



RESTORATION OF TROPICAL PEATLANDS

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Foreword

RESTORATION OF TROPICAL PEATLANDS: EFFORTS UNDERTAKEN BY THE EU FUNDED RESTORPEAT PROJECT

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BACKGROUND

Tropical peatland, which is one of the least known ecosystems of the world, covers approximately 45 Mha, or 12%, of the global peatland resource by area¹. Indonesia, Malaysia and Vietnam contain nearly 70%. Indonesia, with 22 Mha contains about one half of the total area of peat in the tropical zone. Natural peat swamps in SE Asia have been recognized as important reservoirs of biodiversity and stratigraphical information and exhibit a range of important ecological and natural resource functions. In particular they contain a large number of endemic tree species many of which are of significant commercial value. Peat swamp forests are the last refuges for several rare and endangered animals, including orang-utan, while streams and rivers draining from peatlands are important fish habitats. In their natural state tropical peatlands are carbon sinks and stores, but drainage and forest clearance rapidly converts them to carbon sources. Continuing population growth, deterioration of existing land, especially owing to erosion and increasing competition for land from industry and urbanization, are exerting continuous pressure for peatland development.

TOPICS

The EU funded project on the restoration of tropical peatlands (RESTORPEAT) coordinates the activities of 14 international partners in Europe and Southeast Asia to address global and regional issues of carbon balance, water management, biodiversity and poverty alleviation related to restoration and sustainable management of tropical peatland renewable natural resources. It facilitates access to existing knowledge and expertise and conducts targeted research on the restoration of tropical peatland in order to promote sustainable livelihoods for local communities. It also provides a scientific and technological framework for knowledge transfer and human capacity development related to restoration of tropical peatland to the benefit of the EC and DCs. In order to achieve these aims the problems of fire and inappropriate land use planning is addressed by developing a model fire hazard warning and control system based upon remote sensing and operated by local communities through promotion of fire awareness, prevention and suppression. Stakeholder platforms and skills transfer to the DCs are focal activities to provide ownership of the project outputs to the bottom levels and, through partnership with local governments, empower local people to become guardians of their own environment and its resources. Implementation of the project involves a range of measures including, blocking of channels and drains, restoration of hydrology and ecological functions, rehabilitation of peat swamp forest and its biodiversity, identification of alternative funding mechanisms to promote sustainable livelihoods and formulation of guidelines for sustainable agriculture and forestry. These are linked to a better understanding of the socio-economic base of local people and their communities by determining the nature and degree of their dependence on renewable natural resources and how this has been affected by major

land development projects and fire. Project outputs are transferred to local governments through collaboration and to local communities through stakeholder participation platforms that are also used to network information, share experiences and promote action. The project outputs form the basis of peatland landscape management and planning strategies, information dissemination activities and skills transfer to the DCs.

OBJECTIVES

The strategic objectives of the EU funded project on the restoration of tropical peatlands can be summarized as follows:

- Coordinate international activities that address global and regional issues of carbon balance, water management, biodiversity conservation and poverty alleviation related to restoration and sustainable management of tropical peat swamp forest and peatland.
- Provide access to existing knowledge and expertise and conduct targeted research on restoration of tropical peat swamp forest to promote sustainable livelihoods of local people.
- Provide a scientific and technological framework for knowledge transfer and human capacity development related to restoration of peat swamp forest and tropical peatland to the benefit of the EC and DCs.

RESULTS

Results of the RESTORPEAT project are reflected in the 29 papers combined in this book dealing with issues such as:

- Restoration of ecological and natural resource functions
- Restoration of the hydrological integrity and water management: impact on carbon fluxes
- Fire and land use change aspects of restoration
- Socio-economic and governmental aspects of restoration

In addition to this book, scientific and practical results of the RESTORPEAT project are presented in the proceedings of 4 International Symposia and Workshops on Tropical Peatlands, namely: Palangka Raya (2005), Yogyakarta (2005), Yogyakarta (2007) and Tullamore (2008). Other results of the RESTORPEAT project are:

- Literature, scientific, technical and socio-economic database
- Chapters in books
- General articles/reports in popular magazines
- Presentations at workshops, seminars, symposia, conferences and congresses
- Advisory meetings
- Strategies development

Finally training and research assistance is provided to approximately 50 core scientists, 5 collaborating scientists, 15 research assistants, 20 MSc trainees, 5 PhD trainees and 50+ skills trainees in Developing Countries.

DISSEMINATION

The scientific and practical results of the RESTORPEAT project are disseminated to a range of different interest groups among others:

- European Commission;
- Development funding agencies;
- National Water Authorities, Agricultural and Environmental Government Departments, and Agencies in the countries where the project will take place;
- Regional and local Water, Agricultural and Environmental Government Departments, Agencies and Bodies;
- International, regional and local Non Governmental Organizations;
- Farmers' and landowners' associations;
- Scientific community;
- For further details of the RESTORPEAT project reference is made to:
www.restorpeat.alterra.wur.nl

This book on the “Restoration of tropical peatlands” summarizes the scientific and practical highlights of the RESTORPEAT project. It is hoped that these results contribute to the wise use of the critical tropical peatland ecosystem.

Preface

OVERVIEW OF THE NEED FOR RESTORATION AND REHABILITATION OF TROPICAL PEATLAND AND REVIEW OF THE CONTENTS OF THIS BOOK

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Across the world, in both temperate and tropical regions, ecosystems are being degraded, damaged and destroyed through human actions. Wildlife habitats have been lost or fragmented and species diversity is in decline, whilst people are experiencing the consequences of reduced ecosystem services and the impacts of climate change. **Restoration ecology** is the *study* of renewing a degraded, damaged, or destroyed ecosystem through active human intervention, whilst **ecological restoration** is the *practice* of reviving the natural resource functions of degraded ecosystems, thus reinstating the environmental and economic services that these provide. The discipline of restoration ecology can be an ambiguous science because social realities are often as important to restoration plans as scientific theories and predictions (Cairns and Heckman 1996). According to Gann and Lamb (2008), ecological restoration must fulfil four elements if it is to be judged a success: it must improve biodiversity conservation; improve human livelihoods; empower local people; and improve ecosystem productivity.

A distinction is sometimes made between **restoration**, which is often taken to mean a return to an *original* state, and **rehabilitation**, which is the process of returning to a *previous* or *alternative* condition, although the term restoration is often used as a catch-all for both of these actions, without indication of end-point or temporal scale. A more precise ecological definition of restoration emphasises restoration of ecosystem structure and composition, whilst rehabilitation stresses ecosystem processes and functions. It may be possible to rehabilitate the functions of an ecosystem, but to achieve the original ecosystem structure will be more difficult and require a much longer time-scale. For most restoration projects to achieve success, however, local people and stakeholders who are connected with the ecosystem in question need to be involved alongside scientists in both the decision-making process and subsequent project implementation. These types of participatory approaches are likely to produce more viable outcomes than situations in which the decision-making is centralized.

Restoration ecology is a relatively new endeavour, indeed it is described by some as 'experimental' (Fonseca and Jones 2007). Restoration studies have so far been focused predominantly in developed countries, especially in the northern temperate zone, and only more recently has ecological restoration been attempted in tropical regions, with pioneering work in the forests of Costa Rica (Allen, 2002). Likewise, studies of peatland restoration are relatively well established in the northern hemisphere, whilst those in the tropics are at an early stage, although there is a growing interest in and demand for this specialist knowledge, which this volume begins to address.

Extensive peatland areas in Southeast Asia have been degraded through deforestation, drainage and fire, leading to on- and off-site environmental and socio-economic impacts of local to global significance. These impacts embrace the loss of biodiversity, including populations of endemic, rare and endangered species; the loss of a range of economically-valuable timber and non-timber forest products derived from peat swamp forest; disruption of peatland hydrological functions; degradation of the peat carbon store through oxidation and fire; and loss of livelihoods for local communities. In order to address these impacts, the restoration of degraded tropical peatlands is now viewed by scientists and policy-makers alike as a matter of considerable concern and there is an urgent requirement and impetus for landscape-scale restoration measures.

There are several key questions that need to be asked in any restoration project (Miller and Hobbs 2007), and some of the most relevant ones for the restoration of the tropical peatland ecosystem are outlined below:

- What is the goal of restoration projects on degraded tropical peatlands? Is the ultimate objective the restoration of the peat swamp forest ecosystem or some intermediate stage in progression to this ultimate goal? Is it more important that emphasis is placed on rehabilitating degraded peatland to a land-use that meets local socio-economic needs, e.g. crop production, agroforestry or community land, or other environmental needs, such as a reduced risk of fire and flooding?
- What are the ecological and social constraints to achieving the desired endpoint(s) of restoration activities? On degraded peatlands these may include loss of the soil seed bank which will greatly inhibit succession back to forest, an impaired hydrology which may limit either forest regeneration or crop production and continued unsustainable exploitation of remaining forest resources by poor local people. Maintaining livelihoods of local people may be more important than restoration of ecosystem functions and is driven by local and national pressures and priorities.
- What are the key ecosystem elements or functions to be restored? With regard to tropical peatlands these will include hydrology, vegetation structure and dynamics, carbon sequestration and potential for peat accumulation. Restoration of hydrological integrity, i.e. raising water tables to levels that prevailed before degradation and maintaining them, is the first priority after fire control and prevention of unsustainable human activities. This has been carried out so far on small scales on only some tens of hectares and must be tested on much larger areas.
- Will the restored ecosystem be sustainable in the longer-term? Considerations will include habitat connectivity and position within the landscape (e.g. proximity and connection to blocks of existing forest, which will influence availability of tree seeds, seed dispersers etc.), resilience to climatic stochasticity (e.g. resistance to prolonged droughts) and after-care by local communities. In addition, any restored ecosystem needs to be able to sustain itself in future environments and not just past ones (Choi 2007), i.e. there needs to be a recognition of climate change. Re-wetting is not an end in itself and should be linked to specific land uses that do not conflict with each other in terms of their hydrological requirements. If there is still some residual peat swamp forest this should be

conserved and enhanced by elevating the water table to the high level required to sustain it. Forest fragments should be joined together to create larger areas that are more likely to be sustainable than small ones.

- What are the financial constraints – not only for undertaking initial project works but also for ongoing maintenance and monitoring? The cost of negating the drainage channels and canals in both the Ex Mega Rice Project area and remaining peat swamp forest (degraded by illegal logging) is likely to be very high and the likelihood of success in the long term is uncertain. The risks and costs of reforestation may be even greater. There is currently discussion of carbon offset payments for keeping the peat carbon store in place but at present this is still conjectural. The other alternative is to establish plantations of commodity crops on tropical peatland and manage the water table so that GHG emissions and peat subsidence are minimised.
- What are the social constraints – what is acceptable or even desirable? What are the local understandings, values and appreciation of restoration activities?
- What are the administrative, legislative and traditional instruments available that might, on the one hand, be used to promote restoration and, on the other, prevent or delay it? There are also problems of land ownership; although land with forest is mostly under state control local indigenous people also have land right claims over much of it. This can lead to disputes and disaffection. Do the restoration goals have support from local people and decision-takers? The end-point to which an ecosystem is being restored is highly dependent on scientific understandings of the environment but also the attitudes and involvement of local people and authorities (Higgs 1997). Local people must be seen as part of the solution to degraded peatlands. They must be fully involved in the process of restoration and rehabilitation and through their participation and stewardship they must derive benefits from it that increase their livelihoods and reduce poverty.

Ecological constraints will limit what it is possible to restore, whilst financial and social constraints will affect what can be actually achieved. Financial support may depend on the public acceptance of a restoration project and there may well be a trade-off between local social and economic welfare concerns and the complete restoration of ecological functions and biodiversity. Temporary incentives, and usually this implies financial incentives, may have to be provided to local communities in order to ensure that restoration achieves its longer-term goal. This could take the form of short-term, targeted financial support which is aimed at developing self-sustaining community employment and welfare opportunities (i.e. an increase in social capital) alongside the longer-term restoration of natural capital.

There is still much that is not known about the means to restore or rehabilitate tropical peatland for different purposes. For example, is it really possible to rewet large, peat covered landscapes and recreate the conditions that prevailed under the original peat swamp forest? How do we progress towards achieving that aim? Which trees should be planted first and how will they survive on peat which has altered properties as a result of deforestation, drainage, oxidation and fire. Do the tree species exist that can tolerate, on the one hand, drought conditions with surface temperatures in excess of 50⁰C and, on the other, up to half a metre of flood water for several months of the year? The challenges are immense!

Successful restoration outcomes for degraded tropical peatlands will require further studies over larger areas and much longer time scales if the ultimate goals of restoring indigenous biodiversity and ecosystem structure and dynamics are to be achieved (Aronson et al. 1993).

This compendium of research outputs provides an overview of the current state of knowledge on the restoration of tropical peatlands reproducing a large selection of relevant presentations made at several international symposia and workshops. These are:

- International Symposium on Biodiversity, Environmental Importance and Sustainability of Tropical Peat and Peatland, 4-8 September 1995, Palangka Raya, Central Kalimantan.
- International Conference and Workshop on Tropical Peat Swamps, 27-29 July 1999, Penang, Malaysia.
- International Symposium on Tropical Peatlands: Natural Resource Functions and Sustainable Management, 22-23 August 2001, Jakarta, Indonesia.
- International Symposium and Workshop on Tropical Peatland: Restoration and Wise Use of Tropical Peatland – Problems of Biodiversity, Fire, Poverty and Water Management, 20-24 September 2005, Palangka Raya, Indonesia.
- International Symposium and Workshop on Tropical Peatland: Carbon-Climate-Human Interactions On Tropical Peatland: Carbon Pools, Fire, Mitigation, Restoration And Wise Use, 27-29 August 2007, Yogyakarta, Indonesia.
- 13th International Peat Congress, 9-13 June 2008, Tullamore, Ireland, International Peat Society.

