraction indicates a poor decomposition process occurred in the water. This phenomenon was supported by the material input indicator, which also showed the percentage of PP fractions were higher than TDP fractions in almost all stations. The phenomenon in 2003 was different with condition of Lake Loa Kang in 1997 (Hartoto, 1997), in Lake Semayang in 1996-1997 (Hartoto *et al.*1998) and in major inland water types in Central Kalimantan (Hartoto *et. al.* 1999), where the percentage of DIP fractions were higher than PIP fraction. This indicate that in 2003, the decomposition process in Lake Loa Kang is getting worse.

The fourth type of P-finger prints refers to the detritus dependency indicator, which present the percentage of DAHP and PAHP to TAHP (Fig 6.7). Acid hydrolizable fraction of phosphorus represents the organically bound P that is already experienced partial decomposition or demineralization process (Hartoto *et al.* 1998), The percentage of PAHP fraction were higher than DAHP fraction in all stations except in St. 6 where the percentage of PAHP nearly equal to DAHP fraction. Higher PAHP fraction indicates the level of partially decomposed organically bound-P that has diameter larger than 0.45 um. In more advanced decomposition process, the organically bound-P will decrease in size and solve into solution (< 0.45 um diameter) but the phosphorus atoms still weakly bound to organic compound (Hartoto *et. al.*1998). Higher PAHP fraction (66 %) was observed in 1996-1997at Lake Loa Kang as reported by Hartoto (1997) in dry season but the percentage of PAHP (11 %) is decreasing in rainy

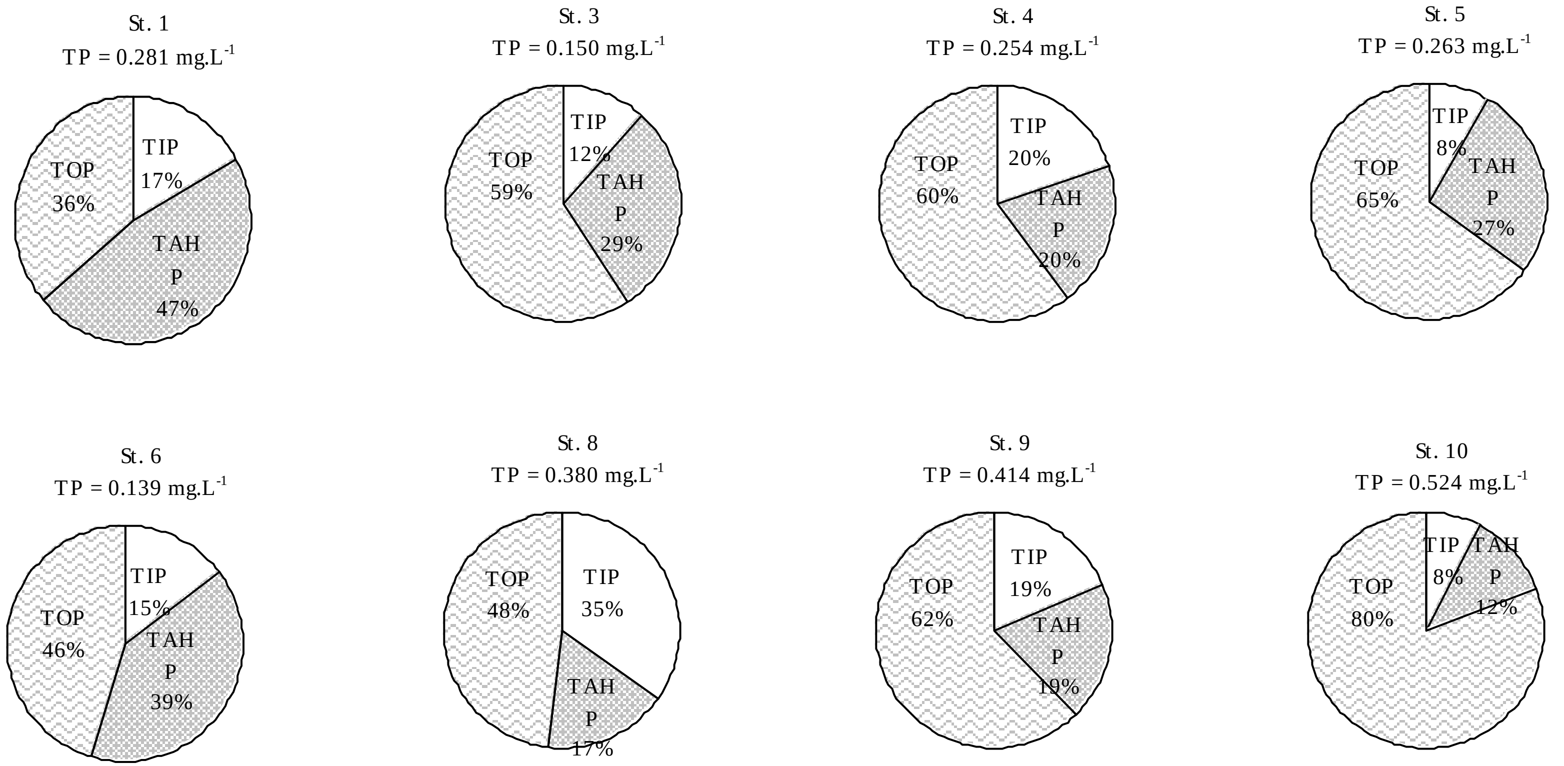

Figure 6.5. Trophic indicator of each sampling stations at Lake Loa Kang Fishery Reserve

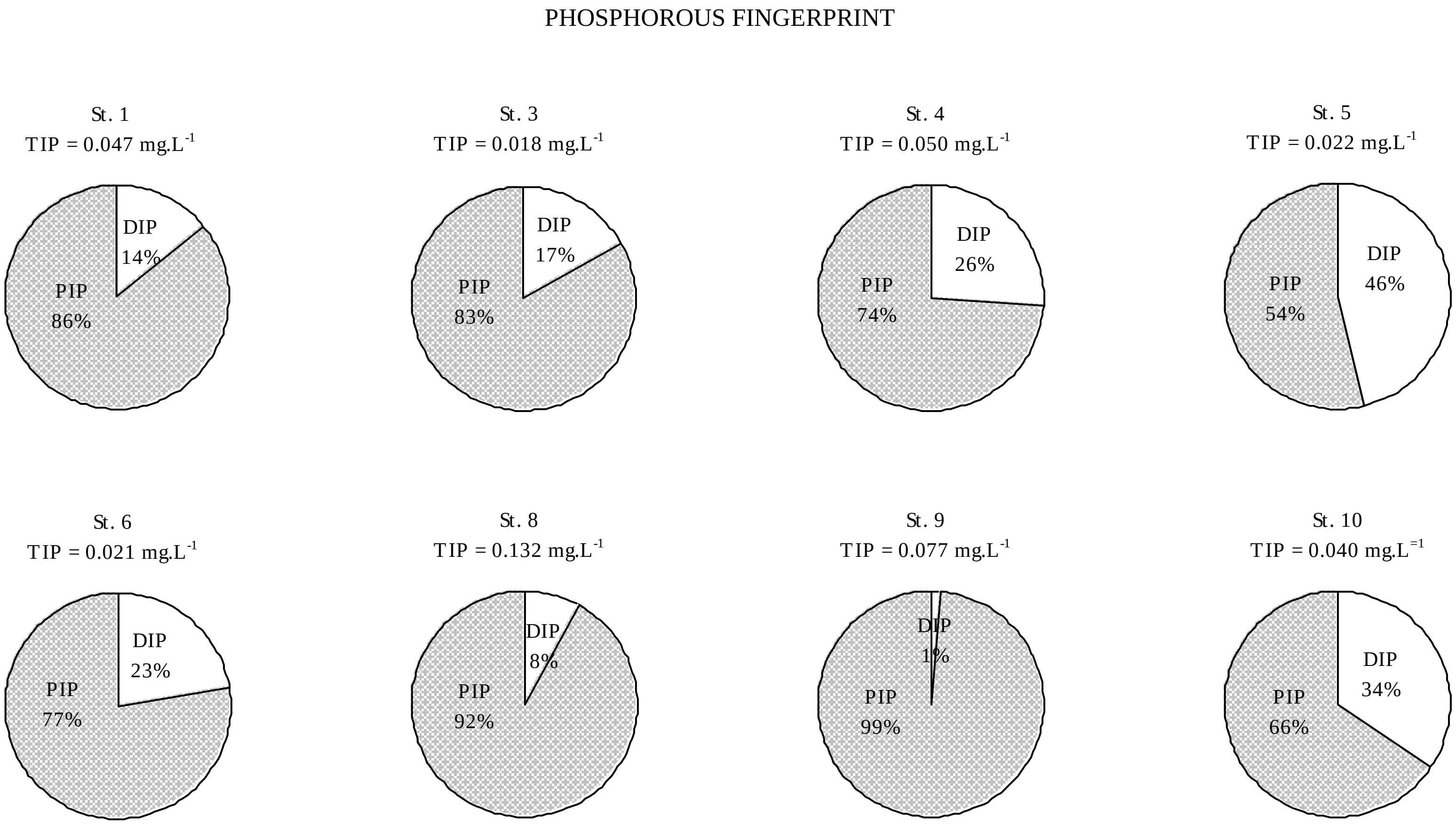

Figure 6.6. Production rate indicator of each sampling stations at Lake Loa Kang Fishery Reserve

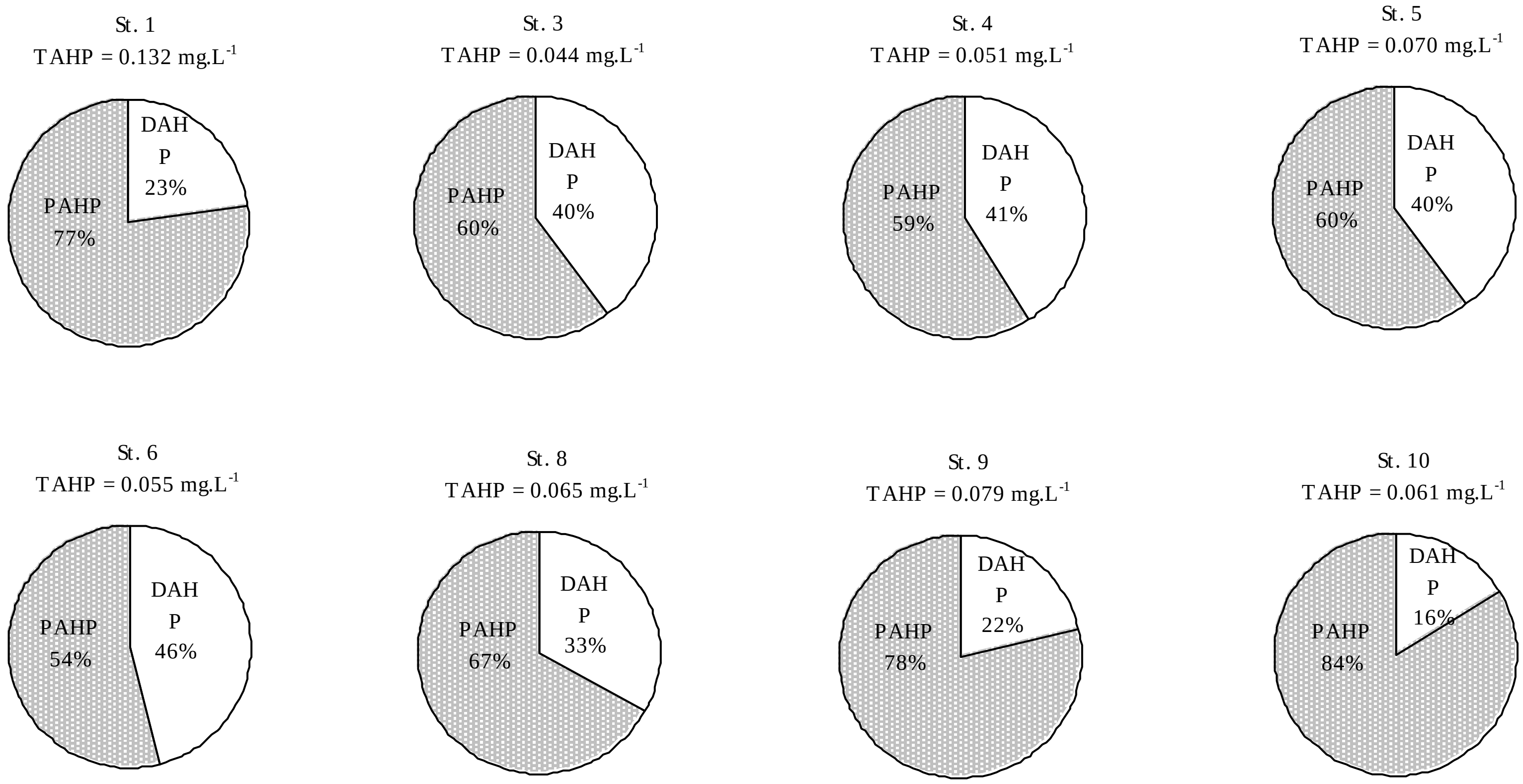

Figure 6.7. Detritus dependency indicator of each sampling station at Lake Loa Kang Fishery Reserve

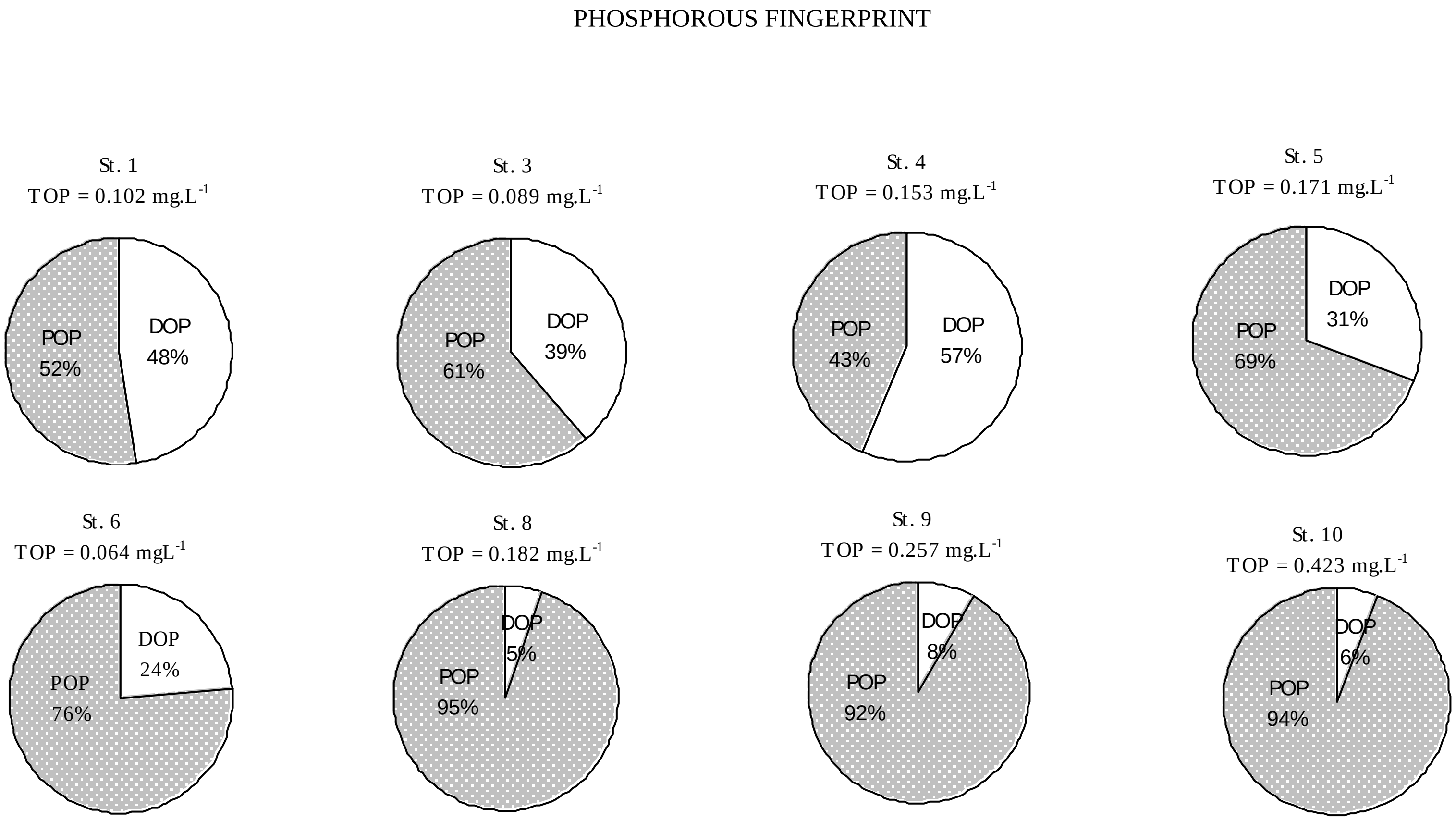

Figure 6.8. Organic material indicator of each sampling station at Lake Loa Kang Fishery Reserve

season. The same phenomenon occur in Lake Semayang where the PAHP fraction was higher (66 %) than DAHP fraction (34 %) in dry season but the percentage was decreasing in rainy season (PAHP = 23 % and DAHP = 77 %). This phenomenon is probably due to two processes, that are (1) the decomposition of already existing terrestrial detritus (PAHP) into smaller size in the lake and (2) dilution of PAHP by larger volume of water during the flood but without significant input of terrestrial detritus. (Hartoto *et al*.1998).

The last. type of P-finger prints is the organic material indicator, that is represented by the percentages of DOP and POP concentrations to TOP concentration (Fig. 6.8). The percentages of POP fraction were higher than DOP fraction in most stations, except in St.1 where the percentage of POP fraction nearly equal to DOP fraction and in St. 4 where the DOP fraction was higher than POP fraction. The higher concentration of POP is considered to be associated with the larger size of allochthonous organic material entering the floodplain as compared to the autochthonous ones (Hartoto *et al*. 1999). Wetzel (2001) reported that of the total organic phosphorus, about 70 % or more is within the particulate (sestonic) organic material and the remainder is present as dissolved or colloidal organic phosphorus. Dominance of POP fraction was observed in Lake Loa Kang as reported by Hartoto (1997) in dry and rainy seasons but different pattern occur in Lake Semayang (Hartoto *et al*.1998) when the DOP fraction was higher than POP fraction in dry season but the DOP fraction nearly equal to POP in rainy season.

CONCLUSION

From average T-P point of view, it seems that all stations were already in hyper-eutrophic condition, It may be because the lake rich in organic matter. In most stations DOP and POP were higher than DIP and PIP. The DOP originated from detritus in that system was carried by surface run off from terrestrial origin. Dominance of PP and PIP fractions indicate a poor decomposition process occurred in the water. Trophic indicator show the dominance of TOP fraction in most station that indicate the system either required sufficient time to produce TIP or there a high P-organic input from other allocthonous sources rather than detritus. Higher PAHP fraction indicates the level of partially decomposed organically bound-P that has diameter larger than 0.45 µm occurred in most stations. Higher concentration of POP is considered to be associated with significant input of the larger size of allochthonous organic material.

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Ecological Integrity of A Mahakam Floodplain System:73-80

7. DISTRIBUTION OF AQUATIC HUMIC SUBSTANCES IN LAKE LOA KANG FLOODPLAIN SYSTEM

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ABSTRACT

Lake Loa Kang Fishery Reserve (LLFR) is a floodplain lake system of River Mahakam located in Kutai Kertanegara Regency, East Kalimantan Province. A study on the concentration of humic acids in various habitat types on this floodplain was conducted in the periods of 2003-2004. The study was aimed to reveal the spatio-temporal distribution pattern of humic acids as a feature of ecological integrity. Analyses of humic acid was done using acid-base separation technique prior to measurement with spectrophotometer at 410-480 nm.. Concentration of humic acid in LLFR are in the range of 2.2-10 mg.L^{-1}, and its concentration was significantly correlated with dissolved organic carbon. Backswamp deposit lake is the habitat types where the lowest concentration and highest concentration of humic acid was observed in rainy and dry season respectively. Comparison with other floodplain system is briefly discussed.

Keywords: Loa Kang, floodplain, humic acid

INTRODUCTION

Humic substances are ubiquitous in environment, in all soils, water and sediment of the ecosphere. These substances arise from the decomposition of plant and animal tissues and are more stable than their precursors. Their size, molecular weight, elemental composition, the number and position of functional group vary depending on the origin and age of material (Schnitzer & Khan,. 1972). Humic substances are the organic compounds found in environment that can not be classified as any other chemical class of compounds (e.g., polysaccharides, protein, etc.). Humic and fulvic acid have been studied extensively for more than 200 year; however, much remains unknown regarding their structure and properties (Gaffney *et al.* 1996)

In aquatic environment, the concentrations of organic compounds are mostly expressed as total organic carbon (TOC) or dissolved organic carbon (DOC). The DOC concentration of aquatic system is in the range from < 1mg L^{-1} in most groundwater to several tens of mg L^{-1} in brown water of swamps. The DOC concentrations in river water is typically a few mg L^{-1}. The contribution of HS to the DOC can be found in the range between 40% to 70%. Humic substances enter in aquatic from two main sources, that are of terrestrial plants and soils origin (allochthonous substances) and the material resulting from biological activities within the water body itself or autochthonous substances (Frimmel, 2001).

The presence of humic material can promote the solubilization of nonpolar hydrophobic compounds. This acts to decrease the sorption of these material (e.g. DDT) to the soil or sediments or sediment or to decrease the volatility rate of the more volatile organics (e.g. polychlorinated biphenyls). Humic and fulvic acids that contains in surface waters and groundwater will have a significant influence on the transport and fate of metals; radio nuclides, and organic contaminants in the environmental (Gaffney *et al.*

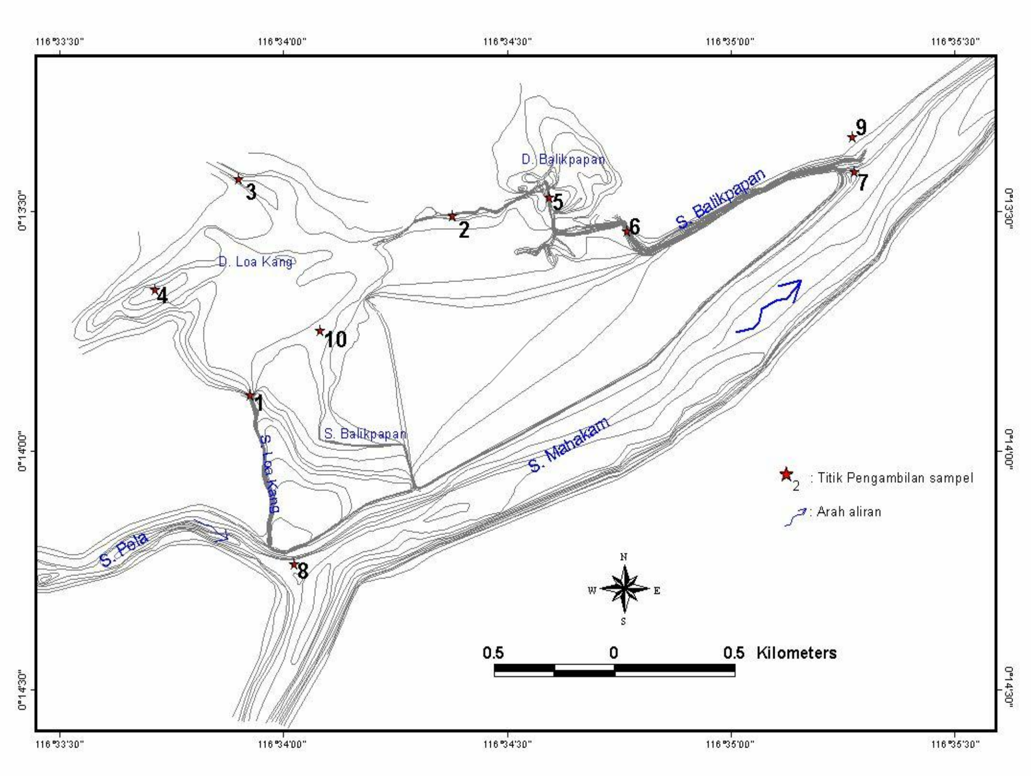


Figure 7.1. Location of sampling station at Lake Loa Kang Fishery Reserve

Table 7.1. Sampling stations in the Lake Loa Kang floodplain system

Station	Location, habitat type	Coordinates	
		South	East
1	R. Loa Kang, a channel connecting L. Loa Kang with R. Pela	S 0^{o} 13' 53.1"	E 116^{o} 33' 55.6"
2	Connecting channel between L. Loa Kang and L. Balikpapan.	S 0^{o} 13' 30.5"	E 116^{o} 34' 22.6"
3	Tunjung Springs, a spring in the LLFR	S 0^{o} 13' 26.0"	E 116^{o} 33' 54.0"
4	Lake Loa Kang *(Hakang)*, a backswamp deposit lake	S 0^{o} 13' 39.9"	E 116^{o} 33' 42.9"
5	Lake Balikpapan, a back swamp deposit lake in LLFR	S 0^{o} 13' 28.3"	E 116^{o} 34' 35.6"
6	River Balikpapan, a connecting channel between backswamp deposit lake with R. Mahakam.	S 0^{o} 13' 32.5"	E 116^{o} 34' 46.1"
7	Mouth of River Balikpapan, junction of R. Balikpapan and R. Mahakam	S 0^{o} 13' 25.0"	E 116^{o} 35' 16.5"
8	Mouth of River Pela, junction of R. Pela and R. Mahakam	S 0^{o} 14' 14.0"	E 116^{o} 34' 0.9"
9	*Lopak*, small size ephemeral pond in LLFR	S 00^{o} 13' 20.7"	E 116^{o} 35' 16.4"
10	Maling Canal, a segment of man made channel that connect L. Loa Kang with River Mahakam	S 00^{o} 13' 45.0"	E 116^{o} 34' 5.0"

Table 7.2. Classification of Ecological Habitat Types in Lake Loa Kang floodplain system

No.	Habitat Types	Location
1.	*Hakang or* Lebung, a depression/deposit lake in floodplain system	L. Loa Kang (St.4) and L. Balikpapan (St.5)
2.	Connecting channel between floodplain lakes	Connecting channel between L. Loa Kang and L. Balikpapan (St.2)
3.	Connecting channel between the floodplain depression lake and main river	R. Loa Kang (St.1) and R. Balikpapan (St.6)
4.	Junction of tributary and main river	Mouth of R. Pela (St.8)
5.	Mouth of connecting channel between the floodplain depression lake and main river	Mouth of R. Balikpapan. (St.7)
6.	A spring in floodplain system	Tunjung Springs (St.3)
7.	Ephemeral ponds	Lopak (St.9)
8.	A segment of man made channel that connect L. Loa Kang with R. Mahakam	*Maling* Canal (St.10)

1996).

Lake Loa Kang is a floodplain lake that located in District of Kotabangun, Kutai Kertanegara Regency, East Kalimantan Province. Lake Loa Kang floodplain already managed for more than five centuries as fish sanctuary or fishery reserve by Moslem Kutai Kertanegara Kingdom that was succeeded by Government of Republic Indonesia. Unfortunately nowadays the fishery reserve are in badly managed condition. Fluctuation of water level in Lake Loa Kang are influenced very much by River Mahakam, a main river that supply water into the lake. In dry season, the lake becomes small and vegetations riparian will grow around the lake, but in rainy season when water supplies increase extremely, vegetations riparian will be inundated and died. This phenomena happened every year, therefore the dump of the died plants will be a precursor to form humic substances. The objectives of this study are to investigate the spatio temporal distribution characteristics of aquatic humic acid; based on the functional groups, element composition and their concentration in floodplain lakes system.