Much of this information was obtained under funding provided by a grant from the UK Darwin Initiative and four subsequent contracts under the EU INCO budget line. These projects operated from 1998 to 2008 and involved up to 14 partner institutes in Europe and Southeast Asia.

This book commences with a foreword by Henk Wösten outlining the background to the EU RESTORPEAT project that was the main vehicle for the research undertaken on restoration of tropical peatland. Jack Rieley then introduces the subject matter of the book by posing questions on the restoration of tropical peatland – why, where and how?

The subsequent papers are divided into four sections:

Restoration of Ecological and Natural Resource Functions

Before embarking on a major problematic reconstruction exercise addressing ecosystem restoration or rehabilitation it is essential first of all to know the context and operation of the ecosystem itself. Studies of the biodiversity and ecology of peat swamp forest have been a core component of the various research projects undertaken by the contributing researchers for more than 10 years. There is now a large body of information on flora, fauna, animal behaviour, orang utan population densities and chemical and physical attributes of the peat itself. This knowledge and its importance are reflected in this section

Restoration of the Hydrological Integrity and its Impact on Carbon Fluxes

The essential first step in ecological restoration of tropical peatland is rewetting by elevating the water table and maintaining it at or close to the surface (above and below) throughout the year. After deforestation and drainage this is not only difficult to do because water control devices have to be constructed and installed but it is very expensive. In addition, there is no certainty of success and various different approaches and methods may have to be tried before achieving the objective. Water table has a major effect on carbon gas emissions from peat with more CO₂ being emitted at lower water table drawdown while CH₄ increases under constant waterlogging and flood conditions. Problems of restoring hydrology and managing water levels are discussed in this section together with appraisal of the impact of different water table regimes on greenhouse gas emissions from tropical peatland.

Fire and Land Use Change Aspects of Restoration

Unfortunately, deforestation and drainage of peat swamp forest, especially in Indonesia, have been accompanied by the use of fire as a land clearance tool. Fire has become so established in peatland development and management that its use has become almost a way of life. Fires are lit every year by small holders and plantation managers as the most effective and cheapest way of clearing peatland and keeping it clear of secondary vegetation. Unfortunately, the fire also takes hold in the peat and as a result massive amounts of carbon are lost with the production of a noxious 'haze' at the same time. No use can be made of tropical peatland unless the fire problem is solved by banning its use and educating people not to use it. The effects of fire in part of the peatland landscape of Central Kalimantan over a 20 year period are described in this section together with methods of monitoring land use and land use change, including fire-burnt areas from space. The role of local communities in fire management is highlighted.

Socio-economic and Governmental Aspects of Restoration

The role of the Indonesian Government at National and Local level in restoration of tropical peatland is reviewed together with analysis of the importance of providing sustainable livelihoods for local people in the peatland areas of Indonesia. It is essential that local people are involved in the restoration process and derive financial and social benefits from it.

Symposium Statements on Restoration and Wise Use of Tropical Peatland

Important policy statements have been issued at the end of all of the symposia that have contributed to this document. They have highlighted the key issues at each moment in time and identified priorities for action to manage tropical peatlands sustainably and, where they have been degraded or mismanaged, recommended courses of action to propel their restoration and future wise use. The main elements of two of these symposia statements are reproduced.

References

- Allen, W. 2002. Green Phoenix: Restoring the Tropical Forests of Guanacaste, Costa Rica. Oxford University Press.
- Aronson, J., Floret, C., Le Floc'h, E., Ovalle, C. and Pontanier, R. 1993. Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. I. A view from the South. *Restoration Ecology* 1: 8-17.

- Cairns, J. and Heckman, J.R. 1996. Restoration ecology: the state of an emerging field. *Annual Reviews* 21: 167-189.
- Choi, Y.D. 2007. Restoration ecology to the future: A call for a new paradigm. *Restoration Ecology*, 15: 351-353.
- Fonseca, R.C. and Joner, F. 2007. Two-sided edge effect studies and the restoration of endangered ecosystems. *Restoration Ecology*, 15: 613-619.
- Gann, G.D. and Lamb, D. (eds) 2008. Ecological restoration – a means of conserving biodiversity and sustaining livelihoods. A call to action by the ecological restoration joint working group of SER International and the IUCN Commission on Ecosystem Management. Available at: www.ser.org/content/Global_rationale.asp
- Higgs, E.S. 1997. What is good ecological restoration? *Conservation Biology*, 11: 338-348.
- Miller, J.R. and Hobbs, R.J. 2007. Habitat restoration – Do we know what we're doing? *Restoration Ecology*, 15: 382-390.

Introduction

RESTORATION OF TROPICAL PEATLAND IN INDONESIA: WHY, WHERE AND HOW?

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SUMMARY

Tropical peatland, especially in Southeast Asia has been developed since the 1970s. In the beginning, projects were mostly on shallow peat near to the coast and linked to small farm agriculture. During the 1990s the size of land use change projects increased dramatically and focused on deeper peat areas further inland. Some of these were for small farmers linked to transmigration but, increasingly, they were for plantations of oil palm and pulp trees. The success rate of these has been variable and the problems created have been many, as exemplified by the Mega Rice Project in Central Kalimantan. This paper analyses reasons for failure of this large and ill-fated tropical peatland development project, consider the environmental and socio-economic problems created and propose strategies for restoration of this degraded landscape in order to promote its future 'wise use'.

Keywords: tropical peatland, Mega Rice Project, peatland restoration

INTRODUCTION

Indonesian and Dutch scientists identified the principal problems of reclamation of tropical peatlands more than 25 years ago (Soepraptohardjo and Driessen, 1976). Apart from chemical impoverishment and the oligotrophic, acidic nature of the peat, with extremely low ash content, they also noted a range of physical problems:

- slow rate of natural decomposition of organic matter linked to the high wood content;
- rapid oxidation and decomposition of organic material after vegetation removal and drainage leading to a high degree of subsidence and subsequent increase in flooding;
- irreversible shrinkage causing adverse water retention and increased erosion;
- extremely rapid horizontal hydraulic conductivity and very slow vertical conductivity;

- high heat capacity and low thermal conductivity causing major temperature variations at the surface;
- low load-bearing capacity causing top-heavy tree crops to topple over and making it almost impossible to use farm machinery or to construct roads and other infrastructure.

They were firmly of the opinion that “*no other soil type combines so many unused possibilities with so many unsolved difficulties*” and that “*a multidisciplinary effort is needed to find ways to exploit the potentially suitable peat formations in a non-destructing way*”. They concluded that the main problems encountered in attempts to reclaim Indonesian lowland peatlands result from the lack of nutrients in the peat, poor physical properties and a lack of access to the peatland areas. The first two constraints mean that only a limited range of crops can grow under these difficult conditions while the latter presents major problems for marketing, storage and transportation. Nevertheless, large areas of coastal peatland, especially within the influence of daily tidal movements were developed for agriculture and human settlement over the ensuing 20 years with limited success.

DEVELOPMENT OF LOWLAND WETLANDS FOR RICE CULTIVATION

In the 1960s Indonesia was confronted by a serious shortage of rice, making it the world’s largest importer. Various sawah (lowland coastal rice cultivation in which drainage and irrigation is assisted by tidal movements along rivers and channels) intensification programs in Java had failed to achieve the desired result because of the limited availability of land with adequate irrigation facilities. Tidal swamps in various parts of the country were assessed in order to provide a solution. These developments were still inspired by traditional techniques, but improved using a systematic soil and engineering approach so that the unit of management could cover a larger area and incorporate better soil and water management that was coupled with Javanese traditional on-farm water management (the ‘surjan system’). The former system controls water at a macro scale while the latter system manages water at a micro scale. The result was remarkable as not only rice could be grown, but also corn, soybean, peanut, vegetables and perennial crops such as fruit trees, coconut, coffee and cloves (Notohadiprawiro, 1997). Development projects were carried out in Sumatra, Kalimantan and Irian Jaya (West New Guinea). By the mid 1980s Indonesia achieved self sufficiency in its rice production for which President Suharto received a medal from the FAO but, by the early 1990s, rice had to be imported once more and this was turning into a national crisis.

THE MEGA RICE PROJECT (MRP)

This ambitious project was initiated by Presidential Decree 82/1995 (Muhamad and Rieley, 2002; Rieley and Page, 2005). It was based on over-simplified, over-pragmatic reasoning by which agricultural production, in particular rice (later on changed into food in general), was the resolute goal to deal with the pressing challenges Indonesia was facing:

1. Rice self-sufficiency that has been achieved in 1984 by the green revolution was gone by 1993. To fulfil the national demand for rice, the country was then compelled to import up to 2 million tons of rice a year (this inflated to 3.1 million tons by 2001).

2. Rice yields of existing sawahs with the application of pre- and post-harvest technology, which were within the economic and technical reach of the average farmer were levelling off, so that the perspective of agronomic intensification was limited.
3. The best sawah lands in Java were gradually being lost owing to conversion into non-agricultural use at a rate of 15,000-20,000 ha a year (Notohadiprawiro, 1995).
4. To build irrigation infrastructures and prepare sawah plots in upland areas by conventional techniques needs big investment.
5. Farmers considered rice cultivation much less attractive in terms of profit making than other, notably horticultural crops. It should be noted that the domestic trade of rice is rigidly controlled by the Government.

The idea of launching the MRP stemmed from an ad hoc, reactive approach characteristic of Indonesia's policy of national development. The ideas behind the MRP were that it would:

1. substitute for the agricultural land lost in Java in such a size that it would remove the necessity to import 2 million tons of rice a year;
2. save expenditure on irrigation infrastructures because the location selected was on wetlands (peatlands) where the water needed is already present;
3. be established in Central Kalimantan where land was obtainable extensively so that there would not be any special problem for procurement;
4. be established on idle land so there would be no problem of conversion of use.
5. Involve transmigration into a region that is sparsely inhabited thereby addressing another of the Government's major policies.

The ideas generating the mega-project show a number of serious flaws. Although the swamp land in question doesn't produce common agricultural crops, it yields natural products such as timber, rattan and fish, which are important to sustain the livelihood of the indigenous inhabitants. Wetlands, especially peatlands, perform significant environmental functions, which cannot be apprehended by untrained minds. A Java-centric thinking of land idleness and emptiness should not have been applied to regions such as Kalimantan where the physical condition and cultural and social situation are quite different from Java.

FAILURE OF THE MRP AND SUBSEQUENT ACTIONS

The total area of the mega-project is 1,457,100 ha located in the province of Central Kalimantan. To facilitate drainage and irrigation for the proposed rice cultivation 4,618 km of channels of varying dimensions were constructed across this peatland landscape. The erroneous reasoning behind the design and alignment of these channels was the fundamental cause of the debacle of the MRP but other, probably more fundamental reasons were:

1. imposition of dry land development models upon wetland realities; wetlands must never be developed separately from the whole hydrological regime they belong to and planning for their development should be based on a holistic concept forming a comprehensive, optimizing approach by which economic and ecological goals can be achieved in a complementary way.
2. reliance on outmoded paradigms of land development and conservation that failed to address the realities of the 1990s, especially the powerful underlying structures of knowledge, political power, social organization and economy that controlled the direction of resources development in Indonesia.

The MRP was formally closed down by Presidential Decree No. 80/1999 in which previous decrees were negated and guidelines for planning and management of the Ex-MRP were issued (Box 1). Following this decree there was much indecision and uncertainty over how to proceed but some steps were taken between 1999 and 2004 (Setiadi, 2007). Attempts were made at reforestation but without either strategy or success. The people who had been settled in Block A before the MRP was closed down, initially 15,600 families but reduced to 8,487 families by the end of 2006, were supported as a matter of priority. They had suffered much from the failure of the MRP to produce rice. Many had no previous experience of growing crops on swampy, peat soils and they were provided with insufficient technical assistance and guidance. Marketing provision and transportation routes were virtually non-existent. Added to these, soil was acidic, nutrient deficient and waterlogged in the wet season but suffered drought in the dry season. Crop productivity was low in terms of both quality and yield and suffered from animal and plant pests.

Alarmed at the lack of progress in rehabilitating the Ex MRP the Government of Indonesia decided to accelerate the process by issuing a further Presidential Decree in March 2007 (No. 2/2007). This endorses PD 80/1999 but specifies a large number of Indonesian Ministries and Agencies that will be involved and detailing the spectrum of projects that would be implemented under the headings of (1) Conservation, (2) Cultivation, (3) Empowerment of Local Community and (4) Transmigrants and Evaluation of Project Implementation (Table 1). It also requires that a 'Master Plan' with actions for implementation be prepared that will be used to guide the process and used to monitor its progress and success within a particular timetable.

Box 1

PRESIDENTIAL DECREE NO. 80/1999 on general guidance of Planning and Management of the Ex Mega Rice Project Zone in Central Kalimantan

Article 1

1. Planning, development and management of the peatland zone will be regulated based on principles of productivity and sustainable conservation of land and water resources, and compatible with zone development and growth based on land suitability criteria and biodiversity of wetland for the sake of the welfare and goodness of society.
2. Consolidation for the development and management of the zone outside the conservation zone at working zones (Blocks) A and D, at the peatland development zone, is to be conducted under the co-ordination of the Governor of Central Kalimantan Province.
3. Land with peat thickness less than 3 (three) metres at the working zone of peatland development can be used for cultivation of forestry, agriculture, fishery and estate plantations, with their development and management executed functionally under the co-ordination of the Governor of Central Kalimantan Province.
4. The wetland zone that possesses peat with thickness over 3 (three) metres and the zone that will function as a protection area in the working zone of peatland development must be set as a conservation zone whose management is under the Department of Forestry and Estate Plantations.
5. Planning, development, management, utilisation and or zone conservation as stipulated by items (2), (3) and (4) should be adjusted with the Spatial Planning of the Peatland Development Zone.

DISCUSSION

It is 12 years since the MRP commenced, and almost nine since it was closed down. In 3½ years it achieved nothing but a deforested, fire-prone landscape and increased poverty of the people who live in its surroundings. The only beneficiaries were logging companies who removed the timber and contractors who excavated more than 4,500 km of drainage and irrigation channels. This landscape is degraded with its ecological functions destroyed, leaking carbon to the atmosphere and rivers and subject to alternating drought and floods.