MATERIALS METHODS

Sampling Sites

Sampling have been done in three times in July 2003, August 2003 and September 2003 and June 2004 each of the month represent the dry, transitional, rainy and dry season seasons respectively. Water samples were taken in nine sampling sites spread in Lake Loa Kang and Lake Balikpapan (Table 7.1, Figure 7.1) that represent . In dry season, several sampling sites were dried because of prolonged drought.

Determination of humic acid in river water

Humic acid was analyzed according to the method developed by Japan Society for Analytical Chemistry (1994). Detailed description of the analytical method were as follows: The sample water was filtrated by filter paper No. 5A to remove the suspension. Half millilitres of 6 M HCl and one ml of 10 % NH_2OHHCl were added to the filtrated water and then heat for five minutes to degrade iron colloid. After the cooling to room temperature, two mL aliquot of 0.1 M EDTA solution was added to the water sample. Then, the pH of the water sample was adjusted to 10 by adding the 6 M NH_3 solution

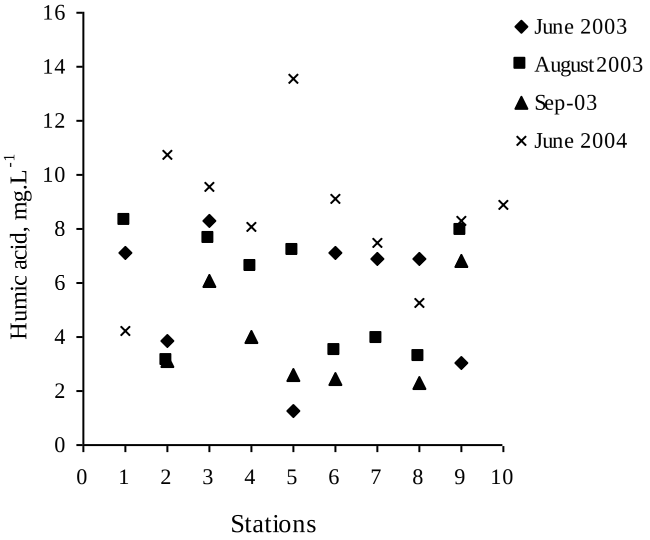


Figure 7.1. Spatio and temporal distribution of humic acid in Lake Loa Kang Fishery Reserve

and transfer to the 50 ml volumetric flask and adjusted to 50 ml with distilled water. The humic acid in the water sample was determined using the Spectrophotometer at 410-480 nm.

Standard solutions were prepared using Jangraga and Lake Loa Kang humic acids (Yustiawati, 2003). The concentration of humic acid was calculated using this calibration curve of Jangraga humic acid.

Determination of TOC and DOC in river water

Total Organic Carbon and Dissolved Organic Carbon was analyzed according to the methods described by APHA-AWWA-WEF (1998) using Shimadzu TOC-5000-A analyzer.

Data analyses

The data collected from this study was analyzed pictorially using Excell Microsoft Windows 2000 Program. Statistics analysis was conducted by the methods presented in Zar (1999).

RESULTS AND DISCUSSION

The data show that concentration of humic acid in Lake Loa Kang in four times sampling are in the range 2.2-10 mg-L^{-1} (Fig. 7.1). Temporal distribution data indicated that the concentration of humic acid in June 2003 and June 2004 are higher than other times (Fig.7.1).Concentration humic acid in Lake Loa Kang is relatively high, if we compare to the concentration of humic acid in River Cikaniki, the concentration is three times higher (Yustiawati, 2003). In spite of non humic lakes, concentration humic acid in Loa Kang is just few mg.L^{-1} lower then the humic lake in Central Kalimantan that range between 23-104 mg.L^{-1}(Tanaka *et al.* 2000). The concentration of humic acid in Tanaka and this studies is relatively much lower than the report on humic acid concentration in

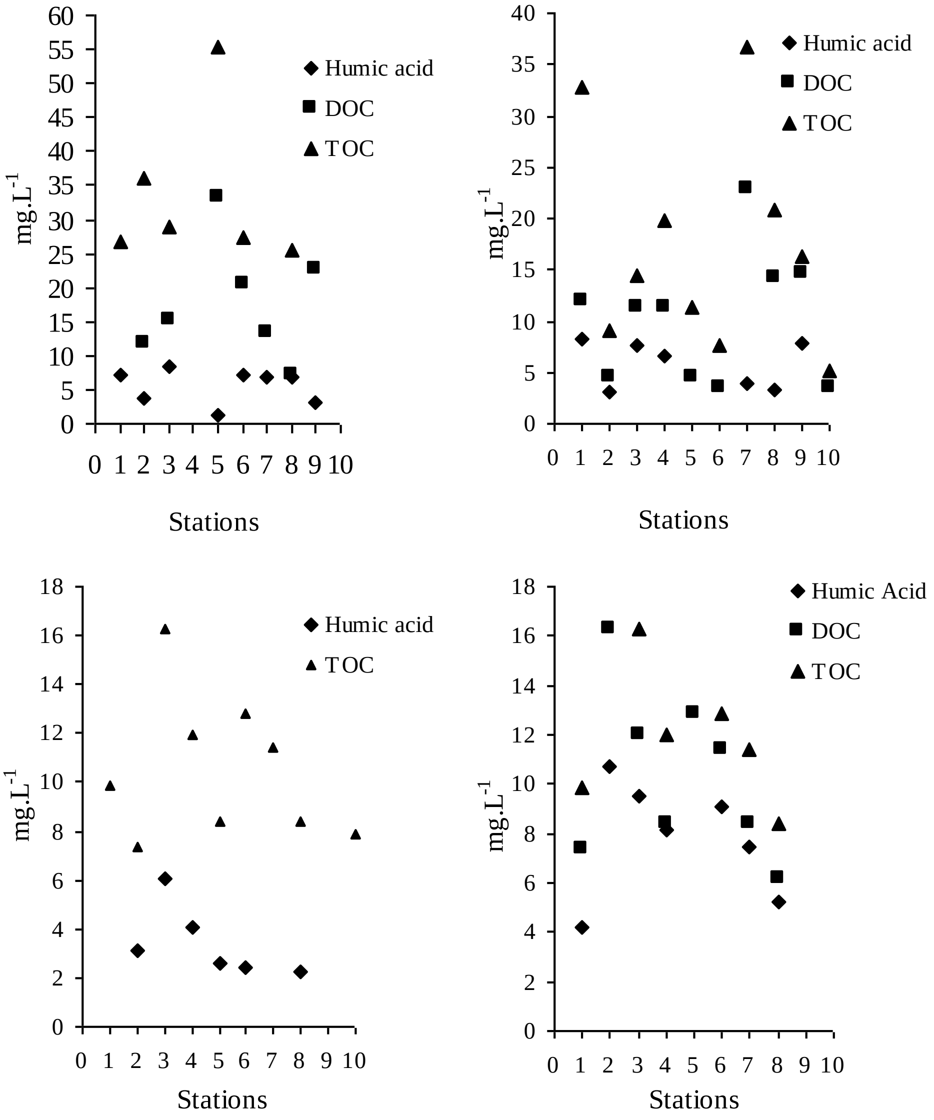
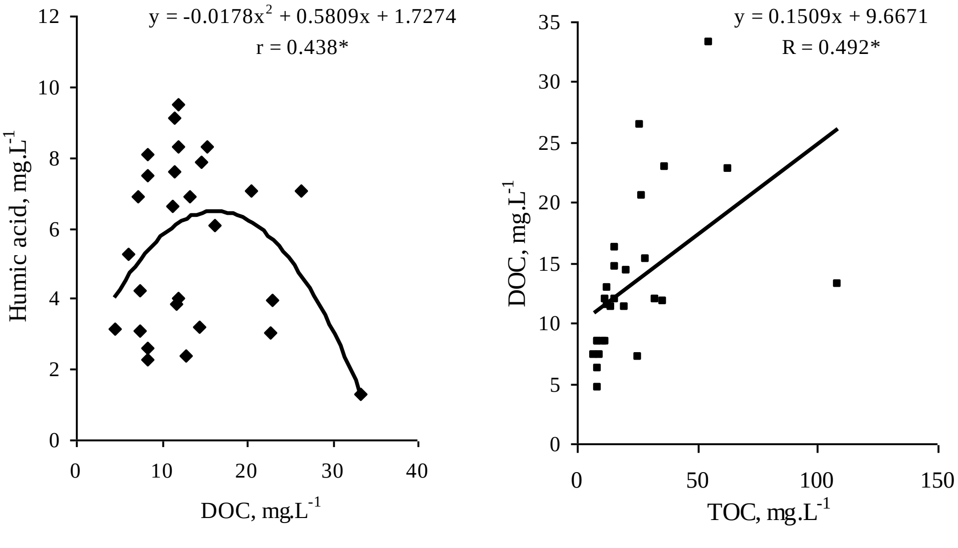


Figure 7.2. Distribution of DOC, TOC and Humic Acid concentration in Lake Loa

the floodplain lakes on the peat land area of Central Kalimantan that range between 654.928-854.067 mg.L^{-1} in the periods of 1995-1997 (Hartoto & Yustiawati, 1999). The differences probably not only due to differences in separation techniques and humic acids standards but also probably because of different sampling time. The area of Lake Loa Kang is not the area of soil with high peat concentration and the water colour is not brown, but all the lakes under study in Central Kalimantan is located in the peat land soil with high peat concentration and the water colour is black to dark coffee. It is questionable that there are only a slight differences in humic acids concentration between the two areas (L. Loa Kang and humic lakes of Central Kalimantan) because visual appearance is significant.

Table 7.3 Percentage of Humic Acid and DOC to TOC in Lake Loa Kang floodplain system

Time	Stations	HA mg.L^{-1}	HA % of TOC	HA % of DOC	DOC mg.L^{-1}	DOC % of TOC	TOC mg.L^{-1}
Jun-03	1	7.085	26.51	26.85	26.390	98.75	26.725
	2	3.833	10.59	32.62	11.750	32.47	36.190
	3	8.305	28.73	54.39	15.270	52.82	28.910
	5	1.289	2.33	3.87	33.300	60.30	55.220
	6	7.085	25.91	34.55	20.510	74.99	27.350
	7	6.882	6.35	51.98	13.240	12.21	108.400
	8	6.882	26.91	95.98	7.170	28.04	25.570
	9	3.020	4.80	13.30	22.710	36.08	62.940
Aug-03	1	8.305	25.41	69.73	11.910	36.43	32.690
	2	3.142	34.83	68.67	4.576	50.72	9.022
	3	7.614	52.99	67.02	11.360	79.06	14.369
	4	6.598	33.27	58.54	11.270	56.83	19.830
	7	3.955	10.77	17.23	22.960	62.51	36.730
	8	3.224	15.48	22.53	14.310	68.70	20.830
	9	7.898	48.64	54.17	14.580	89.78	16.240
Sep-03	2	3.081	41.98	41.98	7.340	100.00	7.340
	3	6.069	37.31	37.31	16.268	100.00	16.268
	4	4.037	33.74	33.74	11.965	100.00	11.965
	5	2.614	31.17	31.17	8.385	100.00	8.385
	6	2.413	18.80	18.80	12.831	100.00	12.831
	8	2.268	27.06	27.06	8.383	100.00	8.383
Jun-04	1	4.240	43.13	57.76	7.340	74.67	9.830
	3	9.524	58.55	79.60	11.965	73.55	16.268
	4	8.102	67.71	96.62	8.385	70.08	11.965
	6	9.118	71.06	80.04	11.392	88.78	12.831
	7	7.492	65.76	89.37	8.383	73.59	11.392
	8	5.256	62.70	85.35	6.158	73.46	8.383
Average		5.531	33.80	50.01	13.34	70.14	24.33
n		27	27	27	27	27	27
Std. Dev.		4.63	19.21	26.26	6.95	25.85	21.11
Confidence		1.74	7.25	9.90	2.62	9.75	7.96



a. b.

Figure 7.3. Correlation between DOC with Humic Acid and TOC in Lake Loa Kang floodplain system

The pattern of spatial distribution is not too distinctive, but the highest (in rainy season, Sept 2003) and the lowest (in dry season, June 2004) concentration of humic acid was observed in backswamp deposit lake (St.5, Lake Balikpapan).The pattern probably because this lake is the habitat type that receives new water at the earliest duration in the rainy season and on the other hand it release water at the latest duration during dry season.

Table 7.3 showed that percentage of humic acid to Dissolved Organic Carbon are in the range 50.01 ± 9.90 %. This figure indicated a condition quite similar to condition of the Amazon watershed. Ertel *et al.* in 1986 as cited by Wetzel (2001) indicated that in Amazon River humic and fulvic acid constituted over 60 % of the river dissolved organic carbon in that river. According to Frimmel (2001), humic substances related significantly with DOC. Mills *et al* (1996) also reported that humic substances make up 50 to 60 % of DOC pool in streams and rivers, and make up 75 % of the DOC pool in wetland area. Sources of DOC and humic acid in LLFR are supposed to be from died plants and fishes as impact of changing water level. More detailed analyses using correlation analyses (Fig.7.3a) showed that although there is strong and significant relationship (r_{table}= 0.388, P< 0.05) between concentration of humic acid and DOC, but the relationship is not linear and simple. More simple relationship was observed between concentration of DOC with TOC (Fig. 7.3b) but no significant relationship was observed between humic acid and TOC. This pattern probably because there are large variety and more complex compounds that formed the total organic carbon rather than only the humic acids.

The presence of humic acid in Lake Loa Kang indicated the potential of Lake Loa Kang to retard or enhance the photochemical decomposition of pesticides or toxic organics. Moreover, Lake Loa Kang also can complex the heavy metal, such as Pb that poured out to the lake from boat machine. Although the binding mechanism of humic acid with metals or organic pollutants not yet well understood, but many research have been done to study about these.

CONCLUSION

Humic acid in Lake Loa Kang is relatively high. In this floodplain system, humic acid formation tend high although it is not peat lake. The source of organic materials supposed origin form flooded system that carry and left organic materials, which through microbiological and chemical processes will form dissolved organic carbon that includes among the others, the humic acid.

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Ecological Integrity of A Mahakam Floodplain System:81-87

Short Note

8. COMMUNITY STRUCTURE OF PHYTOPLANKTON AT LAKE LOA KANG FISHERY RESERVE, EAST KALIMANTAN IN NOVEMBER 2002

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Lake Loa Kang Fishery Reserve is floodplain system located at Lake Semayang outlet between River Pela and River Mahakam. The floodplain system functioned as fishery reserve under the legal protection of local government Kutai Regency with its *Perda Kabupaten Kutai No. 18, 1978*. Because of its important functions as a source of fish fingerling and fish brood, then it is necessary to manage this water to maintain its physical habitat and biotic components and environment. Phytoplankton community in inland waters have special functions like other organism, beside as a food source for higher trophic level, they can also indicate water quality condition. Some phytoplankton community parameters that are usually use as a biological indicator for a typical of waters are dominant among the others, the characteristically dominant group, abundance, dominant species, pigment concentration (especially chlorophyll-*a*), and species composition (Basmi, 1987). Suwignyo *et al* (1987) said that community structure like composition and abundance can be use as a biological indicator, because even in the extreme condition phytoplankton community were survive. Preliminary study about community structure of phytoplankton at Lake Loa Kang Fishery Reserve in this report is expected to complete the information about phytoplankton community of this system to the basis for its ecological management.

Lake Loa Kang Fishery Reserve is located at Kota Bangun District, Kutai Regency, East Kalimantan Province. They have 739 hectares surface area include Lake Loa Kang (34.57 hectares) and Lake Balikpapan (10.39 hectares). Water sampling was done in November 3 – 7, 2002 at thirteen stations (Fig. 8.1). Ten litres waters filtered using net plankton No. 25 (53 µm mesh size) and were fixed with Lugol solution. The calculation of phytoplankton abundance using a Lackey Drop Microtransect Method (Anonymous, 1995) and the identification of phytoplankton genus is done according to the identification keys of Prescott (1955, 1970); and Mizuno (1970). Diversity Index (H’) and Equability Index (E) proposed by Odum (1971) was used for diversity analyses of community.

There were thirty genus of phytoplankton found in Lake Loa Kang Fishery Reserve (Table 8.1). Chlorophyta is the phylum that show the highest genus composition, that comprises of *Chlorella*, *Crucigenia*, *Dictyosphaerium*, *Oocystis*, *Pediastrum* and *Scenedesmus (*Fig.8.2-8.4*)*. From the Cyanophyta group, several genera such as *Chroococcus* and *Glaucocystis* are often found and from Chrysophyta are *Melosira*, *Navicula* and *Surirella*. A high genus composition of Chlorophyta group are usually in tropical waters, Sulastri and Hartoto (1999) reported that at Lakes Lutan, Takapan and Rengas in Kahayan floodplain system of Central Kalimantan, also show a plankton community characterized with a high number of genera that was dominated by

Chlorophyta genera followed by others group such as Chrysophyta, Cyanophyta, Euglenophyta and Pyrrophyta.

The phytoplankton genus found at Lake Loa Kang Fishery Reserve especially the Chrysophyta similar to the composition of phytoplankton from Lake Melintang and Lake Semayang (Purnomo *et al*. 1994). Chlorococcales (Chlorophyta) like *Chlorella*, *Crucigenia*, *Dictyosphaerium*, *Pediastrum* and *Scenedesmus* showing wide distribution patterns; and from Pennales (Chrysophyta) was *Navicula*. Total abundance of phytoplankton is between 23 – 1009 ind.L$^{-1,}$ that showed the condition of the waters with a low abundance. As reported by Purnomo *e. al.* (1994), the same condition are found at Lake Semayang (18 – 540 ind.L^{-1}) and Lake Melintang (12-360 ind.L$^{-1,}$). The low abundance of phytoplankton indicate a poor water of Lake Loa Kang Fishery Reserve, because Landner (1976) said that the abundance of phytoplankton between 0-2000 ind.L^{-1} indicate oligotrophic type of waters. Hartoto (1997) also showed a low concentration of chlorophyll-a (0.002-1.442 µg.L^{-1}), that indicate a very low primary productivity potential of Lake Loa Kang Fishery Reserve. It means that contribution of phytoplankton as food resources for aquatic organisms such as fishes is low in this ecosystem. The values of Diversity Index and Equability Index are range between 1.769-3.315 and 0.656-0.959 respectively (Table 8.1). This Diversity Index values was moderate to high but inclined to a moderate values, which indicate a community condition was change with a little change of environmental condition. The Equability Index are showing values nearly a unity reflecting habitat condition that are relative suitable for the growth and development of each genus of phytoplankton. Community structure of phytoplankton at Lake Loa Kang is better than Lake Balikpapan. Composition, abundance and diversity index at Lake Loa Kang is higher than Lake Balikpapan, i.e. centre of Lake Loa Kang (St. 1), littoral zone at north area (St. 7), and littoral zone (St. 8) compare with a centre of Lake Balikpapan (St. 6). Its means phytoplankton community at Lake Loa Kang was proportionate and stable than phytoplankton community at Lake Balikpapan. In November, 2002 Lake Loa Kang Fishery Reserve was dry season, water will decrease, even at Lake Balikpapan water just at centre of lake at a channel river in 20 cm depth. A continues study must be done at wet season when the water was high and all of waters were flood, to see a community structure of phytoplankton at different season.

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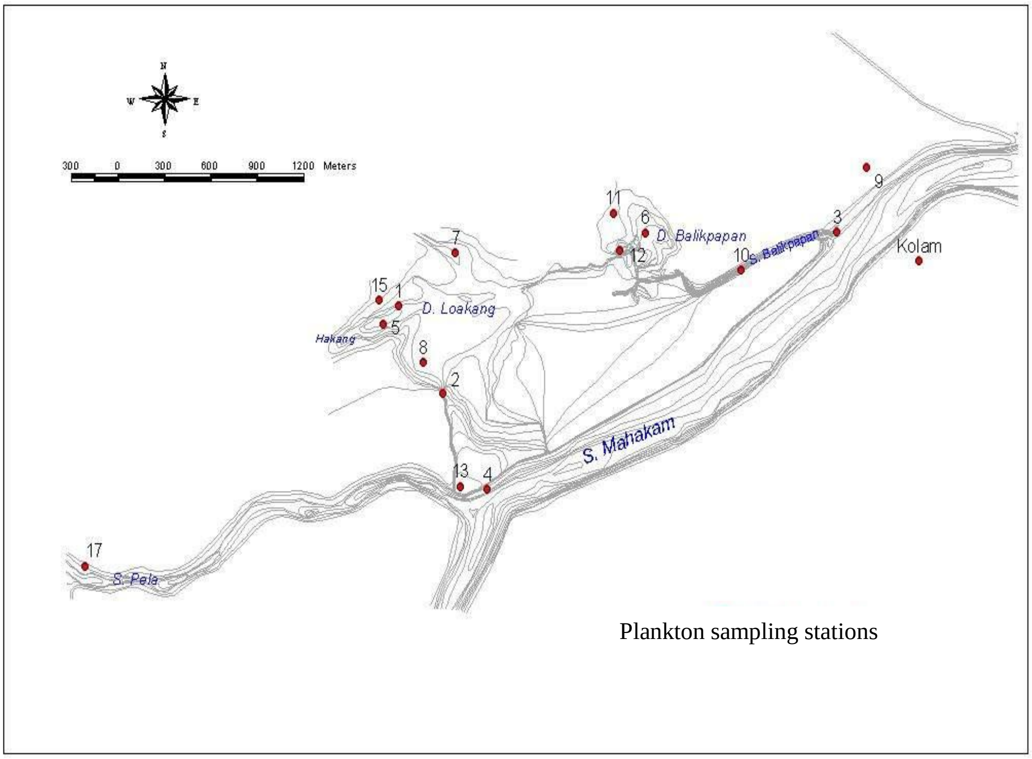
Table 8.1. Composition and abundance of phytoplankton at Loa Kang Fishery Reserve in November 2002

ORGANISMS		Number of plankton (cells.L^{-1})						
		St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7
CHLOROPHYTA	Chlorococcales							
	Chlorella	141		11		3	3	3
	Crucigenia	227	47			80		13
	Botryococcus	3						
	Dictyosphaerium	24	19	3		5		21
	Kirchneriella							3
	Oocystis	5				3	3	13
	Pediastrum	205	11			8		59
	Scenedesmus	248	16			40		21
	Ulotrichales							
	Ulothrix	3		3				8
	Zygnematales							
	Euastrum	5						5
	Hyalotheca	13						
	Spirogyra			3				
	Staurastrum	3						3
CYANOPHYTA	Chroococcales							
	Chroococcus	67				8		
	Glaucocystis	43	3					
	Merismopedia							8
	Microcystis	3						
	Oscillatoriales							
	Oscillatoria		3					
	Spirulina	5						
CHRYSOPHYTA	Centrales							
	Melosira	3	3					3
	Pennales							
	Cymbella							
	Gomphonema							
	Navicula	5					11	11
	Nitzschia	3					3	
	Pinnularia							
	Surirella		3					8
EUGLENOPHYTA	Euglenales							
	Euglena			3			24	
	Phacus							
	Trachelomonas	3						
	Abundance (cells.L^{-1})	1009	105	23	0	147	44	179
	Taxa Richness	19	8	5	0	7	5	14
	Diversity Index (H')	2.835	2.306	2.042	0	1.841	1.769	3.191
	E Index (E)	0.667	0.769	0.879	0	0.656	0.762	0.838

Table 8.1 Continued

ORGANISMS		Number of plankton (cells.L^{-1})					
		St. 8	St. 10	St. 12	St. 13	St. 15	St. 17
CHLOROPHYTA	Chlorococcales						
	Chlorella	13		3			
	Crucigenia		21	3		3	5
	Botryococcus						3
	Dictyosphaerium	11	3	5		8	3
	Kirchneriella	35					
	Oocystis	3				3	
	Pediastrum	8	5	8		64	
	Scenedesmus	5		8	3	11	
	Ulotrichales						
	Ulothrix	21					
	Zygnematales						
	Euastrum	11					
	Hyalotheca						
	Spirogyra						5
	Staurastrum						
CYANOPHYTA	Chroococcales						
	Chroococcus	21					
	Glaucocystis	29			3	8	
	Merismopedia						
	Microcystis					3	
	Oscillatoriales						
	Oscillatoria						
	Spirulina						
CHRYSOPHYTA	Centrales						
	Melosira				11	5	3
	Pennales						
	Cymbella				3		
	Gomphonema		3	32			
	Navicula	29	5	27	3	3	
	Nitzschia		3				
	Pinnularia	3				3	
	Surirella		3		3	5	8
EUGLENOPHYTA	Euglenales						
	Euglena					3	
	Phacus	3					
	Trachelomonas						
	Abundance (cells.L^{-1})	192	43	86	26	119	27
	Taxa Richness	13	7	7	6	12	6
	Diversity Index (H')	3.315	2.299	2.269	2.322	2.51	2.478
	E Index (E)	0.896	0.819	0.808	0.898	0.7	0.959



Plankton sampling stations

Figure 8.1. Sampling site at Lake Loa Kang Reserve in November 2002

Explanation :

Station 1 : Center of Lake or *Danau* (D) Loa Kang
Station 2 : R. Loa Kang
Station 3 : R. Balikpapan section connected to River or *Sungai* (S) Mahakam
Station 4 : R. Mahakam segment near L. Loa Kang floodplain system
Station 5 : *Hakang* at L. Loa Kang
Station 6 : Center of L. Balikpapan
Station 7 : Littoral zone of L. Loa Kang at the north site
Station 8 : Littoral zone at L. Loa Kang
Station 10 : R. Balikpapan
Station 12 : A channel connected to L. Loa Kang
Station 13 : Mouth of R. Pela and R. Loa Kang
Station 15 : Another inlet to L. Loa Kang
Station 17 : Border of buffer zone with R. Pela

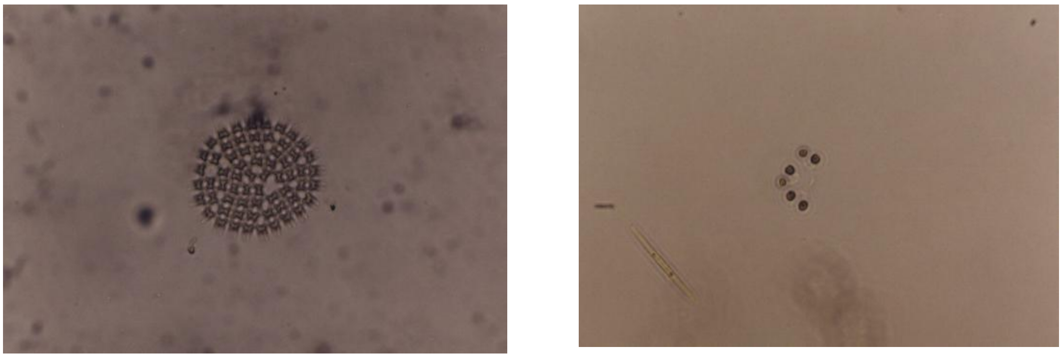


Figure 8.2. *Pediastrum* (left) and *Dictyosphaerium* (right)