There has been much time for reflection and debate about what went wrong and what to do but mostly there was indecision and a lack of positive activity. There has also been an absence of strategy and co-ordination on the part of the Indonesian Government. Too many Government Agencies and Ministries were involved, each with its own sectoral policies and objectives and little co-operation and co-ordination between them. The EU funded projects STRAPEAT, RESTORPEAT AND CARBOPEAT have devoted much time and effort to obtaining a better understanding of the problems created by the MRP using a scientific approach and making numerous presentations to policy makers and stakeholders (Rieley and Page, 2005). The principal problems that need to be addressed were identified at the International Symposium and Workshop that was held in Palangka Raya, Central Kalimantan in September 2005 (Rieley et al, 2007) as biodiversity, fire, peatland restoration and water management, and poverty.

Table 1 PRESIDENTIAL DECREE (INPRES) No: 2/2007

No.	Program	Activity
1.	Conservation	<ol style="list-style-type: none"> 1. Master plan decision for MRP Conservation 2. Decision on Forest Area in MRP 3. Preparation of Action Plan for Conservation 4. Conservation of Deep Peat (>3 m) (281,200 ha) 5. Conservation of Galam forest (76,300 ha) 6. Conservation of Hydrology (273,400 ha) 7. Conservation of Flora and Fauna (133,000 ha) 8. Conservation of Kerangas Forest (87,700 ha) 9. Conservation of Black Water Ecosystem (18,700 ha) 10. Conservation of Mangrove Forest (27,100 ha) 11. Tackling of Forest and Land Fire 12. Reforestation ("<i>Reboisasi</i>") (10,000 ha/year).
2.	Cultivation	<ol style="list-style-type: none"> 1. Preparation of cultivation master plan (330,000 ha) 2. Preparation of Action Plan for cultivation 3. Management of swamp reclamation (93,000 ha and road 30 km) 4. Rehabilitation and development of infrastructure for agriculture (330,000 ha) 5. Development of food crops (rice 123,000 ha and non rice 62,000 ha) 6. Development of horticulture (17,600 ha) 7. Plantation development (22,900 ha) 8. Development of fishery (197 units fish pond) 9. Livestock development 10. Development and Yield processing for agriculture production. 11. Development of facilities and materials for agriculture. 12. Revitalization of Agriculture Extension Program. 13. Establish Forest Industry Forest (HTI). 14. Reforestation ("<i>Penghijauan</i>").
3.	Empowerment of local communities and transmigrants	<ol style="list-style-type: none"> 1. Decision of master plan for rehabilitation and development of transmigration. 2. Prepare of base infrastructure. 3. Development, Increasing and maintenance of roads and bridges. 4. Increasing service facilities on transmigrant settlements and communities (New transmigrants ~ 46,500 families). 5. Human Capacity building 6. Increasing supporting facilities for communities. 7. Development of facilities for transportation.
4.	Evaluation of project implementation	<ol style="list-style-type: none"> 1. Review of environment policy 2. Coordination of policies on economic and community welfare. 3. Program evaluation of economic policy and community welfare. 4. Evaluation of program implementation. 5. Implementation evaluation of policy on conservation 6. Evaluation of project implementation

Biodiversity

Peat swamp forests (PSF) have high natural biodiversity in unique and variable habitats. This should be conserved and enhanced. Conservation of the PSF habitat must include all fauna, flora and ecological and physical processes necessary to ensure their long-term survival. Wherever possible, and especially where fragments remain, peat swamp forest should be rehabilitated to increase the area of this ecosystem in order to provide the maximum habitat for its biodiversity. Conservation areas should be managed according to 'Wise Use' principles and contribute to the livelihoods of local people in a sustainable manner.

Fire

Forest and land fires have become an annual event that causes public health and socio-economic problems locally, nationally and globally in addition to unwanted trans-boundary smoke/haze across the Southeast Asian region. Fires remain the primary tool for land-clearing, although fire is not acknowledged as a major problem by the Indonesian Government at local and national levels as shown by the lack of funding and control resources allocated by them. A lead agency, staffed with experienced people, utilizing local communities, supported by proper legislation, funding, and fire mobilization capabilities, is essential to assess existing resources, determine requirements and coordinate activities on the ground within Central Kalimantan in order to prevent and combat fire.

Peatland restoration and water management

Peat Swamp Forests (PSF) are unique ecosystems with many complex interrelations. Until recently they were regarded as waste land that had to be put into use for humankind. Recent fire, erosion and flood events show the need for restoration of degraded PSF in order to maintain livelihoods and protect the environment. Restoration involves initiating or accelerating the recovery of the ecological functions of peatland ecosystems, as far as possible, for a variety of uses including agriculture, agro forestry, carbon store and wildlife conservation. Because peat occurs, and is maintained, only under water saturated conditions, water management is the basis of peatland restoration.

Poverty

People's ability to escape from poverty is critically dependent on their access to livelihood maintaining assets. The sustainable livelihoods (SL) approach, which is participatory in nature, seeks to determine poor peoples' livelihood priorities and link these with different socio-economic solutions depending upon specific circumstances. SL options for communities living near peat swamp areas include: the potential of different land uses, integrating the conservation and development of tropical peatland, and forging partnerships between local communities, local governments, DC government agencies, NGOs and international donors and experts in order to promote the sustainable restoration and management of peat swamp forest and peatland in general.

CONCLUSION

The key to success is to prepare a management plan that contains strategies for implementing all of the priorities mentioned above and operates in a coordinated manner that does not favour any particular sector. There must be integration at all

levels, especially at the bottom where stakeholders must be empowered to be part of the process and not the problem. There are many constraints to be overcome, including lack of coordination and funding and the need to integrate local knowledge and culture into implementation programmes. Negating the over-drainage effects of the extensive system of channels will be a major, possibly impossible, task for which the technology may not be available and the cost enormous. Rewetting may not succeed even if resources can be found to promote it. There are insufficient people with the skills necessary to implement a restoration and rehabilitation plan for the Ex MRP and resources must therefore be allocated to training and institutional capacity building. The financial resources needed will be great, beyond the ability of the Indonesian Government to pay. The restored landscapes will unlikely provide profitable incomes or livelihoods for many people so it will be unwise to bring in more transmigrants to this poverty stricken and environmentally damaged area and alternative sources of funding will need to be sought from actions related to biodiversity and carbon conservation. It will be interesting to see how the Master Plan currently being prepared, funded by the Dutch Government, will address these problems and to find out whether or not the Indonesian Government will implement them.

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REFERENCES

- Soepraptohardjo, M. and Driessen, P.M (1976). The lowland peats of Indonesia, a challenge for the future. *Soil Research Institute, Bogor Bulletin* **3**: 11-19
- Notohadiprawiro, T. (1996). Constraint to achieving the agricultural potential of tropical peatlands – an Indonesian perspective. In: E. Maltby, C.P. Immirzi and R.J. Safford (eds.), *Tropical Lowland Peatlands of Southeast Asia*. IUCN. Gland, Switzerland. Pp. 139-154.
- Notohadiprawiro, T. (1997). Twenty-five years experience in peatland development for agriculture in Indonesia. In: J.O. Rieley and S.E. Page (eds.), *Biodiversity and Sustainability of Tropical Peatlands*. Samara Publishing Ltd., Cardigan, UK. pp 301-309.
- Notohadiprawiro, T. (1998). Conflict between problem solving and optimising approach to land resources development policies – the case of Central Kalimantan wetlands. *Proceedings of the International Peat Symposium: The Spirit of Peatlands – 30 Years of the International Peat Society*, Jyväskylä, Finland, 7-9 September 1998, International Peat Society, Jyväskylä, Finland, pp. 14-24.
- Muhamad, N.Z. and Rieley, J.O. (2002). Management of tropical peatlands in Indonesia: mega reclamation project in Central Kalimantan. *Peatlands for People: Natural Resource Functions and Sustainable Management. Proceedings of the International Symposium on Tropical Peatland*, 22-23 August 2001, Jakarta, Indonesia. BPPT and Indonesian peat Association. Pp. 155-167.
- Setiadi, B. (2007). *Acceleration of Rehabilitation and Restoration on Ex-peat Area Development in Central Kalimantan*. Report and Recommendations of the *Ad Hoc*

- Team for the Ex-PLG Project, Central Kalimantan. EU RESTORPEAT Project, Alterra Wageningen University and Research Centre, The Netherlands. 60 pp.
- Rieley, J.O. and Page, S.E. (2005) *Wise Use of Tropical Peatlands: Focus on Southeast Asia*. EU STRAPEAT Project, Alterra Research Centre, Wageningen University, The Netherlands. www.strapeat.alterra.nl
- Rieley, J.O., Limin, S.H. and Jaya, A. (Eds.) (2007). Palangka Raya statement on restoration and wise use of tropical peatlands. *Proceedings of the International Symposium and Workshop on Tropical Peatland*, Palangka Raya, Central Kalimantan, 20-24 September 2005. EU RESTORPEAT Partnership, University of Palangka Raya, Indonesia and Alterra Wageningen University and Research Institute, Wageningen, The Netherlands. Pp. xxviii-xxxii.

Restoration of Ecological and Natural Resource Functions

UNLOCKING THE NATURAL RESOURCE FUNCTIONS OF TROPICAL PEATLANDS: UNDERSTANDING THE NATURE AND DIVERSITY OF PEAT SWAMP FOREST VEGETATION AS A FOUNDATION FOR VEGETATION RESTORATION STUDIES

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SUMMARY

The rapid loss of biological diversity that is occurring as a result of species loss owing to habitat destruction and fragmentation is considered one of the world's most pressing environmental problems. Whilst the diversity associated with lowland tropical peatlands is usually lower than adjacent terrestrial rain forest ecosystems, many peatland species are specialists, which are not found in other habitats. The inaccessibility of peatlands has also drawn in species that, although not confined to this habitat, are dependent upon the shelter and food that peat swamp forests provide, compared to the intensively logged forests on mineral soils. As more information on the biodiversity of tropical peat swamp forests accumulate it is clear that this ecosystem has been undervalued as a habitat for rare and threatened species, for example, orang utan.

Keywords: peat swamp forest, biodiversity, restoration, natural resource functions, wise use

INTRODUCTION

Lowland tropical peatlands provide a range of valuable ecological functions and environmental services (Maltby *et al.*, 1996; Page and Rieley, 1998). For example, they support a large diversity of plant and animal species, some of which are endemic or endangered (Page *et al.*, 1997). These vast wetlands are also important catchment and control systems that provide water for drinking and irrigation and, in coastal areas, they are buffers between salt and freshwater hydrological systems. During the last 15 years, there has been increasing interest in the important role played by tropical peatlands in the global carbon cycle; they are recognized as storing globally significant amounts of carbon and are also repositories of important geochemical and palaeoenvironmental information (Sorensen, 1993; Neuzil, 1997; Page *et al.*, 2004; Weiss *et al.*, 2002; Wüst and Bustin, 2004). In addition, lowland tropical peatlands have contributed to the way of life and economy of indigenous people for centuries through the provision of plant and animal resources for food, shelter, medicine and cultural well-being.

In recent decades, tropical peatlands have come under increasing pressure from human-mediated disturbances, in particular logging, drainage and conversion to agriculture or plantation forestry. The associated changes in forest and land management practices have impaired the natural resource functions of the peatland ecosystem, greatly reducing the area of undisturbed forest and increasing its

susceptibility to degradation and fire (Page *et al.*, 2002). The challenge facing those involved in the management of tropical peatlands in the 21st century is to develop integrated planning and management mechanisms that balance the conflicting demands on the tropical peatland resource to ensure its continued survival. This strategy of 'wise use' involves evaluation of natural resource functions and uses, the impacts caused by development, and the priorities for future sustainable management and use, including mitigation of damage. These mitigation measures may, where appropriate, include efforts to promote restoration of the original forest cover, but restoration efforts will only be effective if they are based upon sound understanding of natural ecosystem processes.

This paper provides a brief overview of the current state of knowledge of the vegetation of lowland peat swamp forests in Southeast Asia and the key ecological features that need to be considered before embarking on restoration initiatives.

PEAT SWAMP FOREST VEGETATION

Lowland tropical peat swamps are almost exclusively ombrogenous systems (i.e. the peat surface only receives water from precipitation), whilst geogenous peatlands, that are fed additionally by water that has been in contact with the mineral bedrock and soils, are of more limited distribution, being confined to the edges of coastal lagoons, the banks and flood zones of rivers, and the margins of lakes. Undisturbed, lowland ombrogenous peatlands support peat swamp forest, whilst geogenous wetlands support freshwater swamp forest. The ombrogenous swamps provide a unique tropical forest environment: the peat substrate, which may exceed 10 m in thickness, affords an extremely unstable, acidic, nutrient-poor, and almost continually waterlogged rooting environment. Many of the forest trees have buttress or stilt roots that provide improved stability on the waterlogged peat soils and also breathing roots (pneumatophores) that protrude above the peat surface, enabling respiratory gas exchange to occur under anaerobic conditions.

The global centre of tropical peat swamp forest distribution lies in the Indo-Malayan realm, in Malaysia, Indonesia, Vietnam, Thailand and the Philippines. In most of these countries the area of peat swamp forest has been reduced to a small fraction of its former extent, with the largest remnants found in Malaysia and Indonesia. Approximately 800 tree species have been recorded from the peat swamp forests of western Malesia (i.e. excluding the peat swamps of Papua New Guinea), comprising 71 families and 237 genera. The principal tree families represented in the peat swamps are Euphorbiaceae, Myrtaceae, Lauraceae, Clusiaceae, Rubiaceae and Dipterocarpaceae. Members of the Pandanaceae often form a dense ground cover; pteridophytes and insectivorous pitcher plants (Nepenthaceae) also occur. In marked contrast to boreal and temperate peatlands, the principal peat-forming plants are the trees, whilst bryophytes, grasses, sedges and herbaceous species play a very minor role in both the vegetation and peat formation.