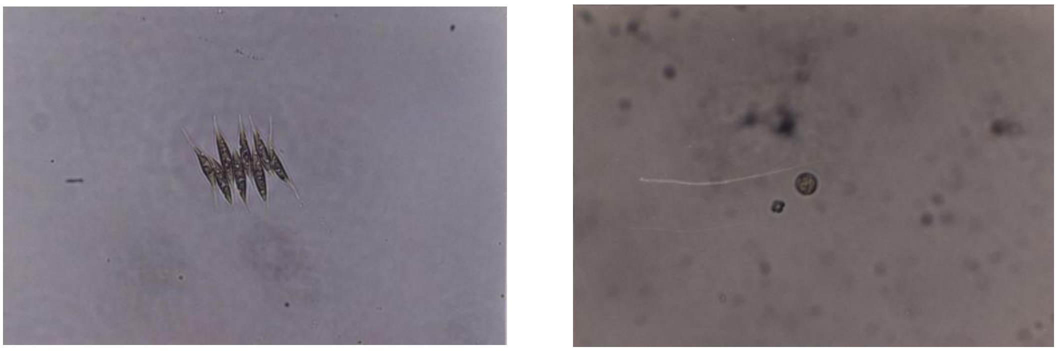


Figure 8.3. *Scenedesmus* (left) and *Chlorella* (right)

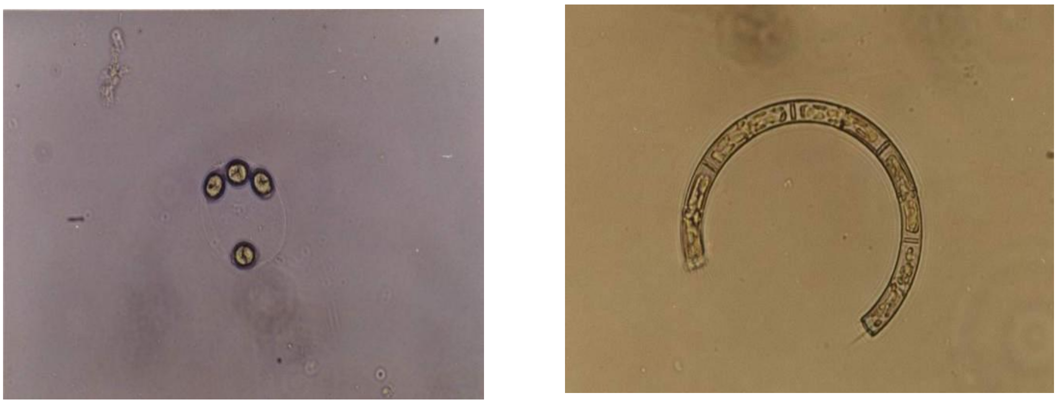


Figure 8.4. *Oocystis* (left) and *Melosira* (right)

3. Collaborative study
(5)

Ecosystem function and genetic diversity in wetland forests of Kalimantan

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Utilization of Epiphytic and Endophytic Bacteria for Reforestation and Sustainable, Hydrophilous Agricultural Management of Wet, Abandoned Tropical Peat Land to Protect Peat Soil and Swampy Forest from Fire

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Abstract

This report implies human dimensional approach to preservation of tropical swampy forest and tropical peat soil. What we can do for protection of peat soil in abandoned area from the peat fire is probably to discuss a practical way to set up attractive agro-forest systems on the abandoned peat land. The concept of "deposit-from-trees" originally proposed by Suhardi, Gadjah Mada University, is attractive to both local residents and environmentalists, particularly when it was combined with hydrophilous agriculture to produce aquatic crops under peat-tolerant big trees. According to his idea, 20 year after the trees produce enough deposit for persons who planted the trees, true beneficial ones are next generation, though. Since many sphingomonads isolated from the rhizoplane of native trees and crops had several functionalities as plant growth promoting rhizobacteria, they are useful bio-resources to create peat-shading forest. While the planted trees are young, hydrophilous agriculture results in effective water table management, and the grown trees create not only timber but also enough shade to protect peat soil there. Our next approach is to find better and more adaptable species and cultivers for hydrophilous agriculture and economically important tree species such as *Shorea balangeran*. For hydrophilous agriculture, sago, aroid, paddy plant or water convolvulus will be candidate for introductive crops tolerable to swampy conditions. To minimize root system and also fertilization, some endophytic nitrogen fixers should be widely screened. In the case of sago, two endophytic bacteria showed a synergic effect on nitrogen fixation in preliminary screening of functional endophytes in tropical plants. Study field of human dimension is to be created from both local-social needs and global needs, along with three items: economical benefit, traditional heritage and bio-rational land management.

Key Words: Water table management, *Sphingomonas*, Bio-reforestation, Deposit-from-tree, Hydrophilous agriculture, Endophytic nitrogen-fixer.

1. Relationship between Peat Fire and Fern Vegetation

Now a day, tropical peat soil is recognized as a huge carbon sink, and swampy forest developed throughout the peat land is regarded as a cradle of the peat soil itself. A heavy rainfall during rainy seasons results in leaching mineral elements necessary for maintaining swampy forest, and also tannin-rich plant tissues often prevent decomposed liters from mineralization of proteins. So, the forest trees effectively circulated and re-use nutrients from liters before liters were completely washed away from the decomposed leaves or tannized as unavailable N in peat soil. As long as the top soil is present and a high water table necessary for wet land vegetation, swampy forest can maintain and regenerate this ecosystem. This means that swampy forest is no longer able to maintain this forest ecosystem when top soil had been lost by forest fire and repeated peat fire (1).

Plain peatlands throughout low land of Central Kalimantan, previously developed for agricultural farm by destroying swampy forests in the southeast regions, have remained as large abandoned area due to frequent forest fires, mainly caused by human activities. Along canal construction leading to low water table on the peat land, such deforestation due to the human impact results in unusual dryness of the peat soil. When severe drought hit over such deforested regions, occasion of peat fire destroys peat top soil, which is necessary for reforestation due to active elemental circulation in the ecosystem. Generally, heavy rainy season followed after the dry season to wash out the ash from the peat land, resulted in fern community development. In fact, ferns are poor nutrient –tolerant and also have tough rhizome and underground part as networks in deep soil, so they often emerge from the places where thickness of peat layer burnt and lost peat layer by peat fire is estimated to be over 1 meter (Fig. 1a). Subsequently, fern vegetation covers throughout the burnt ground in a short time.

Unfortunately, fern land prevents recovery and reforestation of the swampy forest ecosystem. Even worse, pure fern communities seem to result in positive feedback regulation of peat fire and peat loss. Due to characteristic root systems and low shading effect against peat soils, fern vegetation accelerates dry up of the land. As shown in picture (Fig. 1b), ferns possess fibrous but hard root systems to form a gourd sponge-like root mat. This root mat easily catches and ignite peat fire, allowing the fire to break into deep soil, smolder there and completely burn down the top soil on and around the fern community. In fact, large scale of peat fire that occurred in 2002 brought severe damages on non-shaded, deforested area of peat land where also lost shading trees by forest fire in 1997 (Fig. 2). New shoots soon arise to emerge further extend their niche, and peat fire is again repeated to destroy peat layers (Fig. 1c). This is severe vicious circle in peat land disruption, occurring now on large area of peat land in Central Kalimantan.

a: Peat fire smoldering in deep peat layer (Finland plot)

b: Root mat of fern, Karakai (Kapuas border, Central Kalimantan).

c: Fern land emerged throughout peatland where top soil had burnt by peat fire (Kalampangan).

Fig. 1 Emergence of fern vegetation afetr severe peat fire leading to further top soil damage.
The fern vegetation never allow succession to recover forest. Non-shading fern land seems to be a positive feed back regulation to destroy tropical peat soil.

Fig. 2 Severe top soil damage only around fern vegetation area in Finland plot by grassland fire occurred in August, 2002. In this semi-wet land, the area covered with *Xyris complanata* had soon recovered its vegetation, but the area covered with fern did not recovered by any plants due to severe top soil damage.

2. Human Dimensional Approach for Water Table Management for Protection of Peat Soil: Hydrophilous Agriculture Combined with Endophytic Nitrogen Fixer as Biofertilizer

To prevent such non-shaded, dry peat land from the peat fire and bio-degradation concerning fern emergence, it is most reasonable to keep the water table of the peat land high to nearly natural level. Hence, such water table management is obviously fundamental manner for peat soil protection from peat fire (2). Then, query arises: how and who should and can do water table management in Central Kalimantan? It is obvious that neither governments, politician nor scientists but the local peoples must do it. So, our scientists should be allowed only to join discussion on the way of water table management, because it is probably necessary to motivate the local people to concern such land management more positively, not only for social obligation but also for economical benefits. A low-input, extensive agriculture in such wetland is therefore reasonable as a proposal for profitable care and management of peatland. Since soil acidity and nutrient deficiency lied on such peat soil as serious problems for agricultural use, the best choice of agricultural crops suitable for wet peat soil and bio-rational cultivation manners adaptable to the local society and local community are awaited, being directed for extensive agriculture in such adverse land.

The root symbiotic microbes often play an important role in the survival of their host plants by assisting effective nutrient uptake in stressed soils. Root nodulating bacteria and ectomycorrhizal and arbuscular mycorrhizal fungi are those representative partners of plants (3-5); however, in most of the cases they have a narrow host-specificity and/or a low adaptability to wet and acidic soil conditions. In contrast, epiphytic and/or endophytic bacteria, including non-nodulating, plant growth promoting rhizobacteria (PGPRs) and mycorrhizal helper bacteria (MHBs), are more effective partners for plants under any adverse soil environments (6). It is, hence, necessary to search and screen remarkably functional rhizobacteria under swampy peat soil.

Thus, our next approach is to find utilizable and more adaptable crop species and also economically important tree species for hydrophilous agriculture and agroforestry, respectively. Our possible choice for low-cost agricultural management in wet peatland is to utilize epiphytic and/or endophytic nitrogen-fixing bacteria and organic phophate-decomposable bacteria as biofertilizers in cultivation of hydrophilous vegetables and crops suitable for hydrophilous agriculture. Aroid, taro, kangkong (water convolvulus), sago and paddy plant (rice), all of which have a possibility as crop tolerable to swampy peatland conditions, will be strong candidates for such agriculture system. To minimize dependency on root system and also chemical fertilization, some endophytic nitrogen-fixers should be widely screened and introduced into hydrophilous crops (7). In our preliminary screening of endophytic nitrogen-fixers in aerenchyma-rich tropical plants, two endophytic bacteria, *Herbasprillum* sp. and *Bradyrhizobium* sp., isolated from leaf stem marrow and inner tissues of aerial root of sago, respectively, showed a synergic effect on nitrogen fixation capability as acetylene reduction activity. Although it is just started to search such water-tolerant and practically effective biofertilizers as local bioresources, further screening of functional endophytic bacteria from the wild tropical plants and traditional crops is most likely to promise us to obtain new and effective biofertilizing agents.

3. Human Dimensional Approach for Water Table Management for Protection of Peat Soil: Agroforestry System to Create Economical Base and Tree Shade

We thus propose a new agriculture-agroforest system to rehabilitate the destroyed peatland, combining hydrophilous agriculture and agroforestry system to grow shading trees, such as *Anacardia* sp., *Artocarpus* sp., *Hopea megarawan* and *Shorea balangeran* highly adaptable to peat soil (5,8). In particular, economically important timber trees including *Shorea* spp. can be used as symbolic tress of wetland management. This "symbolic" means not only ecological significance but also economical benefits.

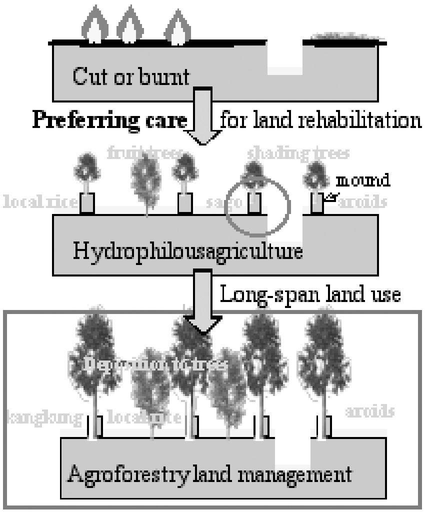

Fig. 3 Importance of water table management.

The concept of "deposit-to-trees" originally proposed by Suhardi, Faculty of Forestry, Gadjah Mada University (9), is highly attractive to both local residents and environmentalists, particularly when it was combined with hydrophilous agriculture to produce aquatic crops under peat-tolerant taller trees. According to his idea, 20-years after, the deposit-to-trees produce enough interest together with deposit either as living tree or timer product. In this system, the owner can withdraw the deposit plus its interest anytime for his family, or can keep the trees for next generation and local community. While the planted trees, even when they are young, create shade (Fig. 3). The hydrophilous agriculture in the open spaces among the trees, with appropriate shading, would result in effective water table management, and the grown trees would gradually produce not only timber but also stable peat soil protected from peat fire. Such planted trees are beneficial not only for tree owner and local community but also for all of us, because those trees would directly and indirectly minimize carbon emission from peat land in this area.

Many efforts have been done for searching functional microorganisms, including ectomycorrhizal fungi, arbuscular mycorrhizal fungi, actinorhiza, PGPR, MHB and free-living nitrogen fixers, to assist tree growth promotion. In fact, several groups have successfully isolated effective biological agent and practically demonstrated their activity. Furthermore, several tree species adaptable to Central Kalimantan area have been screened by some research groups. Kitso and Sampang in SIMTROP also searched several peat soil-preferring tree species using cuttings. In pot experiment using sand and peat soil, *Artocarpus champeden* grew remarkably well within 3 month characteristically in peat soil pots, in which many test cuttings of other tree species showed a worse growth than in sand pots (8). Our investigation of rhizosphere microfloral difference between sand pot-growing and peat soil pot-growing *A. champeden* resulted in characteristic isolation of a *Sphingomonas* sp. only from peat soil-pot growing specimens. This *Sphingomonas* sp. was uniquely able to produce extracellular polymeric substances (EPS) as mucilaginous matrix around the rhizoplane, so its functions in nutrient assimilation and rhizosphere environmental regulation are awaited. Combining such peat adaptable trees with tree growth promoting microorganisms, agroforestry system will be successfully established in Central Kalimantan.