Forest type	No. tree species / hectare	Reference source
Lowland dipterocarp forest	270-393	Davies and Becker 1996; Suzuki <i>et al.</i> 1999.
Heath forest	70-171	Davies and Becker 1996; Suzuki <i>et al.</i> 1999.
Peat swamp forest	75-120	Anderson 1963; Siregar and Sambas 2000; Waldes unpublished.
Sub-montane forest	115	Simbolon and Mirmanto 2000
Montane forest	48	Simbolon and Mirmanto 2000

Table 1 Comparison of tree species diversity between five forest types on the island of Borneo.

The tree species diversity associated with peat swamp forests is usually lower than that of adjacent forest ecosystems on mineral soils (Table 1), but several tropical peatland trees are specialists and restricted to this habitat. Studies of the peat swamp forests of western Malesia have revealed that *Archidendron clypearia*, *Dactylocladus stenostachys*, *Gonystylus bancanus*, *Horsfieldia crassifolia*, *Shorea belangeran* and *S. teysmanniana* are confined almost exclusively to this habitat and three of these species, *G. bancanus*, *H. crassifolia* and *S. belangeran*, are included on the IUCN (www.iucn.org) red list of globally endangered plants. Phytogeographic studies have also indicated considerable regional variation in the peat swamp flora, with only five tree species (from the total of 800) displaying a widespread distribution across west Malesia, namely *Baccaurea bracteata*, *Camposperma coriaceum*, *Ilex cymosa*, *Madhuca motleyana* and *Stemonurus secundiflorus*. Across the peat swamp forests of the island of Borneo there are only three widespread tree species (*Dactylocladus stenostachys*, *Cratoxylum arborescens* and *Koompassia malaccensis*) and there are striking sub-regional differences in floristics between the peat swamps of northern Borneo (Brunei and Sarawak), west, central and east Kalimantan. Thus at both regional and sub-regional scales, tropical peat swamp forest vegetation displays considerable heterogeneity.

Differences in hydrology and nutrient availability exert strong influences on the composition and structure of the forest vegetation, with most large tropical peatland domes exhibiting a concentric zonation of forest sub-types, ranging from tall, floristically-diverse and structurally-complex forest over shallow peat at the margins to less diverse, low-canopy pole (small diameter) forest over thicker peat towards the centre, although some exceptions to this general pattern have been described (Page *et al.*, 1999). Six phasic communities have been described for the peatlands of Sarawak (Anderson, 1963, 1964), ranging from a structurally complex, species-rich community around the edges of large peat domes, to stunted, dense low pole and *padang* (open) communities on deep peat which coincide with zones of hydrological and nutrient stress (as a result of waterlogging and low nutrient availability); intermediate communities are dominated by the dipterocarp tree *Shorea albida*. In the peat swamps of Central Kalimantan, five phasic communities have been identified (Table 2) (Page *et al.*, 1999). These differ in several respects from those described from Sarawak, principally the absence of *S. albida*, and the presence of a tall forest community dominated by *Palaquium leiocarpum* on the central part of the peatland dome. By contrast, the peatlands of the Malay Peninsula and Sumatra appear to

support only two main forest types, a tall, marginal mixed swamp forest and a lower, pole forest on the thicker peat, although it should be noted that there are only a few accounts of the vegetation of Sumatran peat swamps. The high levels of vegetation heterogeneity associated with peat swamp forests may, at the regional and sub-regional scale, reflect long-term biogeographical events (i.e. changes in geological configuration, climate, sea-level changes and land-sea distributions) (Metcalf, 2002), or ecological events that operate over shorter time scales, including variability in succession trajectories and differences in disturbance regimes. Whatever the underlying cause or causes, this information highlights the individualistic nature of both regional and local community dynamics within tropical peat swamp forest.

Principal tree species	Mixed swamp forest at the edge of the peat dome on peat up to 6m thickness	Low pole forest nearer to the centre of the peat dome on peat from 6 to 10 m thickness	Tall interior forest on the central peatland dome on peat from 10 to 13 m thickness
<i>Palaquium ridleyi</i>	x		
<i>Calophyllum hosei</i>	x		
<i>Mesua sp.</i>	x		
<i>Mezzettia parviflora</i>	x		
<i>Combretocarpus rotundatus</i>	x	x	
<i>Sizygium</i> ???		x	
<i>Tristaniopsis obovata</i>		x	
<i>Shorea teysmanniana</i>		x	x
<i>Palaquium leiocarpum</i>			x
<i>Stemonurus secundiflorus</i>			x
<i>Mezzettia parviflora</i>			x
<i>Neoscortechinia kingii</i>	x		x
<i>Palaquium cochlearifolium</i>	x		x

Table 2 Principal tree species occurring in three peat swamp forest communities on peat of increasing depth across a peatland dome in the Sebangau catchment, Central Kalimantan.

In general terms, the taller peat swamp forest sub-types (e.g. marginal mixed swamp forest) which have the greatest tree species diversity and canopy stratification, also support the greatest floral and faunal diversity (Page *et al.*, 1997). Lower canopy forest sub-types (e.g. low pole and padang forest) are less species diverse. These forests are not without interest, however, and several noteworthy species of plant, mammal and bird have been recorded in low pole forest (Page *et al.*, 1997), whilst the many water-filled hollows on the forest floor support unusual species of blackwater fish (Ng *et al.*, 1994).

Where tropical peat swamps have been degraded by human activities, various secondary forest and non-forest plant communities replace the original vegetation, ranging from open canopy forest with invasive tree species (e.g. *Macaranga* spp.) at sites that have been logged-over, through to seriously degraded sites which have been logged, drained and/or burnt on at least one occasion. At these latter sites there will, at best, be a fragmentary forest canopy and ground vegetation dominated by ferns (including *Stenochlaena palustris*, *Lygodium* and *Pteris* spp.), grasses (e.g. *Imperata cylindrica*), sedges (*Scleria* and *Cyperus* spp.), shrubs (e.g. *Melastoma malabathricum*) and other fast-growing species. In Central Kalimantan, studies are currently underway to determine the pathways of secondary vegetation succession following various types of peatland degradation, including successive fire events. This will provide useful information on the processes of spontaneous vegetation recovery. In conjunction with planting trials of native peat swamp forest tree species, this work will provide initial data on the site treatments that may be required to enhance restoration success, e.g. manipulation of hydrology and nutrient conditions or the removal of barriers to tree regeneration, such as the lack of bird perches at deforested sites.

KEY BIOPHYSICAL FUNCTIONS

In any ombrotrophic peatland there is an intimate relationship between the hydrological and nutrient-supply conditions and the associated features of the vegetation. The fluctuation of the water table within tropical peatlands depends mainly on rainfall because evaporation and outflow are fairly constant. During the wet season, rainfall always exceeds the combination of evaporation and surface run-off. In this period, the water table increases and may come to or rise above the surface, creating several months of anaerobic rooting conditions. By contrast, during the drier months of the year when the rain-free period may last for several weeks, the water level drops below the soil surface often to depths of 0.2 to 0.6 m, and peat swamp forest vegetation may be faced with a physiological water deficit. Water table fluctuations vary across an intact peat dome by up to 0.60 m near the edge and 0.45 m near the centre. (Ong and Yogeswaran, 1992; Yonetani and Takahashi, 1997; Page *et al.*, 1999; Takahashi *et al.*, 2002). These differences in hydrology play a fundamental role in determining the fine-scale spatial vegetation patterns observed across intact peatland domes, with the low pole and padang forests normally occupying the wettest central parts of the dome where water levels are highest, and the taller forest types occupying locations where there is a greater hydraulic gradient and thus reduced levels of waterlogging. By contrast, in degraded and drained peatlands, low rainfall during the dry season may enable groundwater levels to drop to 1 m or even 1.5 m below the soil surface. Under these conditions, not only may the low water table limit the range of plant species able to establish and survive, but susceptibility to fire will also be greatly increased. During the wet season, areas that have subsided as a result of peat degradation or fire may experience extensive flooding with groundwater levels of more than 1 m above the soil surface for a prolonged period of time. Studies in the peatlands of Jambi province, Sumatra have shown that this creates shallow lakes where plant species cannot re-establish (Wösten *et al.*, 2006). The restoration of near-normal seasonal water levels is, therefore, likely to be crucial to the successful re-establishment of a closed forest cover, although it is too early to speculate to what extent the fine-scale differences in hydrology and hence vegetation can be replicated in restoration schemes.

Plant nutrients are in limited supply in ombrotrophic peatlands and subtle differences in nutrient cycling may have significant impacts upon the growth and performance of peatland plants. In tropical peat swamps, vegetation growth is dependent upon both the supply of nutrients from the atmosphere and efficient recycling of the existing nutrient pool within the ecosystem (Page *et al.*, 1999). In a study of the nutrient dynamics of a peat swamp forest ecosystem in Central Kalimantan (Sulistiyanto, 2004) it was demonstrated that internal nutrient transfers were related to forest tree biomass through gravitational influence (throughflow, stemflow and litterfall) and recycling (organic matter decomposition and uptake by the trees), and to storage in and release from the surface peat (accumulation or degradation) (Weiss *et al.*, 2002). Nutrient inputs (in precipitation and dry fall) were higher than nutrient losses (in runoff from the peat dome). The overall nutrient budget indicated that chemical elements were being retained within the forest vegetation, with any surplus being stored in currently accumulating peat. In contrast, studies on non-peat forming tropical forests have shown mostly annual net losses of most plant nutrient elements (Lewis, 1986; Bruijnzeel, 1991). Intact peat swamp forest vegetation clearly operates under limiting but efficient conditions of nutrient supply and cycling; studies of nutrient cycling in secondary peatland plant communities could play an important role in highlighting the extent to which nutrient pathways have been disrupted and their likely impact upon vegetation performance.

LESSONS FOR WISE USE AND VEGETATION RESTORATION

Wise use strategies for tropical peatlands need to acknowledge the global importance of the tropical peat swamp forest ecosystem, which supports a high diversity of tree species, including some species which are both habitat endemics and globally endangered. These strategies also need to recognise the high levels of vegetation heterogeneity that tropical peatlands display at a range of scales. There is clearly a lot more work that needs to be done to provide a comprehensive description of peat swamp forest plant communities; there is also some urgency given the current high rates of land conversion of tropical peatlands. These data are important in their own right as they enable comparisons between different locations, which may be important in terms of setting regional conservation priorities, but they are also an important guide for restoration initiatives since they enable local restoration targets to be set which can be used to determine the eventual success or failure of restoration measures. Restoration studies in tropical peat swamp forest are in their infancy but owing to the nature of the system and the range of disturbances it is clear that defining the success of the restoration cannot be standardized easily across sites. Understanding the cause or causes of forest damage will be important if the restoration is to succeed; equally, preventing further disturbance, in particular that caused by fire, will be absolutely vital. Establishing the right environmental biophysical conditions will also be an important prerequisite of success. The hydraulic conductivity, water level, acidity and nutrient content of the peat substrate will determine which tree species can establish, but these parameters may have been altered as a result of drainage or fire. Research needs to be carried out on the tolerance of individual tree species to these altered conditions. Other questions that need to be answered include (1) should the forest be left to re-grow naturally, perhaps with some mitigation measures in place, or (2) should trees be reintroduced artificially, by planting out from nursery stock? Future areas of research should also include long-term vegetation monitoring of restoration sites, accompanied by analysis of

hydrological conditions and biogeochemical pathways that occur as the system is restored, and which can be useful in relating the restored forest to the reference system. Time in post-fire vegetation development is extremely important and should be considered as an, if not the, over-riding dimension that shapes all vegetation formation factors (Mueller-Dombois, 2001). It is unlikely that the success of tropical peatland restoration schemes will be measured in decades or perhaps even centuries. The advantages of restoring peat swamp forest vegetation are numerous and should be pursued in a range of locations across Southeast Asia, but particularly in those areas where the peat thickness is so great that it is likely to prohibit any other form of sustainable land use. Restoration of the forest cover will contribute to improvements in water quality and water supply, maintenance of the peatland carbon store, and provide the people living in or adjacent to peatland landscapes with an improved quality of life.

REFERENCES

- Anderson, J.A.R. (1963) The flora of the peat swamp forest of Sarawak, and Brunei, including a catalogue of all recorded species of flowering plants, ferns and fern allies. *Garden Bulletin, Singapore*, 20: 131-228.
- Anderson, J.A.R. (1964) The structure and development of peat swamps of Sarawak and Brunei. *Journal of Tropical Geography*, 18: 7-16.
- Bruijnzeel, L.A. (1991) Nutrient input-output budgets of tropical forest ecosystems: a review. *Journal of Tropical Ecology*, 7: 1-24.
- Davies, S.J. and Becker, P. (1996) Floristic composition and stand structure of mixed dipterocarp and heath forests in Brunei Darussalam. *Journal of Tropical Forest Science*, 8: 542-569.
- Lewis, W.M. Jr. (1986) Nitrogen and phosphorus runoff losses from a nutrient-poor tropical moist forest. *Ecology*, 67: 1275-1282.
- Maltby, E., Immirzi, C.P. and Safford, R.J. (Eds.) (1996) *Tropical Lowland Peatlands of Southeast Asia*. IUCN, Gland, Switzerland.
- Metcalf, I. (2002) Tectonic history of the SE Asian-Australian region. In: Kershaw, P., David, B., Tapper, N., Penny, D. and Brown, J. (Eds.). *Bridging Wallace's Line: The Environmental and Cultural history and Dynamics of the SE-Asian-Australian Region*. Advances in Geoecology 34, pp. 29-48. Catena Verlag, Reiskirchen, Germany.
- Mueller-Dombois, D. (2001) Biological invasion and fire in tropical biomes. In: Galley, K.E.M. and Wilson, T.P. (Eds.) *Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species*. The First national Congress on Fire Ecology, Prevention and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL. Pp. 112-121.
- Neuzil, S.G. (1997) Onset and rate of peat and carbon accumulation in four domed ombrogenous peat deposits, Indonesia. In: J.O. Rieley and S.E. Page (Eds.), *Biodiversity and Sustainable Management of Tropical Peatlands*. Samara, Cardigan, UK, pp. 55-72.
- Ng, P. K. L., Tay, J.B. and Lim, K.K.P. (1994) Diversity and conservation of blackwater fishes in Peninsular Malaysia, particularly in the north Selangor peat swamp forest. *Hydrobiologia*, 285: 203-218.

- Ong, B.Y. and Yogeswaran, M. (1992) Peatland as a resource for water supply in Sarawak. In: B.Y. Aminuddin (Ed.), *Proceedings of the International Symposium on Tropical Peatland*, Kuching, Sarawak. MARDI, Malaysia, pp. 225-268.
- Page, S.E. and Rieley, J.O. (1998) Tropical peatlands: a review of their natural resource functions, with particular reference to Southeast Asia. *International Peat Journal*, 8: 95-106.
- Page, S.E., Rieley, J.O., Doody, K., Hodgson, S., Husson, S., Jenkins, P., Morrogh-Bernard, H., Otway, S. and Wilshaw, S. (1997) Biodiversity of tropical peat swamp forest: a case study of animal diversity in the Sungai Sebangau catchment of Central Kalimantan, Indonesia. In: J.O. Rieley and S.E. Page (Eds.), *Biodiversity and Sustainable Management of Tropical Peatlands*. Samara, Cardigan, UK, pp. 231-242.
- Page, S.E., Rieley, J.O., Shotyk, W. and Weiss, D. (1999) Interdependence of peat and vegetation in a tropical swamp forest. *Philosophical Transactions of the Royal Society London, Series B*, 354: 1885-1897.
- Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.-D.V., Jaya, A. and Limin, S. (2002) The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, 420: 61-65.
- Page, S.E., Wüst, R.A.J., Weiss, D., Rieley, J.O., Shotyk, W. and Limin, S.H. (2004) A record of Late Pleistocene and Holocene carbon accumulation and climate change from an equatorial peat bog (Kalimantan, Indonesia): implications for past, present and future carbon dynamics. *Journal of Quaternary Science*, 19: 625-635.
- Simbolon, H. and Mirmanto, E. (2000) Checklist of plant species in the peat swamp forests of Central Kalimantan, Indonesia. *Proceedings of the International Symposium on Tropical Peatlands*, 22-23 November, 1999, Bogor, Indonesia, pp. 179-190.
- Siregar, M. and Sambas, E.N. (2000) Floristic composition of peat swamp forest in Mensemat-Sambas, West Kalimantan. *Proceedings of the International Symposium on Tropical Peatlands*, 22-23 November, 1999, Bogor, Indonesia, pp. 153-164.
- Sorensen, K.W. (1993) Indonesian peat swamp forests and their role as a carbon sink. *Chemosphere*, 27: 1065-1082.
- Sulistiyanto, Y. (2004) Nutrient dynamics in different sub-types of peat swamp forest in Central Kalimantan, Indonesia. *PhD Thesis, Department of Geography, University of Nottingham*, Nottingham, United Kingdom.
- Suzuki, E., Kohyama, T. and Simbolon, H. (1999) Vegetation of fresh water swampy areas in West and Central Kalimantan. *Paper presented at the Workshop of Biodiversity and Sustainable Management of Peat Swamp Forest*, 12 February 1999, Bogor, Indonesia.
- Takahashi, H., Shimada, S., Ibie, B.I., Usup, A.D., Yudha and Limin, S.H. (2002) Annual changes of water balance and a drought index in a tropical peat swamp forest of Central Kalimantan, Indonesia. In: J.O. Rieley, S.E. Page and B. Setiadi (Editors), *Peatlands for People: Natural Resource Functions and Sustainable Management, Proceedings of the International Symposium on Tropical Peatland*, Jakarta, Indonesia. BPPT (Badan Pengkajian dan Penerapan Teknologi) and Indonesian Peat Association, Jakarta, pp. 63-67.
- Weiss, D., Shotyk, W., Rieley, J., Page, S., Gloor, M., Reese, S. and Martinez-Cortizas, A. (2002) The geochemistry of major and selected trace elements in a

- forested peat bog, Kalimantan, SE Asia, and its implications for past atmospheric dust deposition. *Geochimica. et Cosmochimica Acta*, 66: 2307-2323.
- Wösten, H.M., Van Den Berg, J., Van Eijk, P., Gevers, G.J.M., Giesen, W.B.J., Hooijer, A., Idris, A., Leenman, P.H., Rais, D.S., Siderius, C., Silvius, M.J., Suryadiputra, N. and Wibisono, I.T. (2006) Interrelationships between hydrology and ecology in fire degraded tropical peat swamp forests. *International Journal of Water Resources Development*, 22: 157-174.
- Wüst, R.A.J. and Bustin, R.M. 2004. Late Pleistocene and Holocene development of the interior peat-accumulating basin of tropical Tasek Bera, Peninsular Malaysia. *Paleogeography, Paleoclimatology and Paleoecology*, 211: 241-270.
- Yonetani, Y. and Takahashi, H. (1997) Studies on microclimate and hydrology of peat swamp forest in Central Kalimantan, Indonesia. In: J.O Rieley and S.E. Page (Editors), *Biodiversity and Sustainability of Tropical Peatlands*. Samara, Cardigan, UK, pp. 179-187.

FLORAL DIVERSITY OF THE PEAT SWAMP FORESTS OF SARAWAK

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SUMMARY

The total peatland area of Sarawak is estimated to be about 1,657,600 hectares, representing 13% of the whole land area. Many of the peat swamp forests (PSF) have been harvested or transformed into agricultural lands and settlements along the coastal areas of Sarawak's lowland plains. Owing to the rapid transformation of the PSF, there has been increased attention on conserving some of what is left for biodiversity, water resources, recreation, ecotourism and other purposes, including that of being a carbon sink. The existing protected peat swamp areas are Loagan Bunut National Park, which encompasses 10,736 ha, Maludam National Park of 43,147 ha, Pulau Bruit Wildlife Sanctuary (1,776 ha) and several isolated islands of PSF located in Bako National Park, Samunsam Wildlife Sanctuary, and Mulu National Park. This paper presents a review on the flora study of the PSF in the Loagan Bunut National Park and the disturbed PSF of Kota Samarahan and Sedilo. In our inventory studies, the traditionally important trees of the peat swamp were also identified, namely *Gonystylus bancanus* Miq. Kurz. (Ramin), *Shorea albida* Sym. (Alan bunga), *Dactylocladus stenostachys* Oliv. (Jongkong), *Shorea inequilateralis* Sym. (Semayur), *Platea excelsa* Bl. (Jejangkong), *Dyera polyphylla* (Miq.) Steenis (Jelutung), *Dryobalanops rappa* Becc. (Kapur paya), *Cratoxylum glaucum* Korth. (Geronggang padang) and *Combretocarpus rotundatus* (Miq.) Dans. (Keruntum). Nevertheless, these species were no longer dominant in the disturbed habitat. This paper also discusses the importance of flora in the PSF ecosystem that plays an important role in enhancing the carbon sink and storage.

Keywords: peat swamp forest, floral diversity, Sarawak.

INTRODUCTION

The land area of Sarawak is covered by diverse forest types ranging from mixed dipterocarp forest (57%), peat swamp forest (12%), kerangas or tropical heath forest (3%), mangrove forest (1%), beach or littoral forest (less than 1%), riverine or alluvial forest (less than 1%), montane forest (less than 1%), limestone forest (less than 1%), and secondary forest of various succession periods. The distributions of the forest types are influenced by several factors including soil type, altitude, topography, climate and geology. The current estimate of the vascular plants species in Sarawak is about 10,000-12,000 species.

The pristine peat swamp forest of Sarawak was considered unique when Anderson in 1963 and 1964 classified six distinct types of vegetation communities. The first community on shallow peat is known as mixed peat swamp forest. This type of forest

is comparatively rich in species composition compared to the other five communities. The associated species present in this community are *Shorea albida* - *Dactylocladus* and *Neoscortechinia*. The second community is characterized by the presence of huge individuals of *Shorea albida* associated with *Gonystylus* and *Stenonurus spp.* The third community is also dominated by *Shorea albida*. The fourth community is known as padang alan and is dominated by *Shorea albida* with two other genera, *Litsea* and *Parastemon*. The fifth community that occurs near to the centre of the dome is referred to as padang paya with *Tristinia* – *Palaquium* – *Parastemon* as the common associated species. The central community is known as padang keruntum and is dominated by *Combretocarpus rotundatus* together with *Dactylocladus*. This is comprised of small and stunted trees resembling the features of woodland.

It has been reported that PSF plays an important role in global carbon balance. Its large biomass contributes to carbon sequestration and storage. Consequently, it is timely that intensive study on this fragile ecosystem should be given priority by the Government and stakeholders. Hence, the objective of this paper is to highlight the floral diversity of totally protected PSF compared to logged over PSF and to give better understanding of the ecosystem and the flora diversity of the remaining and existing PSF in Sarawak, for the purpose of biodiversity and ecosystem conservation.

MATERIALS AND METHODS

The data incorporated in this paper were derived from the brief floral inventory carried out in the following selected PSFs. The site at Universiti Malaysia Sarawak at the East Campus is located at 1° 27' N, 110°27' E in Kota Samarahan Division. It is considered as a re-established mixed peat swamp forest after being logged in 1957. This area is conserved for educational purposes. The survey was conducted on a one ha plot comprising of 25 subplots of 20 x 20 m. The area at Sedilo is logged over mixed peat swamp forest located at 1° 26'N, 110° 48 E' in Kota Samarahan Division. The samplings were only done using 3 plots of 20 x 20 m selected within the sites. The Loagan Bunut National Park is located at 3° 48' N, 114° 13'E. It is the first peat swamp National Park of Sarawak being gazetted in 1991 and encompasses an area of 10,736 of peat swamp while the huge lake within the park occupies 650 ha. Loagan Bunut National Park is one of the fascinating forests featured by its huge natural lake located in the upper reaches of Sungai Bunut, Miri. The floral survey was only done through samples collected from various locations in the Loagan Bunut National Park.

All tree species of ≥ 5 cm of diameter breast height (DBH) from the three sites were measured. Specimens were collected, oven dried and preserved accordingly for identification. Identifications were made at the Sarawak Herbarium (SAR). The heights of trees were measured using a Haga meter. The estimated above ground biomass at the Universiti Malaysia Sarawak East Campus PSF and Sedilo PSF were determined by the methods of Yamakura *et al.*, 1986.

RESULTS

Floral diversity and total above ground biomass

The results of the study were included as below.

Universiti Malaysia Sarawak, East Campus PSF

In the one hectare plot a total of 1600 individual trees of DBH \geq 5.0 cm from 167 species identified of 37 families were enumerated. The top ten families which showed a high number of species recorded were Lauraceae (19 species), Myrtaceae (14 species), Annonaceae (10 species) Euphorbiaceae (10 species) Fabaceae (9 species), Burseraceae (8 species), Anacardiaceae (7 species), Myrtaceae (7 species), Sapotaceae (7 species) and Clusiaceae (6 species). Other families identified were Dipterocarpaceae, Ebenaceae, Eleocarpaceae, Sapindaceae, Apocynaceae, Rosaceae, Aquifoliaceae, Bombacaceae, Celasteraceae, Meliaceae, Fagaceae, Icacinaceae, Melastomaceae, Moraceae, Oleaceae, Oxalidaceae, Polygalaceae, Rhizophoraceae, Rutaceae, Alangiaceae, Magnoliaceae, Myrsinaceae, Simaroubaceae, Sterculiaceae, Tetrameristaceae, Thymelaeaceae, Tiliaceae, Based on the DBH classification, the percentage of 1600 individuals trees enumerated were as follows:- 905 (56.6%) individuals with DBH ranging from 5-10.0 cm, 481(30.1%) individual trees with 10.1-20.0 cm DBH, 123 (7.7%) individual trees with 20.1-30 cm DBH, 34 (2.12%) individual trees with 30.1-40.0% and only 5 (0.3%) individual trees with 40.1-50 cm while only individual with 50.1 - 60 cm DBH and only 1 (0.06%) individual with 60.1-70 cm DBH (Ipor, *et al.* 2006).

The ten families which contributed to the most TAGB were Sapotaceae (69,482.56 kg/ha), followed by Euphorbiaceae (38,360.47 kg/ha), Sapindaceae (23,722.15 kg/ha), Lauraceae (17,155.28 kg/ha), Bombacaceae (14,432.08 kg/ha), Anacardiaceae (13,123.66 kg/ha), Annonaceae (9,896.46 kg/ha), Myrtaceae (8,446.65 kg/ha), Fabaceae (7,561.64 kg/ha) and Apocynaceae (7,004.24 kg/ha) (Ipor *et al.*, 2006)

Sedilo PSF

From the three plots surveyed, a total of 218 trees with a DBH of \geq 5 cm from 22 families comprising of 47 species were recorded. The top ten families which showed a high number of species recorded were Dipterocarpaceae (37 species), Sapotaceae (25 species), Myrtaceae (24 species), Polygalaceae (20 species), Lauraceae (14 species), Annonaceae (13 species), Myristicaceae (11 species), Euphorbiaceae (10 species), Fagaceae (10 species) and Dilleniaceae (9 species). The other families recorded were Ebenaceae, Aquifoliaceae, Rubiaceae, Anacardiaceae, Linaceae, Burseraceae, Fabaceae, Thymelaeaceae, Sapindaceae, Apocynaceae, Icacinaceae and Oleaceae. Of the 218 individuals trees enumerated, 131 (60.1%) individuals with DBH ranging from 5-10.0 cm, 50 (22.9%) individual trees with 10.1-20.0 cm DBH, 20 (9.2%) individual trees with 20.1-30 cm DBH, 9 (4.1%) individual trees with 30.1- 40.0% and only 8 (3.7%) individual trees with 40.1-50 cm.