4. Functions of *Sphingomonas* spp. isolated from rhizoplane of acidic soil-tolerant plants applicable for bio-reforestation in Southeast Asia

For investigation of microfloral components in the rhizoplane of acid-tolerant plants inhabiting acid-sulfate soil in Central and South Kalimantans, Indonesia, we frequently isolated sphingomonads. *Sphingomonas* is a genus of α-subclass proteobacteria, possessing unique characters, as sphingolipid-producing bacteria (10,11), xenobiotic-degrading bacteria, including polyaromatics and polychlorophenols degrading bacteria (12-15), and biofilm-forming bacteria (15,16).

The *Sphingomonas* spp. isolated from acid sulfate soil-tolerant plants in South Kalimantan were, on the basis of 16S rRNA gene analysis, mostly unknown species. One of the most characteristic behaviors among them is to produce extracellular polymeric substances (EPS) to form organic matter sink, representative of an isolate from rhizoplaneof *Artocarpus champeden* cuttings grown on peat soil in Central Kalimantan. We found that *A. champeden* grows well in peat soil than sandy soil, unlike many tropical trees. After 3-6 month, the *A. champeden* youngsters grew up well to over 2 meters in peat soil pots, while sandy soil allowed them to grow only 30 cm tall. Hence, we investigated the root system and rhizoplane microfloral compositions, and found the *Sphingomonas* sp. as a powerful EPS-producing microorganisms, nevertheless relatively poor root system of the *A. champeden* grown on peat soil.

Sphingomonas spp. and *Frateuria* spp. were characteristically co-inhabiting in rhizosphere of *Xyris complanata*, which is tolerant against severely nutrient-poor soils. *Frateuria* grew well in nutrient broth media but it grew very pooly in Winogradsky's mineral salt mixture. In contrast, *Sphingomonas* spp. were oligotrophic, so it grew well in Winogradsky's mineral salt mixture but did not grow in nutrient broth medium at all. When these isolates were all applied to PCR with specific primers for dedetction of *nif*H region and acetylene reduction assay, three *Sphingomonas* isolates were positive in the assay, while none of *Frateuria* spp. showed any nitrogen-fixing ability.

In co-inoculation assay, some *Sphingomonas* spp. showed a growth promotion activity toward *Frateuria* sp. that had been impregnated in modified Winogradsky's mineral mixture plus 0.5% saccharose agar plate. *Frateuria* sp. was thus dependent on sphingomonads in its propagation. It is certainly clear that *Sphingomonas* sp. contributes to increase microfloral diversity in the rhizoplane, and this is important because high microfloral diversity leads to relatively active elemental circulation and availabilities in the rhizosphere microcosm. It is also known that a *Sphingomonas* sp. isolated from certain activated sludge enabled an unculturable bacterium culturable along their mix-culture (17).

A *Sphingomonas* sp., isolated from *Melastoma malabathricum* and tentatively identified as *S. rosa*, was also found as representative plant growth promotion bacteria toward *M. malabathricum* seedlings in nitrogen-free and highly acidic (pH 3.0) conditions. After 8 weeks incubation at 23^{o}C, the *S. rosa*-inoculated seedlings established stable rhizosphere microflora of *S. rosa* and a root-associating fungus, tentatively identified as genus *Nectria*. These microbial complex may be applicable to bio-reforestation on highly stressed soil in disturbed lands.

5. Conclusion: What is human dimension?

In practical approach from human dimension point of view, effective peat soil protection should be based up on such human activity and social necessity associated with economical motivation and traditional evaluation. In this respect, what natural scientists can do for several issues in peatland in Central Kalimantan is to accumulate knowledge and data for practical land managements to give reliable idea for peatland managements. Our tentative conclusion is as follows: study fields based up on human dimension is to be created from both local-society needs and global society needs. These two requirements from different sides that are often contradictory each other should be harmonized collaboratively along with three items: economical benefit, generation value with heritage and bio-rational land management. Furthermore, human dimensional approach to the best solution and sustainable development of peatland in Central Kalimantan should also be supported by three more items utilizable as pearls of wisdom: traditional manner, scientific knowledge, and also future view and willing (Fig. 4). Water table management to protect peat soil is thus symbolic test case for all of us.

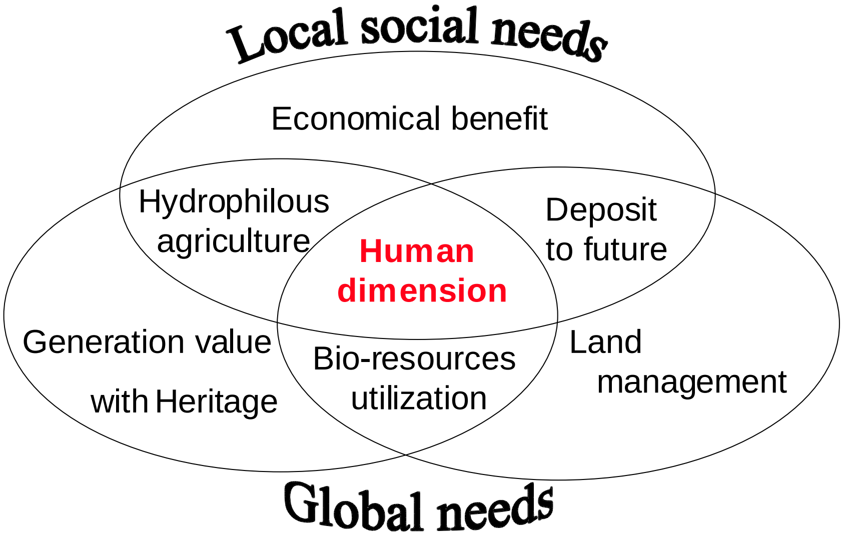

Fig. 4　Structure and concept for human dimension

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Rehabilitation of destroyed tropical peat swamp forest using livestock

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Objectives

The objectives of this study are to verify effectiveness and benefit of introducing livestock into re-forestry and agroforestry farming from the following viewpoints: 1) Clean up weeds in peat swamp using livestock, instead of burning; 2) Improvement of acidity soil with feces and urine from animals; 3) Increase farmer’s income by animal production.

Research Activities

An experiment site of 4 ha was set up the peat swampland fired in 1997 at near Kalampangan village. The experiment site has 16 grazing pastures and 1 control pasture of each 0.25 m^2. Since December 2000, a farmer employed by CIMTROP has kept 9 local goats (Kambing Kacang breed, 8 females and 1 male) on grazing pastures in the experiment site using electric fence. The Indonesian researchers and their students have determined the following parameters: 1) Animal production: growth performance, feeding behavior, reproductive performance and animal disease; 2) Plant production: identification of forage, floristic composition, biomass and chemical composition; 3) Land: carrying capacity and soil characteristics; 4) Social-economic: labor time and income of the farmer.

In this report, results of goat production, plant production and soil characteristics during 4 years were presented.

Goat production in the fired swamp forest

The land use and stocking rate of goats during the 4 years were shown in Table 1. Average cumulative grazing area, rotation time and grazing duration per pasture were 6.0 ha per year, 2.1 times per year and 14.0 days, respectively. Average stocking rate was 1,168 goat days per hectare, annually. This stocking rate corresponds to 3.2 heads per hectare.

The reproduction performance of the native goats was shown in Table 2. In those 4 years, we have kept average about 6 adult female goats, and gotten 29 kids through 25 times of calving. Average calving interval of the female goats was estimated as 286 days. We could get twin kids in 16 % of calving, and total about 8 kids annually. The female goats showed a high reproduction performance as 1.3 kids per female annually. The relationship between age and bodyweight in young goats was shown in Figure 1. From the slope of the line, it was calculated that the growth rate of the young goats was very low as 43 g per day. It is estimated that the goats need more than 5 months to grew up until 10 kg of body weight, and more than 9 months until 15 kg of body weight.

During the 4 years, 6 adult goats and 21 kids died. The mortality of kids was very high as 72 % of the born kids. The distribution of mortality age in the goats was shown in

Table 3. More than 70% of mortality was occurred with in 6 months of age. The mortality of immediate after birth was highest as about 30%, particularly. A change in population of the goats kept on the pastures was shown in Figure 2. The goat population increased during the 2nd and the 3rd years, but turned to decrease in the 3rd year due to high mortality of kids. Plasma mineral contents in the adult goats grazed on the pastures were shown in Table 4. As compared to standard concentration, the adult goats had lower mineral concentrations, especially on phosphorus. It seemed that the low plasma mineral contents related to the mortality of kids.

Table 1. Land use and stocking rate of goats in the experiment site

Year	1st	2nd	3rd	4th *	Average
Land use					
Grazing area (ha)	2.3	2.8	4.0	2.0	2.8
Cumulative grazing area (ha)	6.5	6.3	9.3	2.0	6.0
Grazing rotation					
Rotation time per year	2.9	2.3	2.3	1.0	2.1
Grazing interval (days)	127	164	108	204	151
Duration per paddock (days)	14.2	14.4	9.9	17.3	14.0
Stocking rate					
Goat days per ha per year	1310	1356	1074	933	1168
Goat heads per hectare	3.6	3.7	2.9	2.6	3.2

* Grazing period of the 4th year was 138 days

Table 2. Reproduction performance of female goats

Year	1st	2nd	3rd	4th *	Sum / Av.
Number of female goats	4	8	7	6	6.3
Number of calving	2	9	10	4	25
Number of born kids	2	9	14	4	29
Reproduction performance during the 3.6 years					
Delivery interval (days)					286.2
Twin calving (%)					16.0
Kid production (heads / year)					8.1
(heads / female / year)					1.3

* Period of 4th year was 220 days

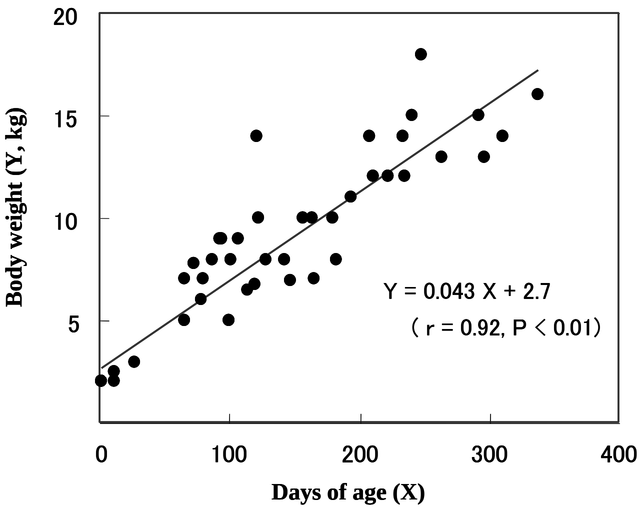

Figure 1. Relationship between age and bodyweight in young goats

Table 3. Distribution in mortality age of goats

	Heads	Percentage
Within 1 day	8	29.6
Less than 3 months	5	18.5
Less than 6 months	6	22.2
Less than 12 months	2	7.4
More than 1 year	6	22.2

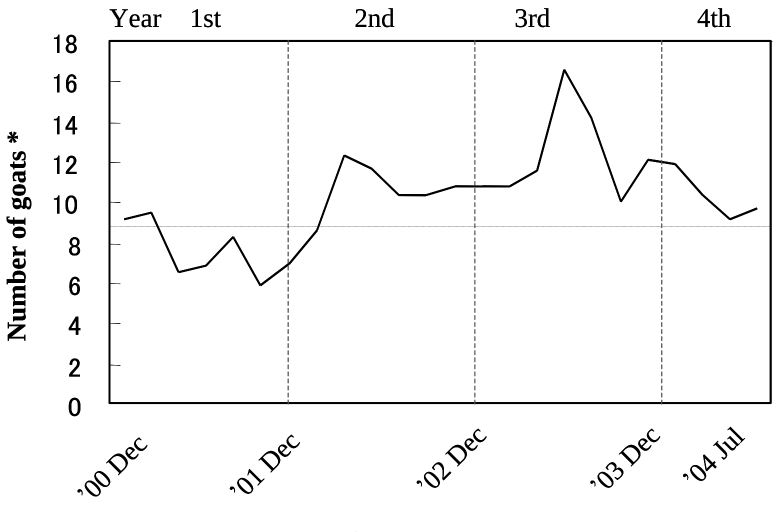

Figure 2. Change in population of goats kept on grazing pastures (* Number of goats is corrected as 15 kg of body weight)

Table 4. Plasma mineral contents in adult goats kept on pastures

	Mg (mg/dl)	Ca (mg/dl)	P (mg/dl)
Male	3.9	12.3	1.9
Female No1	2.0	6.5	2.4
No3	1.0	2.0	2.0
No4	1.2	2.2	2.1
No5	1.8	5.3	3.0
No6	2.5	11.8	3.9
No8	1.9	5.6	2.9
Average	2.0	6.5	2.6
Standard concentration	2.5 ±0.3	9.8 ±0.3	6.4 ±0.2

Plant production of grazing pastures in the fired swamp forest

A change of biomass in the pastures was shown in Figure 3. Biomass in the control pasture increased slightly during the 4 years, whereas biomass in the grazing pastures was higher at beginning but declined remarkably in the 2nd and the 3rd years. The decline of biomass in the grazing pastures was caused by the increase of goat population during the 2nd and the 3rd years, and stopped grazing of goats in the 4th year. Chemical compositions of plants in the grazing pastures were shown in Table 5. The native plants had a low phosphorus contents as compared to Orchard grass and Kentucky Bluegrass. It seemed that the shortage of feed-mass and the low phosphorus content of feed plants in the grazing pastures related to the mortality of kids.