The ten families which contributed most to the TAGB were Dipterocarpaceae (8,617.69 kg/ha), Thymelaeaceae (6,119.42 kg/ha), Sapotaceae (4,001.48 kg/ha), Lauraceae (3,346.18 kg/ha), Euphorbiaceae (3,118.57 kg/ha), Annonaceae (3,078.83 kg/ha), Fagaceae (2,615.69 kg/ha), Myrtaceae (1,666.96 kg/ha), Polygalaceae (1,589.55 kg/ha) and Myristicaceae (942.01 kg/ha)

Loagan Bunut National Park PSF

From the survey conducted from the four sites of the peat swamp forest viz: Teluk Udang, Teluk Bedil, Sungai Babi, Teluk Lepa and along Sungai Bunut in the Loagan Bunut National Park a total of 97 species from 42 families were so far identified. Among these species several were important commercial peat swamp species. These species were *Gonystylus bancanus* (Miq.) Kurz., (*Ramin*) *Shorea albida* (Alan bunga),

Dactylocladus stenostachys (Jongkong), *Shorea inequilateralis* (Semayur), *Platea*, *Dyera polyphylla* (Jelutong), *Dryobalanops rappa* (Kapur paya), *Cratoxylum glaucum* (Geronggang padang), *Combretocarpus rotundatus* (Keruntum) and *Tristianopsis beccariana* (Selunsor merah).

Several ferns were identified namely *Asplenium nidus* (Paku bajang), *Atrophyum callifolium* (Paku pakis), *Dynaria quercifolia* (Paku pakis), *Huperzia phlegmaria* (Ekor tupai), *Lindasaya scandens* (Paku pakis), *Selaginella willdenowii*, *Stenochlaena palustris* (Midin), *Syngramma cartilagidens* (Paku pakis), *Platynerium riddlei* (Tanduk rusa), *Platynerium coronarium* (Tanduk rusa). Four species of nepenthes are commonly found growing as climbers or scramblers on the wet forest floor and surrounding shrub and trees. The species identified were *Nepenthes ampularia*, *Nepenthes bicalcarata*, *N. gracilis* and *N. rafflesiana*. Several orchid species had been identified namely *Agrostophyllum bicuspidatum*, *Bulbophyllum beccarii* (Orkid telinga gajah), *Cymbidium finlaysonia*, *Dendrobium onosmum*, *Grammatophyllum speciosum*. *Bulbophyllum beccarii* is endemic to Borneo occurring in Brunei, Kalimantan, Sabah and Sarawak (Wood, 1997). On the forest floor some aroid herbs were found. Among the species identified are *Alocasia longiloba*, and *Aglaonema simplex* and *Labisia pumila*. The larger trees are normally habitats for numerous epiphytic species such as *Aeschynanthus*, *Asplenium nidus*, *Dynaria quercifolia*, *Dendrobium amonum*, *Hoya* and *Urceola*.

DISCUSSION

Based on the previous study by Anderson 1963 and 1964, the pristine natural PSF of Sarawak was rich in plant diversity with several endemic species from six distinct communities. He enumerated a total of 1528 Dicotyledons, 106 Monocotyledons, 6 Gymnosperms and 66 species of Pteridophyta inhabiting this PSF. The forest has been well known as an important habitat for several endemic plants of Borneo such *Coipfera palustris*, *Dactylocladus stenostachys*, *Dryobalanops rappa*, *Shorea albida*, *Shorea inaequilateralis* and *Shorea uliginosa* (Tawan, 2006). These are large timber trees and contribute large biomass to the PSF. *Gonystylus bancanus* is one of the most popular tropical timbers and is specifically confined in this type of forest. Its population was once dominant in the natural habitat but is now greatly depleted. It has also been reported that this species showed poor regeneration (Tawan, 2007). This species is now listed under Appendix 11 of the CITES (Convention of International Trade of Endangered Species).

The six types of community mentioned by Anderson, 1963 still exist in Loagan Bunut National Park, although in some areas its ecosystem had been disturbed due to logging activities. It was noted that the peat swamp forest of Loagan Bunut is still rich in its flora composition. Several species that were found in Loagan Bunut National Park are protected under the Wild Life Ordinance of Sarawak, 1998. Examples of the species are *Nepenthes* spp., *Huperzia phlegmaria*, *Aeschynanthus* sp. The species composition in the other two study sites, Universiti Malaysia Sarawak East Campus and Sedilo, are basically altered. This is evidence that there are different top ten families recorded in both sites. Both sites recorded very few trees with the DBH greater than 30 cm that indicated larger trees have been extracted in the past. However, no attempt was made to compare the two sites in their species diversity and TABG as the number of plots taken from Sedilo was far fewer than at Universiti

Malaysia East Campus. It is suggested that permanent research plots of at least one ha in selected PSF should be made for comparative study in the future.

Peat swamp in Sarawak is considered a very important natural resource and has been providing economic benefits use for the forest industry, agricultural development, water source, ecotourism, minor forest products, sources for food and medicine to the local community. In actual fact, the logging activity was first introduced in 1950s by the British Colonial Government concentrated in the coastal area of PSF. This timber industry contributed much to the state revenue. The timber extraction from the PSF was carried out until in the 1970s when the logging activities intensified in the hill forests (Sawal, 2003). Realising the importance of the PSF, the State government gazetted two major areas as totally protected area (TPA), the Loagan Bunut National Park and Maludam National Park. However, in some repeated logged PSFs areas, the forest condition was very much degraded and contributed negative impacts to ecosystems and environment. These degraded areas obviously require a long term rehabilitation programme. The environmental significance and function of PSF is due to its unique hydrology system. The organic plant materials remain undecomposed in the peat soil due to waterlogged condition and through the natural processes of the peat swamp is capable to act as a carbon sink rather than as a carbon source (Sawal, 2003). The existence of PSF vegetation with high total of above ground biomass would lead to a more efficient role to maintain the carbon balance in the environment. Large timber species such as *Shorea albida*, *Gonystylus bancanus*, *Dryobalanops rappa*, *Dactylocladus stenostachys*, *Shorea inequilateralis*, *Platea excelsa*, *Dyera polyphylla*, *Cratoxylum glaucum*, *Combretocarpus rotundatus*, which produce high amount of above ground biomass should be selected for enrichment planting to rehabilitate degraded PSF.

The preservation of PSF is also important for the ecotourism industry. Foreign and local nature lovers are normally attracted to experience and observe the myriad species diversity and the spectacular view of the truly tropical forest environment. As discussed by Lim *et al.*, 2005, activities in ecotourism which involves jungle trekking, farm tours, cultural shows and home stay programmes are beneficial to increase the socio-economy of the local people. Thus, it is important to conserve our PSF not only as a national heritage but serves as a reservoir for carbon storage.

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REFERENCES

Anderson, J.A.R. (1963). The flora structure of the peat swamp forest of Sarawak and Brunei. *Gardens Bulletin Singapore*, 20:131-228.

- Anderson, J.A.R. 1963. The structure and development of the peat swamp forest of Sarawak and Brunei. *Journal Tropical Geogrography*.18.
- Ipor, I.B., Tawan, C.S. and Mustafa, H.S. (2006). Floristic Structure and Tree Species Composition. In F. Abang, and I. Das, (eds.). *The Biodiversity of a Peat Swamp Forest in Sarawak* . Universiti Malaysia Sarawak Publication. pp.61 - 86.
- Lim, H.F., Woon, W.C. and Mohd. Farid, M. (2005). Improving the socio-economic livelihood of indigenous communities via eco-tourism development in Malaysia. In W. Nyoman, R.A. Lingam, S. Chubo. J.K. James, G. Zamri, Bokhari, S. (eds.). *Proceeding International Forestry Seminar: Synergistic Approach to Appropriate Forest Technology for Sustaining Rainforest Ecosystem*. UPM Publication. pp. 137-146.
- Tawan, C.S. and Ipor, I.B. (2007). *Gonystylus bancanus* (Miq.) Kurz. (Ramin): A potential species for rehabilitation of the peat swamp forest in Sarawak. In I.B Ipor, C.S. Tawan, P. Bulan, I. Jusoh, B.A. Fasihuddin and K. Meekiong. (eds.). *Proceedings of Conference on Natural Resource in the Tropics: Development and Commercialization of the Tropical Natural Resources*. Lee Ming Press. Sdn. Bhd. Kuching. Sarawak. Malaysia. pp. 391-394.
- Tawan, C.S. (2006). Plant Diversity and commercial timbers. In F. Abang, and I. Das, (eds.). *The Biodiversity of a Peat Swamp Forest in Sarawak*. Universiti Malaysia Sarawak Publication. pp. 29 - 60.
- Sawal, P. (2003). Threats to Peat Swamp Forests (PSF) of Sarawak Final Report, 42 pp. The Netherlands-Malaysia Project on The sustainable management of peat swamp forests of Sarawak with Special Reference to Ramin (*Gonystylus bancanus*). Sarawak Forestry Department.
- Wood, J.J. 1997. Orchids of Borneo. Vol. 3. *Dendrobium, Dendrochilum and others*. The Sabah Society, Kota Kinabalu and Royal Botanic Gardens Kew, England. 299 pp.
- Yamakura T, Hagihara, A., Sukargjo, S. and Ogawa, H. 1986. Above ground biomass of tropical rainforest stands Indonesia, Borneo. *Vegetatio*, 68. pp. 72-82.

THE POTENTIAL EFFECTS OF NATURALLY LOW RATES OF SECONDARY SEED DISPERSAL, COUPLED WITH A REDUCTION IN DENSITIES OF PRIMARY SEED DISPERSERS ON FOREST TREE SPECIES DIVERSITY IN REGENERATING PEAT SWAMP FOREST

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SUMMARY

A pilot study carried out at the Laboratorium Alam Hutan Gambut (Natural Laboratory for the study of Peat Swamp Forest, LAHG hereafter), observed the extent of secondary seed dispersal and in-situ predation of seeds found on the forest floor. Predation in-situ and removal rates were found to be similar, with little evidence of seed caching, suggesting secondary seed predators do not play an important role in the seed dispersal loop. This is unlike many other tropical seed-fate studies in which removal rates frequently reached 100%, and evidence of caching was high. As such, the role of primary seed dispersers, in dispersal and maintenance of tree species diversity in tropical peat swamp forest (TPSF), is fundamental, yet their population densities are in decline. This study considered alongside a case study of the Mega Rice Project area, which collaborated that tree species diversity in areas burnt in 1997 has declined and become even further reduced after a second large-scale burn in 2002. In light of the previous study, one of the potential reasons for this continued forest diversity decline can be linked to a decrease in the adjacent primary disperser populations. The implications from this indicate therefore, that if this decline continues tropical peat swamp forest may struggle to regenerate naturally in disturbed areas.

Keywords: Seed dispersal, tropical peat swamp forest, regeneration, seed predation, tree species diversity.

INTRODUCTION

Indonesia hosts nearly 30,000 species of vascular plants, of which nearly 60% are endemic. (Butler, 2006). The tropical peat swamp forests (TPSF) of Central Kalimantan are no exception, and whilst a complete classification list is lacking, over 100 tree species have been identified (Shepherd et al., 1997). It has been suggested one of the main reasons for this high biodiversity is the narrow niche specification that species evolved, allowing a very high level of coexistence (Wright, 2002). Coupled with this niche separation, however, is the potentially high level of species vulnerability to local extinction, through a minimal level of habitat disturbance.

The degradation of 1.5 million hectares of peat swamp forest in Central Kalimantan occurred in the mid 1990's owing to the construction of extensive canals, created for the failed Mega Rice Project (PLG) (Schwiethelm, 1998). The canals enabled peat

swamp forest water to be drained from the surrounding areas of TPSF into the Sungai Kahayan and Sungai Sebangau. Furthermore, many of the forested areas adjacent to the canals were clear-felled and the timber sold. The combination of these two processes led to the drying of the peat in the adjacent forested areas with an annual loss of peatland carbon estimated at 545g Cm^{-2} (Page et al 2002). In 1997, this was further exacerbated by the cyclic southern oscillation weather front of El Niño, leading to the fires of 1997 destroying forested areas of over 200,000 Ha in Central Kalimantan (Cane, 1983; Gurhardja et al., 2000). Subsequent fires occurred in 2000 and 2002, and during this time, much of the tree species diversity and over all biodiversity was lost.

In order to determine if biodiversity is in recovery, two aspects are considered in this paper. Firstly, a 5-year study based in the fire-disturbed PLG area monitored the level of tree species diversity from 2001 to 2005, with comparison control study sites located in the Natural Laboratory for Peat Swamp Forest (LAHG) within the Sebangau National Park. This study shows the impact the fire has taken on the fauna, and the rates of recovery of the tree species diversity. Secondly, after disturbance, to determine if the processes necessary for regeneration frequently become altered, as key species may not have been able to adapt to the drastically altered environment. Therefore, establishing the natural sequence for regeneration in an undisturbed site is essential and this knowledge transposed to the area of disturbance. Thus, in the LAHG, a study was conducted to assess secondary seed dispersal by terrestrial seed predators across the forest floor. From this, the relative importance of both primary and secondary seed predators, acting as seed dispersers, in promoting forest regeneration were determined.

Numerous studies have been made of the successional patterns of tropical forest following disturbance, especially in dipterocarp forest of Borneo (Fox, 1976; Whitmore, 1975 and 1984; Woods, 1989; Pinnard and Cropper, 2000). Whitmore (1984) expanded the simple model of forest growth from gap, building and mature phase to a more generalised pattern. If a gap is small then shade tolerant seedlings (particularly climax tree species) already present in the forest structure tend to dominate the gap. If the gaps are larger, shade tolerant tree species mortality is increased or growth is suppressed by fast growing species, which exhibit rapid germination responses at high light levels. These light tolerant pioneer species grow at an accelerated rate, ultimately closing the gap to form a new, lower canopy. Over a longer period of time more shade tolerant trees replace those of the lower canopy, reforming the original tall canopy. Whilst this pattern could be used to describe small areas of disturbance within TPSF of the PLG, the massive spatial gaps generated from the fires of 1997 and 2002 requires a longer term study of tree species diversity to determine the successional pattern in operation there, and whether the forest will be able to recover to a pristine state.

The importance of seed dispersal and seed predation in determining forest dynamics, ecology and regeneration has received much attention since the 1970's (Levey and Benkman, 1999, Nathan and Casagrandi, 2004, Wilson and Traveset, 2000, Stiles, 2000, Webb and Peart, 2001). Further, recent work demands that seed dispersal, along with seed production, predation, germination must be considered, each as sections of the 'seed dispersal loop', in order to understand the crucial factors necessary for continued forest regeneration (Wang and Smith, 2002) (Figure 1).

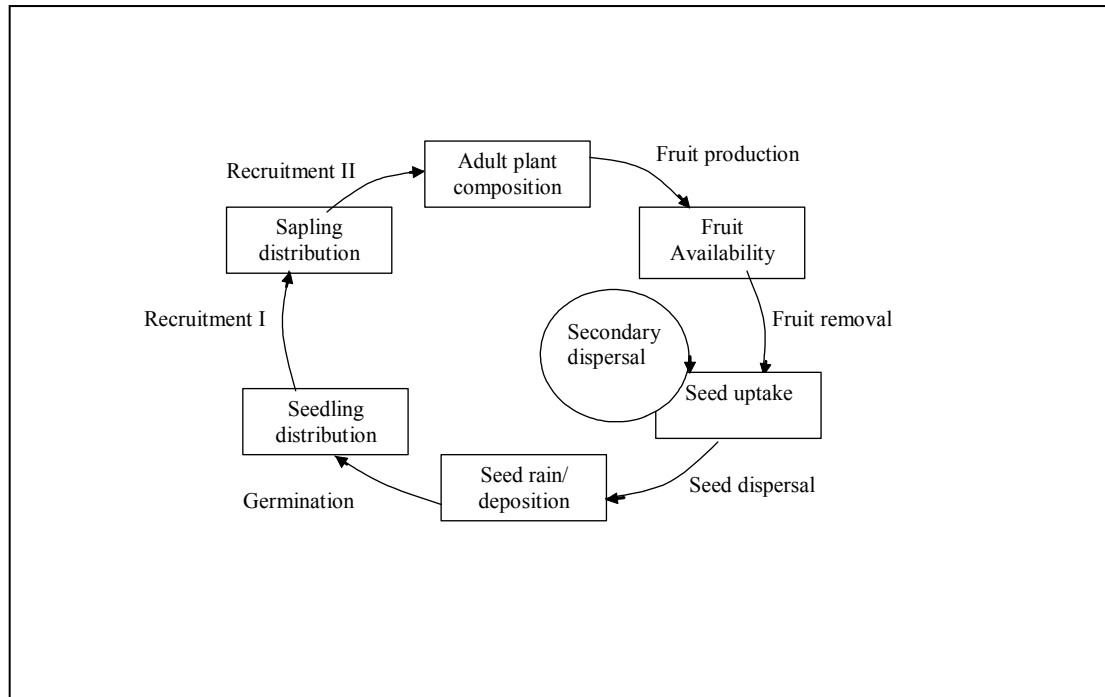


Figure 1 The seed dispersal loop, as proposed by Wang and Smith (2002)

Seed dispersal, defined as the removal of the seeds away from the parent tree, is suggested to be essential for the survival of both seeds (Janzen, 1970) and seedlings (Connell, 1971) in order to avoid density dependent predation and pathogen pressure. Both primary and secondary seed dispersal may be crucial to this dispersal. If either of the disperser guilds were to alter it can then be anticipated the natural forest regeneration would also. Furthermore by determining the importance of secondary dispersers in this seed dispersal loop will weight the importance of the primary disperser in seed dispersal (Forget, 1991).

Early studies suggest large birds and primates are the essential primary dispersers e.g McConkey, 2000, whilst smaller birds and insects are the key secondary dispersers. Work pioneered by Forget (1990) showed, however, that rodents cached 70% of foraged seeds, dropped from the parent tree either by windfall or primary dispersers. Then a significant number of these caches were forgotten, leaving seeds dispersed and protected. Several studies (e.g. Wenny, 2000), across three continents in different evolutionary lines of seed predators (Forget and Van der Wall, 2001) found similar results, thus establishing small mammals as seed dispersers, rather than just seed predators (Jansen and Forget, 2001).

Little work has been done in the TPSF of Central Kalimantan, Indonesia, on the role of seed predators as seed dispersers, and much of the evidence is anecdotal (Corlett, 1998). Within this habitat there are many primary dispersers including tree shrews, pigs, deer, rodents, orang-utans, macaques, of which gibbons and hornbills are considered amongst the most important (Corlett, 1998). Where orang-utans and gibbons coexist, it is thought they are both important in primary seed dispersal, both for local/macro dispersal through spitting and dropping seeds during feeding bouts in the parent tree and on a larger scale by excreting the seeds in their faeces.

METHODS

Regeneration studies

In 1999 a single belt transect was established in the burnt area of the PLG, to measure diversity, density and regeneration through seedling and sapling counts. For the purpose of this study only adult trees over $>6\text{cm}$ dbh were analysed. The transect was surveyed in 1999, 2001, 2003, 2005, but not in 2002 as the area was burning and considered unsafe to survey. The study was expanded in 2001 to include saplings over 1 m in height with a dbh $>2\text{ cm}$. This enabled the identification of the key tree species that were regenerating after the disturbance, and thus the regeneration patterns could be established.

Dispersal study

A study was carried out in the LAHG to determine the activity of secondary seed predators: to compare the removal rates of seeds from beneath seed shadow of the parent tree to the level of in situ predation. More specifically, this study focused on seed fate after the fruit had been primarily displaced onto the forest floor during a feeding bout by an orang-utan. Three tree species were selected, of which, all the fruit were known to be predated upon by orang-utans and gibbons, in high fruiting abundance and showed different morphological characteristics (Appendix 1). The species chosen were *Parartocarpus venenosus* (Moraceae), *Eugenia grandifolia* (Myrtaceae) and *Blumeodendron tokbrai* (Euphorbiaceae).

Of the seeds collected, half were used to create non-threaded 'natural' sets, to give natural predation rate (results not discussed here), and half to create sets of threaded seeds - using white cotton and a unique identification tag, to establish seed-fate (Forget, 1990). After threading the sets were set around the parent tree (Figure 2).

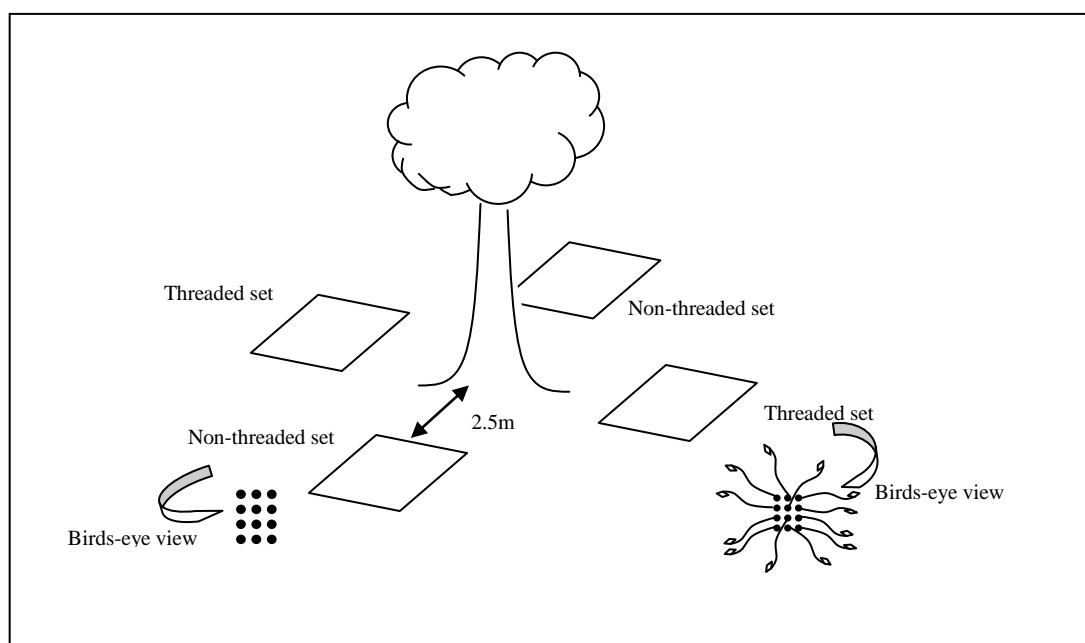


Figure 2 Diagram of the layout of threaded and non-threaded sets around the parent tree. (Diagram showing 12 seeds per set is in accordance with the abundance of *Eugenia* and *Blumeodendron*. For *Paratocarpus* seed sets would each contain 25 seeds all at a radius of 2.5 m from the parent tree)

Each setted parent tree was checked every three days for fifteen days and recordings of seed movement noted (Table 1). When a threaded seed had been removed from a set, a search was conducted for the thread and ID tag within a 10m radius from the tree. At the site of recovery (deposit point) the seed fate was recorded as consumed, cached or abandoned.

Set type	Observation	Recorded as	Assumptions	Validity of assumptions
Threaded	Seed no longer in set, thread remaining	Vertebrate predated in-situ	Before removal there were no insects in fruit	Work in this study showed after insect predation, vertebrate predation appeared much lower.
Threaded	Seed and thread no longer in set	Vertebrate removal	Before removal there were no insects in fruit	Work in this study showed after insect predation, vertebrate predation appeared much lower.
Threaded	Infested with insects	Insect predated	Infestation by insect prevented seed from germinating	Opening of infested seeds revealed extensive decay

Table 1 Description of the type of recordings made when inspecting the seed sets, plus associated assumptions.

RESULTS

Regeneration plots

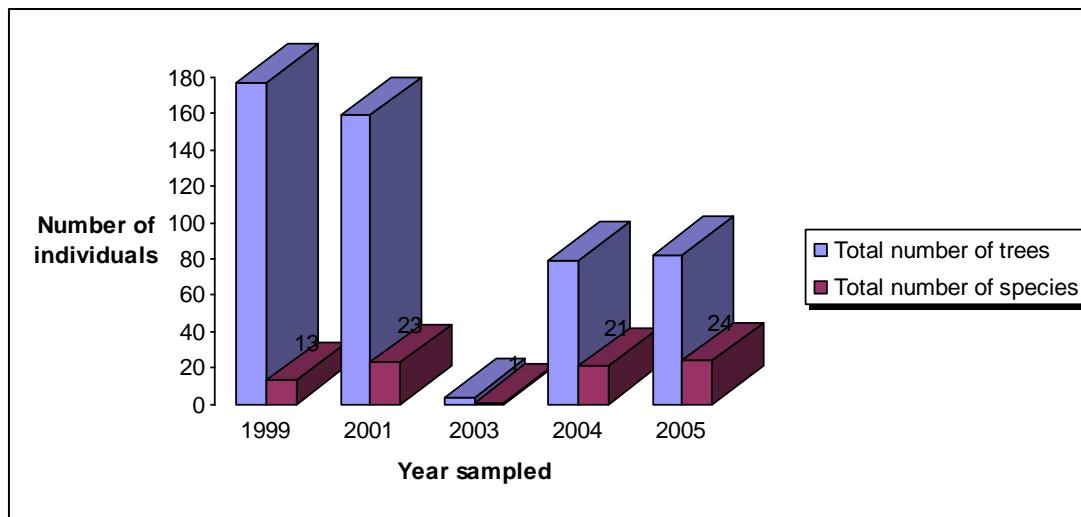


Figure 3 Graph showing the number of individuals and species recorded over a 6-year period in the PLG Block C area, Central Kalimantan, Indonesia.

After the second burn of 2002 the number of adult individual trees in the transect was found to have decreased dramatically (Figure 3). The sample first taken in 1999 only took into account trees > 6cm dbh, but the recovery rate in 1999, two years after the initial burn, was double the recovery rate observed in 2004, two years after the second

burn. It should be noted that improved accuracy in species identification may have contributed to the slightly higher tree species diversity in 2004 and 2005. To avoid this variable, newer species were classified and group for analysis to genus rather than species.

The dominant tree genera pre-2002 were determined to be of the Santiria sp. and Sterculia sp groups, with more commercially interesting trees included Shorea sp, Dyera sp, Eugenia sp. Gonystylus bancanus appearing two years following the 1997 fires. Post 2002 re-burnt transect species diversity changed dramatically with Elaeocarpus sp, Syzygium sp. and Ilex sp becoming more dominant. Of the trees >6cm dbh, only Combretocarpus rotundus was found to be viable. Adult trees of C. rotundatus (tumih) had been found to have survived both fires, but sapling numbers (2 cm – 6 cm dbh) of this wind dispersed species were low in number.

Following the second burn overall tree species diversity for the emerging species was found to have decreased even 3 years after the second fires (Figure 3). Therefore the removal from the habitat of potential fruiting species such as Santiria sp. and Dyera sp. which are known to be orang utan food would ultimately have a direct impact on the remaining frugivore species in the area.

Determining seed-fate

Eaten in-situ versus removed

The results for the predation in situ by vertebrates versus their removal rate was analysed using a pair-wise t-test. Unlike many other studies, high levels of in situ predation by vertebrates were observed, such that there was no significant difference between the levels of predation in-situ versus the removal rate (Table 2).

Tree sp.	No. of seeds predated in-situ	No. of seeds removed	p-value
Parartocarpus	13	11	0.351
Eugenia	7	6	0.791
Blumeodendron	10	6	0.726

Table 2 Summed levels of predation in-situ of vertebrates, versus removal rates. The p-values of the paired t-test for predation in-situ versus removal rates are also given.