Table 5. Chemical compositions of plants in grazing pastures

	(%DM)						
	Ash	CP	C. Fiber	C. Fat	NFE	Ca	P
Sasendok	11.4	8.2	47.5	2.8	30.1	2.92	0.12
Kalakai	7.9	13.7	57.0	0.9	20.5	0.61	0.39
Delingu	3.8	10.3	52.9	2.7	30.3	0.59	0.33
Pakis Burung	7.2	12.9	34.2	4.0	41.7	0.33	0.41
Geronggang	4.3	7.9	54.9	3.4	29.5	0.62	0.19
Jambuan	11.9	9.1	15.3	2.2	61.5	2.51	0.25
Aseman	5.7	6.4	33.4	1.9	52.6	1.02	0.14
<Reference>							
Orchard grass	11.3	18.4	24.7	4.9	40.7	0.53	0.54
K. Bluegrass	9.4	17.4	25.3	3.6	44.3	0.52	0.69

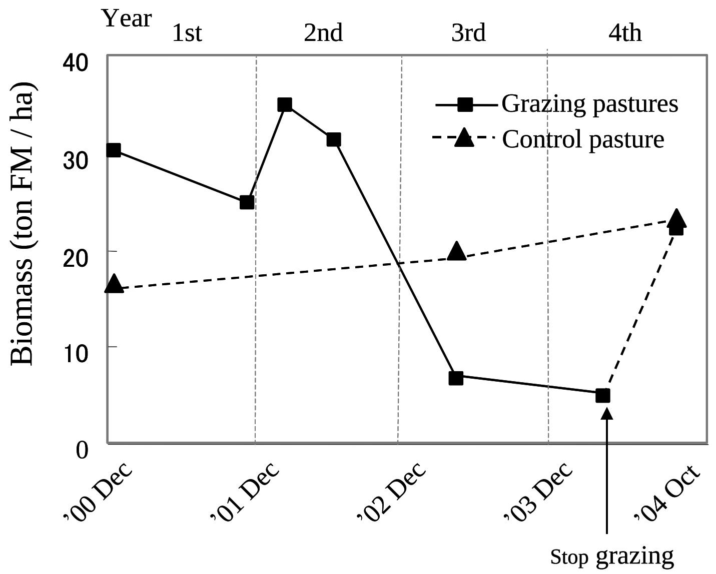

Figure 3. Change in biomass of pastures in fired swamp forest

Soil characteristics of pastures in the fired swamp forest

Soil characteristics of the pastures measured in the 3rd year were shown in Table 6. The grazing pastures had slightly but significantly higher pH value than the control pasture. Except potassium, the grazing pastures had lower mineral contents than the control pasture. Grazing of livestock seemed to decrease soil mineral contents via increasing plant re-growth.

Table 6. Soil characteristics of pastures in fired swamp forest

	Grazing pastures	Control pasture
Moisture (%)	21.5	13.7
pH H_2O	4.0 b	3.8 a
Organic C (%)	42.6	45.1
Total N (%)	0.95	0.95
Total P (ppm)	27.6 a	73.4 b
Total K_2O_5 (ppm)	235 b	139 a
Ca (mEqu/100g)	1.2	1.4
Mg (mEqu/100g)	2.0	3.8
Fe (ppm)	773 a	2273 b
Cu (ppm)	1.9 a	8.2 b
Zn (ppm)	6.0	6.7
Mn (ppm)	19.9 a	34.5 b

a,b: $P<0.05$

Summary

In grazing on fired swamp forest, female goats had a high re-productivity as 1.3 kids annually, but young goats showed a low growth rate as 43 g / day. Mortality of kids was high as 72%. It seems to be caused by deficiencies in mass and mineral contents of feed for female goats. Grazing of goats slightly improved pH in acidity soil, but seemed to decrease soil mineral contents via increasing plant re-growth. In grazing on fired swamp forest, it is important to keep adequate carrying capacity less than 3 goats / ha and supply minerals especially for female goats.

The importance of ground water control for the prevention of the peat/forest fire in tropical peatland

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Abstract

Tropical peatlands share 10% of total peatland area in the world and have an important role on the global environment with the huge amount of carbon storage in peat. But the wild fire in tropical peatlands increased drastically since the last decade of the 20th century in Southeast Asia. Combustion process of peat fire differs from the forest fire and bush fire above the ground, because the peat was sometimes burned with a smoldering process in the deep layer of peatland. But the peat layer should be dry enough for ignition and continuous burning. Drying processes of peat layer were estimated with high resolution by a simple bucket model during dry season in the peatlands. Using the model, the effect of the initial ground water level on the soil moisture of peatland in drying process during dry season was clarified.

1.Introduction

Long-term observation of the ground water level in a tropical peat swamp forest has provided much information on the hydrological conditions of such a forest. The daily actual evapotranspiration from a tropical peat swamp forest was estimated from the daily change of ground water level in a forest (Takahashi et al., 1998). Takahashi et al (2003) pointed out the importance of ground water regulation for prevention of peatland fire. Some behavior and mechanism of tropical peat fire were clarified by Usup et al (2004). They mentioned that the surface peat should be dry to less than 100 gr.% to be ignited. Those results show the importance of the ground water level and the surface peat moisture for forecasting the peatland fire and making a plan to extinguish the fire. Therefore, following three objectives are focused in this study. (1) Hydrological processes, such as the surface peat moisture, ground water level during dry season in tropical peatland. (2) Hydrological model, which can represent the moisture of surface peat in tropical peatland. (3) Estimation of the effect of the initial ground water level on the drying process of surface peat in tropical peatland.

2. Study site and methodology

The field observation on the hydrology and meteorology in the tropical peatland was carried out at the farmland near University of Palangka Raya, Central Kalimantan. Soil of the study site was peat with about 1 m deep, which was well decomposed but contained some wood fragments in deeper layer than about 40 cm. The total area of the firm land was 1 ha with several small trees and the small residential house in northwest edge. The experimental site of 20 m square was set up on the central part of the farmland. The experimental site was divided into five blocks. Soybean (*Glysine max(L) Merril*) and pepper (*Capsicum frutescent*) were planted in two blocks for each crop. The soybean was seeded on 26th April, 17th May and 7th June. When the measurements of the evapotranspiration in the soybean block were carried out on the middle June, middle July and the begging of August, the heights of plant reached to 70-80 cm. One block, the bare soil block, was kept without planting and used for monitoring of such climatic and hydrological elements, as air temperature and humidity (by Kadec HTV, Kona System) at 1.5 m high in the shelter, integrated solar radiation with one hour interval (sensor: PCM-01 PREDE, logger: Kadec Up Kona System) at 1.2 m high and wind speed and direction (sensor: M-05103 Young, logger: Kadec Un) at 3.5 m high. Ground water level was measured at the same monitoring block by using a pressure sensor (Druck Ltd, PDCR830) and a data logger (Kadec-Mizu). Hourly rainfall was measured with a tipping-bucket rain gauge and a data logger (Kadec-Pls). Soil moisture from ground surface to 11 cm deep at the monitoring block and the soybean block were measured manually twice a day at 0900 LT and 1700 LT (Indonesia West Standard Time) by using a TDR sensor and logger (TRIME-3P).

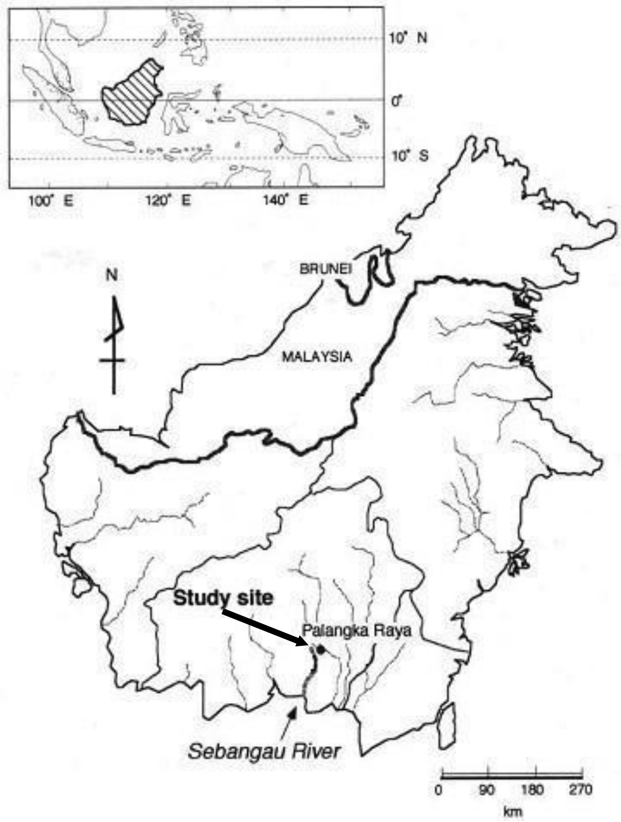

Fig.1 Location of study area

3. Model of peat moisture estimation

3.1. *Water budgets in layers*

The soil layer from surface to 100 cm in depth is divided into 20 layers with 5 cm thickness (Fig.2). The upper surface of the first layer is ground surface with or without plants. Water budget through this surface are rain and evaporation. When the ground surface is covered by plant, the transpirations from the first and second layers are added on the surface water budget. Soil water exceeded the field capacity in the first layer flows out from the first layer and flows into the second layer. Capillary water flows into the first layer from the second layer with water vapor deficit caused by evaporation and/or transpiration from ground surface. Water budgets in the deeper layers than the third layer are in and out flows of the gravity water and capillary water. Water budget by vapor is neglected in this model.

The water budget in the first layer in the unit time is shown in next equation.

$$\Delta W_1 = P + E + T_1 + F_{o1} + C_{i1} \qquad \text{3-1}$$

where, ΔW_1: the change of water in the layer and subscript means number of layer, P: Rain, E: evaporation from the ground surface, T_1: transpiration through plant, F_{o1}: flow out to lower layer by infiltration, C_{i1}: flow in from lower layer by capillary.

The evaporation E in Equation 3-1 is replaced with the water flew into the first layer by capillary C_{i1} from the second layer. The rain P is replaced with the water F_{o1} flew out from the first layer. Transpiration T_2 becomes active when the second layer is unsaturated by water.

$$\Delta W_2 = F_{o1} + F_{o2} + C_{i1} + C_{i2} + T_2 \qquad \text{3-2}$$

Water budgets in the layers deeper than the second layer are follows to next equation.

$$\Delta W_{\mathrm{n}} = F_{on-1} + F_{on} + C_{in-1} + C_{in} \qquad \text{3-4}$$

where the subscript n: number of layers changed from 3 to 20.

3.2. *Soil structure of peat layers*

The solid part of peat is composed of mineral, humus and plant in decomposition process. Contents of lignin and protein are very high in humus but plant decomposing in the ground contains a lot of cellulose and hemicellulose. Such organic materials in peat can contain water easily in the texture. According to Kamiya and Kawabata (2002), the surface peat at Kalampangan located about 20 km southeast from the study site had such physical properties as the ignition loess of 96%, the specific gravity of 1.46, the water content of 391 gr%, the degree of saturation of 61% and void ratio

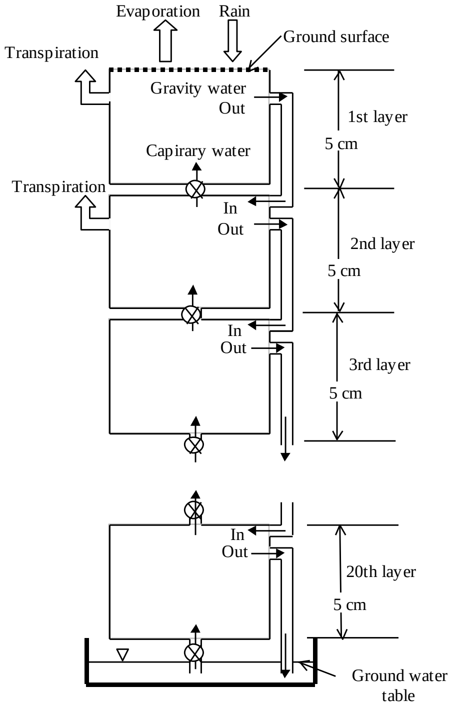

Fig.2 Bucket model for water budget in peat layers

of 5-14, and the dry density of 0.1-0.2.

The void ratio of was used in this study. Then solid space of 0.167 and the pore space of 0.833 were derived from the void ratio 5. Soil moisture was represented by volumetric percent of water in the layer.

3.3. *Suction water by root and water flow by capillary*

The root system of soybean develops to deeper soil layer with growing of plant and lowering of ground water table. In this model, it was supposed that the soybean block was covered by the soybean leaves. Then the evapotranspiration was sheared by the transpiration from soybean, and the most of the water budget from the ground flew through the roots of soybean. If the soil moisture in the first layer is lower than the field capacity of the soil, the suction by root is controlled by the deficit of the soil moisture to the field capacity. Next empirical equation was used to control the suction of root by the water deficit in the soil layer.

$$U_{\mathrm{r}} = E_{\mathrm{t}}(1-\mathrm{a}(F_{\mathrm{c}}-M_{\mathrm{e}})) \tag{3-5}$$

where U_{r}: suction flow through roots, a: empirical coefficient, 1.1 was used, F_{c}: field capacity of soil, 0.75 vol.% was used, M_{e}: moisture equivalent of soil, 0.45 vol.% was used in this study.

When the moisture of a soil layer is lower than the field capacity, the capillary water is sucked up from deeper soil layer. The strength of capillary water flow should be proposed with the moisture deficit between upper and lower soil layers. Then the empirical equation as shown in following was used in this study.

$$P_{\mathrm{cn}} = \mathrm{b}(M_{n}-M_{\mathrm{n+1}}) \tag{3-6}$$

where P_{cn} : water flows into n soil layer from n+1 layer by capillary, b: empirical coefficient, 0.2 was used, $\mathrm{M_n}$,$\mathrm{M_{n+1}}$: Soil moisture vol.% at n and n+1 layers.

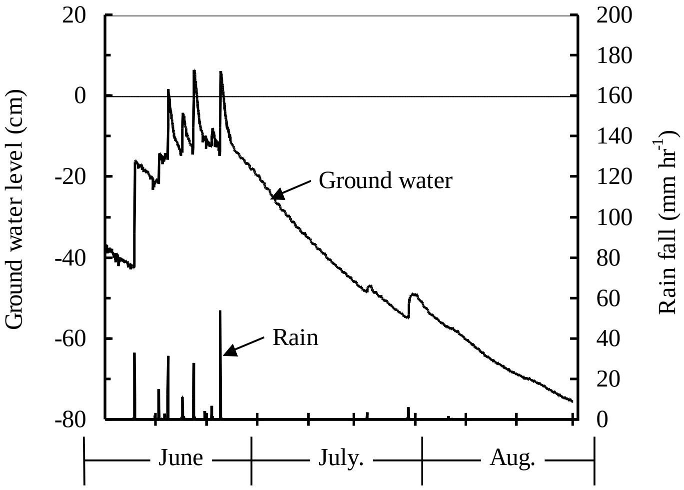

Fig.3 Change of ground water level and rainfall at the study site in Central Kalimantan during dry season in 2002.

4. Results of the field observation

4.1. *Ground water level and surface soil moisture.*

The ground water level was fluctuated but kept in high due to several heavy rainfalls until 26 June. After that the ground water level dropped continuously till the end of August excepting two small rises with the small amount of rainfall on 22nd and 30th July. The specific productivity, which represented the response of ground water level

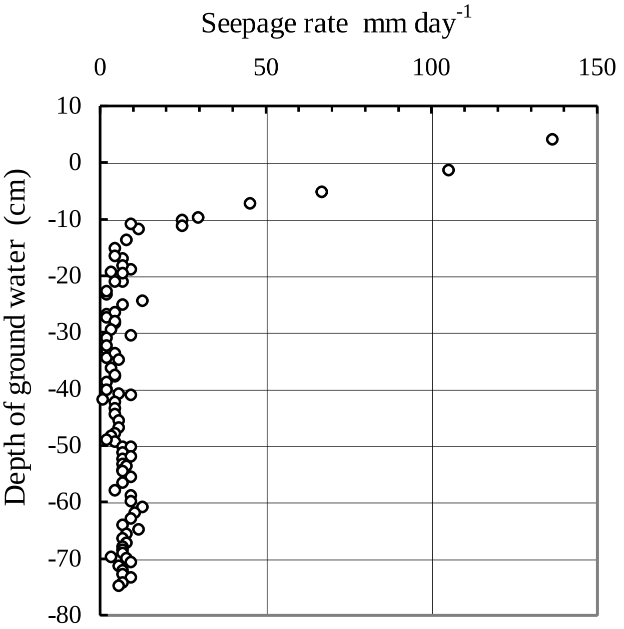

Fig.4 Seepage rates in the study area during dry season in 2002.

against the rain, was determined to be 3.0 mm mm^{-1} using the data of ground water level and rain in June. The seepage rates in the site were obtained from the deviation of the ground water level without rain events from 1900 LT to 0500 LT in the next morning (Fig.4). The seepage rates in lower ground water level than 15 cm in depth were small with 2-12 mm day^{-1}. On the other hand, those of higher ground water level than 15 cm in depth increased sharply to around 110 mm day^{-1} at the ground surface level of ground water. This relationship between the ground water level and the infiltration rate was represented by the equation of the 5th degree with R^2=0.97.

The surface soil moistures in the Soybean and the bare soil blocks were fluctuated largely but kept in much more moist condition than 60 vol.% during June. The soil moistures in the soybean block were relatively higher than those in the bare soil block. But the surface soil moistures in the soybean block were decreased more quickly than those in the bare soil block, then the surface moisture in the soybean block became dryer than those in the bare soil block. This was caused by the larger evapotranspiration rate in the soybean block than the bare soil block. The decreasing processes of the surface soil moisture became gentle at around 40 vol.% of moisture in both blocks. Following this result, the lower limit of the soil moisture in each layer was determined to be 45 vol.%.

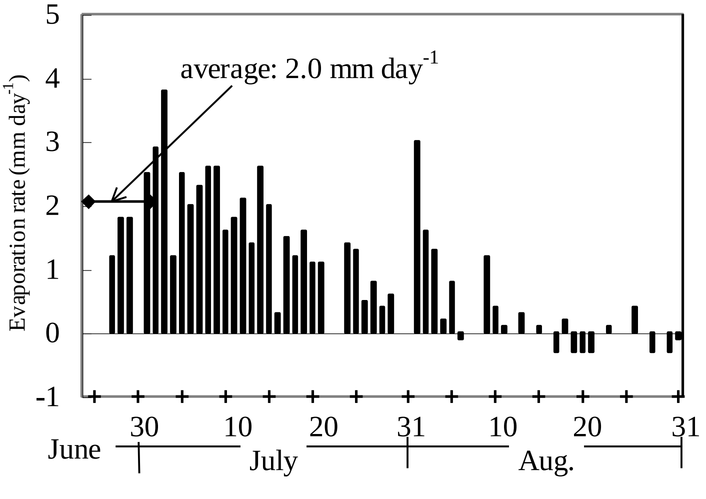

Fig.5 Evapotranspiration estimated from ground water level at the study site.

4.2. *Evapotranspiration from the ground*

Evaporation from the bare soil surface was estimated from the diurnal changes of ground water level with the infiltrate rate in the study site following the methods proposed and applied by Umeda and Inoue(1985) and Takahashi et al. (1998). The daily evaporation from the bare soil

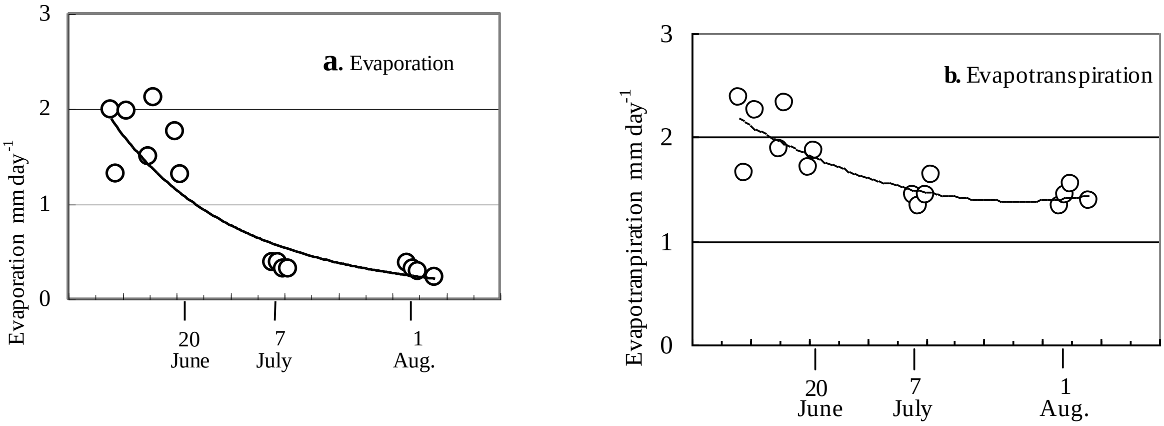

Fig.6 (a) Evaporation from the bare soil block and (b) evapotranspiration from the soybean block in the study site obtained by the chamber method in 2002.

block was shown in Fig.5. The daily evaporation rate at the beginning of dry season in 2002, from 26th June to 1st August, was 2.0 mm day^{-1} in average. The evapotranspiration from the soybean block and the evaporation from the bare soil block were measured simultaneously by the chamber method (Sato, 2003). The results were shown in Fig.6. Unfortunately, the duration of measurements on the evaporation from the bare soil block were not same in the both methods, the ground water method and the chamber method. But the evaporations measured by the chamber method in the end of wet season, 10th –20th June, were from 1.2-2.1 mm day-1, which were roughly coincided with the results obtained from the ground water analysis. Evapotranspiration from the soybean in the end of the wet season was around 2 mm day^{-1} and decreased gradually to around 1.7 mm day^{-1}. This evapotranspiration rate from the soybean block and the decreasing process were used in the estimation of the peat surface moisture. The decreasing process of evapotranspiration was represented in the next empirical equation.

$$e_{\mathrm{t}} = 3.0\times10^{-5} D_{\mathrm{y}}^{\ 2} - 7.1\times10^{-3} D_{\mathrm{y}} + 1.004 \qquad \text{4-1}$$

where e_{t}: the rate of evapotranspiration to that of the first day, 24th June. D_{y}: the number of days after 24th June.

5. Results from the simulation model

5.1. *Drying process of the surface soil during dry season in 2002*

The initial condition of ground water was on the ground surface level in the model, which was equivalent to that in the field on 24th June. Soil moisture in the surface 11 cm layer was 83 vol.% in the model and decreased day by day with the transpiration through the soybean leaves (Fig.7). The simulated surface moisture increased slightly with the rain of 3.4 mm day-1 on 21st July, and largely with the rain of 11.0 mm day-1 on 30th July. But such increases of the surface moisture in both days are not clear due to luck of the field

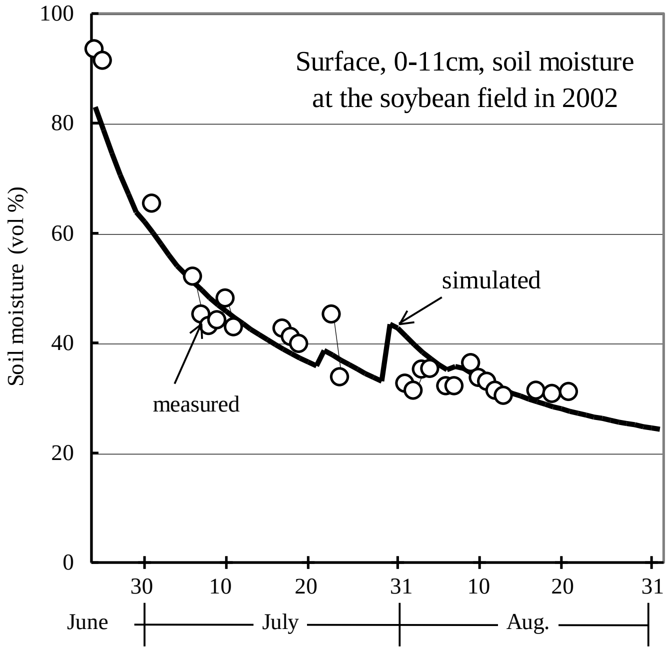

Fig.7 Observed and simulated soil moistures in the surface layer of the soybean block of study site during the dry season in 2002.

measurement. However, the simulated surface soil moistures reproduced well those in the field with the coefficient of determination R^2=0.9.

5.2 *Moisture profile in peat layer*

The vertical profile of simulated moisture on 8th August is compared with the field data sampled at the fire event site in the secondary forest of Kalanpangan on same day. The soil moistures from surface to 50 cm deep in Kalampangan were around a half of the simulated moisture for the study site. The large differences of the soil moisture in two sites were due to differences in the vegetation, the quality and structure of peat layers, and the hydrological system of two sites. Ground water level in the study site was 58 cm deep on 8th August, which was corresponded to the depth of unsaturated layer of 60 cm in the simulated soil moisture profile.

5-3. *The effect of the ground water level in the beginning of dry season on the drying process of surface peat layer*

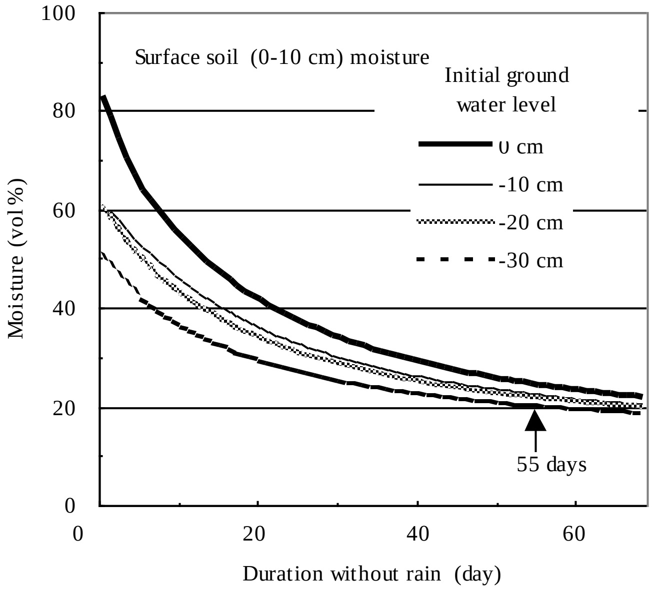

Fig.8 Difference of drying processes of peat surface moisture with difference of initial depth of ground water level in a tropical peatland.

Because, the soil moisture of surface layer and the ground water level were simulated with good similarity in this model, this model was applied for estimation of the effect of the ground water level in the beginning of dry season on the moisture of surface layer in a peatland.

Four cases of the initial conditions on the ground water level, which were at ground surface, 10 cm, 20 cm and 30 cm in depths at the beginning of dry season, were simulated and shown in Fig.8. According to Usup *et al* (2004), 100 gr.% of the peat moisture of ground surface layer is a threshold for ignition of surface peat. In the case of the initial ground water level was at ground surface, it was taken more than 65 days for the surface peat moisture to reach to the threshold level. But in the case of the low initial ground water level with 30 cm deep, the moisture of surface peat reached to the threshold level 55 days after.

This result indicates the importance of the high ground water level in the beginning of dry season to prevent the peat fire. In other words, any human activity, which makes the ground water level lower, will change the peatland for the worse with increasing of peatland fire.

5. Conclusion

The moisture of the surface soil layer and ground water level at a farmland in tropical peatland was measured from the end of rainy season to the end of dry season. A bucket model was constructed to estimate the moisture of the surface soil layer. The drying process of the estimated by the model was coincided with high similarity to the process observed in the field. Using this bucket model for estimation of the surface soil moisture, it was clarified that the initial ground water level at the beginning of dry season affected on the drying process of surface peat. The deeper ground water level at the beginning of dry season make the peatland sensitive for peat fire in the shorter duration.

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