Recovery of removed seeds

Seed searches for the removed threaded seeds proved successful with a recovery rate of over 70%. However, of the removals, 38% of the seeds were removed less than 1m from the set. Distances of recovery from the source set ranged only up to 8.4m. A larder-ward cache (with multiple seeds) was discovered in Eugenia sp. and a scatter-ward cache (with single seed) was discovered in Parartocarpus sp. Of the consumed seeds, threads were discovered, taken down holes and lodged up trees branches.

DISCUSSION

The secondary seed dispersal study found no significant difference between the predation rates of vertebrates eating the seeds in-situ and those removing them (Table 2). Conversely, other studies have shown very high removal rates of seeds from under the parent tree, with 70-100% disappearing within 3 days (Forget and Milleron, 1991, Yasuda, 2000). Very few studies have recorded predation in situ, and those which have done so usually record much lower predation in situ than removal rates compared to the present study (Wenny, 2000).

Reasons for the different findings of this study may be the unusual living environment created by the peat swamp forest within which terrestrial animals are often well-protected and hidden from view or, at least, near to vegetation cover from above. Thus there is less need for the seed predators to remove the seeds to an area of high vegetation density to consume the seeds in safety, previously observed in other studies (Forget, 1990; Forget and Milleron, 1991). A second possibility for the low removal rates is that, in other studies, high removal rates were associated with a high caching rate, and caching would occur at a particular microhabitat (Jordano, 2000). Reduced caching may be a feature of the environment of the peat swamp, particularly where extensive flooding occurs annually, in turn destroying any caches. It should be noted this study was carried out only during the dry season. Caching can be seasonally affected, and caches in this forest may be formed at other times during the year. As such due to the limited temporal and spatial scale of this study, it cannot be assumed the animals in this area do not cache at all.

These results highlight that natural regeneration does not always proceed either at speed, or towards its previous end point following repeated, high levels of disturbance. Work across many tropical areas show similar findings that after high levels of disturbance, forest ecology is affected to such an extent that normal regeneration may not proceed. Once an area had been opened up through deforestation, previous stands of Dipterocarp pioneer species have a propensity to form monostands (Fox, 1976). Furthermore, tropical rainforests are one of the most bio-diverse ecosystems in the world, and as such, some species are found at very low density. A survey in Los Tuxtlas Mexico, covering 20 Ha, found more than 50% of tree species had a frequency of only 1 (Alvarez-Buylla et al., 1996). Although after a forest has been regenerating for 40 years, post disturbance it has been shown key forest features; such as above-ground biomass and tree density can return, and even species richness. Yet, these low-density late-successional species may still be absent, and the species composition may be quite unlike that before the disturbance (Aide et al., 2000). It is thus essential to understand the diversity and frequency of species in natural forest, in addition to the natural regeneration processes, which occurs in the TPSF environment.

Forest fires have been found to greatly restrict the regeneration of an area, through the deterioration of seed banks (Uhl et al., 2000), reduction in the plants that normally resprout post disturbance, removal of parent trees and a decline in soil fertility owing to loss of organic material. The regeneration capabilities of burnt primary forest, rather than logged forest, have previously been found to be good (Woods, 1989). The results of the 1999 survey support this, however, resurveys of the area after the second burn of 2002 show a much greater reduction in species diversity and stand density

suggesting repeated high levels of disturbance may prevent natural regeneration occurring.

The similarity of TPSF at the LAGH and at the PLG (before its extreme disturbance) allows the conclusions of seed dispersal study to be compared with the findings of the PLG study. Although the seed dispersal study is only a preliminary work into one section of the seed dispersal loop, it already highlights that in this unique ecosystem, it is not possible to simply extrapolate from other studies elsewhere, despite apparent convergent evolution witnessed across the globe in caching and seed dispersal by secondary seed predators. This study suggests once fruit reaches the forest floor, movement occurs only over short distances and removal from the parent tree seed shadow is rare. Instead, most seeds once dropped suffer predation or germinate on the floor, where they fall.

In this study all the fruit considered were adapted to vertebrate dispersal and were known food species. If secondary dispersal does not occur, this suggests that the most abundant primary dispersers, in this instance orang-utans and gibbons must play a much more crucial role in seed dispersal compared to other known forest types. As such, a reduction of primary vertebrate disperser would in turn reduce the dispersal ability of the tree species and ultimately the numbers of adult individuals of those tree species. Therefore with a much reduced habitat to support such large herbivores population numbers would surely fall. It should be acknowledged that seed dispersal may also be achieved through other means, for example, abiotic (wind or water/rain splash) (Van der Wall et al., 2004, however, this study focused on only tree species with a preference for vertebrate dispersal.

The spatial distances covered by the primates illustrates how large-scale distribution of tree species may occur, though Van Shaik et al. (1993) noted that few dipterocarp fruits could be successfully dispersed further than 40m, in primary forest. At the LAGH the orang utan density has decreased by almost half in the last 5 years. (Husson pers com). In 1996 orang utan numbers at forest edge, bordering the area of the LAGH, were found to be 2.01 individuals per km² this dropped to 0.39 individuals per km² in 1999 post fires and has now been levelled in the last 4 years at 1.22 individuals per km² (Husson et al., 2005). The PLG area has only once been surveyed for orang utan density, in 1999, and was found to be 0.42 individuals per km², similar to that of the LAGH at that time. It could be extrapolated then that the orang utan density at the PLG should still mimic that of the LAGH but since the fires in 1997 and 2002, there is anecdotal evidence (per obs) to suggest that orang utan and gibbon densities has since dropped much lower than those recorded in LAGH. This would be in agreement with numerous other studies that state that high levels of disturbance has detrimental effects on many of the floral and faunal species including the orang utan (*Pongo pygmaeus*) (MacKinnon, 1974; Kuuluvainen, 1988; Huth et al., 1997; Uuttera et al., 2000).

Connell and Slayter (1977) stated that tropical rainforest maintains such a high level of diversity through a constant state of stress and flux, created by persistent low level disturbance. Though this may be true for low levels of disturbance, the study at the PLG shows that after repeated high levels of disturbance, TPSF loses a large percentage of its tree individuals and tree species. Furthermore, this work gives no indication the forest and species composition are in recovery. Whilst this study, at present, has not been conducted over a sufficiently long period of time to determine if

any forest recovery is possible, we can draw on other studies to ascertain how likely future recovery is. The initial work based at the LAHG suggests that in TPSF secondary seed dispersers play a minor role in facilitating tree species seed dispersal. As such, this shifts this crucial role in supporting natural forest regeneration to the dominant primary dispersers, the orang utans and gibbons. However, if their densities have truly reduced at the PLG, as is suspected, this may define one crucial regeneration barrier, preventing the fire-disturbed TPSF returning to its former state through natural regeneration alone.

REFERENCES

- Aide, T., Zimmerman, J., Pascarella, J., Rivera, L. and Marcano-Vega, H. (2000) Forest restoration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. *Restoration Ecology*, 8: 328-338.
- Alvarez-Buylla, E.R., Garcia-Barrios, R., Lara-Moreno, C. and Martinez-Ramos, M., (1996) Demographic and genetic models in conservation biology: applications and perspectives for tropical rainforest. *Annual Review of Ecological Systems*, 27: 387-421.
- Butler, R. (2006) Tropical rainforest: Indonesia. Sourced from: www.Mongabay.com
- Cane, M.A. (1983) Oceanographic events during El Niño. *Science*, 222: 1189-1195.
- Connell J.H and Slatyer R.O (1977) Mechanisms of Succession in Natural Communities and Their Role in Community Stability and Organization, *American Naturalist*, 111: 1119-1144.
- Corlett, R. T. (1998) Frugivory and seed dispersal by vertebrates in the Oriental (Indomalaysian) Region. *Biological Reviews*, 73: 413-448.
- Forget, P.M. (1990) Seed-dispersal of *Vouacapoua americana* (Caesalpinaceae) by caviomorph rodents in French Guiana. *Journal of Tropical Ecology*, 6: 659-468.
- Forget, P.M. (1991) Scatter-hoarding of *Astrocaryum paramaca* by *Proechimys* in French Guiana: Comparison with *Myoprocta exilis*. *Tropical Ecology*, 32: 155-167.
- Forget, P.M. and Milleron, T. (1991) Evidence for secondary seed dispersal by rodents in Panama. *Oecologia*, 87: 596-599.
- Forget, P.M. and Vander Wall, S. B. (2001) Scatter-hoarding rodents and marsupials: convergent evolution on diverging continents. *Trends in Ecology and Evolution*, 16: 65-67.
- Fox, J.E.D. (1976) Constraints on the natural regeneration of tropical moist forest. *Forest Ecology and Management*, 1: 37-65.
- Guhardja, E., Fatani, M., Suitisna, M., Nori, T., Ohta, S. (2000) Rainforest ecosystems of East Kalimantan. Springer Verlag, Tokyo, 331 pp.
- Husson, S., McLardy, C., Morrogh-Bernard, H., D'Arcy, L.J and Limin, S. (2005) Orang utan population changes. In: S. Husson (Ed.), *OuTrop annual report for 2005*.
- Huth, A., Ditzer, T. and Bossel, H. (1997) Rainforest growth model FORMIX3: A tool for forest management planning towards sustainability. Model development and case study for Dermakot Reserve in Sabah, Malaysia. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn, 78 pp.
- Jansen, P. A. and Forget, P. (2001) Scatter-hoarding rodents and tree regeneration. In: F. Bongers, P. Forget, P. Charles-Dominique and M. Théry, M. (Eds.), *Dynamics and Plant-Animal Interactions in a Neotropical Rainforest*. pp. 275-288.

- Janzen, D.H (1970) Herbivores and the number of tree species in tropical forest. *American Naturalist* 104:501-528.
- Jordano, P. (2000) Fruits and frugivory. In: M. Fenner (Ed.), *Seeds: The ecology of regeneration in plant communities*. 2nd edn. CABI Publishing UK.
- Kuuluvainen, T. (1988) Troopisen sademetsän arkkitehuuri. Summary: the architecture of topical rainforests- relationships between structure and function. *Silva Carelica*, 12: 41-56.
- Levey, D. J. and Benkman, C. W. (1999) Fruit-seed disperser interactions: timely insights from a long-term perspective. *Trends in Ecology and Evolution*, 14: 41-42.
- MacKinnon, J. (1974) The behaviour and ecology of wild orang utans (*Pongo Pymaeus*) *Animal behaviour*, 22: 3-74.
- McConkey, K, R. (2000) Primary seed shadow generated by gibbons in the rainforests of Barito Ulu, Central Borneo. *American Journal of Primatology*, 52: 13-29.
- Nathan, R. and Casagrandi, R. (2004) A simple mechanistic model of seed dispersal, predation and plant establishment: Janzen-Connell and beyond. *Journal of Ecology*, 92: 733-746.
- Page, S.E., Siegert, F., Rieley, J.O., Boehm, H-D.V., Adi Jaya and Suwido Limin (2002) The amount of carbon released from peat and forest fires in Indonesia in 1997. *Nature*, 420: 61-65.
- Pinnard, M.A. and Cropper, W.P. (2000) Simulated effects of logging on carbon storage in dipterocarp forest. *Journal of Applied Ecology*, 37: 267-283.
- Schweithelm, J. (1998) The fire this time. An over view of Indonesia's forest fires in 1997/98. Indonesian discussion paper WWF Jakarta.
- Shepherd, P.A, Rieley, J.O and Page, S.E (1997) The relationship between forest vegetation and peat characteristics in upper catchment of Sungai Sebangau, Central Kalimantan. In: J.O Rieley and S.E Page (Eds), *Tropical Peatlands*. Samara Publishing Ltd, Cardigan U.K.
- Stiles, E. W. (2000) Animals as seed dispersers. In: M. Fenner (Ed.), *Seeds: The ecology of regeneration in plant communities*. 2nd ed. CABI Publishing UK.
- Uhl, C. and Kauffman, J.B (1990) Deforestation, fire susceptibility and potential rainforest tree responses to fire in the Eastern Amazon. *Ecology*, 7: 437-449.
- Uttera, J., Tokola, T. and Maltamo, M. (2000) Differences in the structure of primary and managed forests in East Kalimantan, Indonesia. *Forest Ecology and Management*, 129: 63-74.
- Van der Wall, S.B., Forget, P.M., Lambert J.E. and Hulme, P.E. (2004) Seed fate pathways: Filling the gap between parent and offspring. In: P.M. Forget, J.E. Lambert, P.E. Hulme and S.B. Van der Wall (Eds.), *Seed Fate: predation and secondary dispersal*. CAB International Wallingford, Oxfordshire. pp. 1-8.
- Van Schaik, C.P., Terborgh, J.W. and Wright, S. J. (1993) The Phenology of Tropical forest: Adaptive significance and consequences for Primary consumers. *Annual Review of Ecological Systematics*, 24: 353-377.
- Wang, B. C. and Smith, T. B. (2002) Closing the seed dispersal loop. *Trends in Ecology and Evolution*, 17: 379-385.
- Webb, C. O. and Peart, D. R. (2001) High seed dispersal rates in faunally intact tropical rainforest: theoretical and conservation implications. *Ecological Letters*, 4: 491-499.
- Wenny, D. G. (2000) Seed dispersal, seed predation and the seedling recruitment of a neotropical montane tree. *Ecological Monographs*, 70: 331-351.

- Whitmore, T.C. (1975) Tropical rainforests of the Far East, Clarendon Press, Oxford, U.K
- Whitmore, T.C. (1984) Tropical rainforests of the Far East, 2nd Edn Clarendon Press, Oxford U.K.
- Wilson, M. F. and Traveset, A. (2000) Ecology of seed dispersal. In: M. Fenner (Ed.) Seeds: The ecology of regeneration in plant communities. 2nd ed. CABI Publishing.
- Woods, P. (1989) Effects of logging, drought and Fire on Structure and composition of Tropical Forest in Sabah, Malaysia. *Biotropica* 21(4): 290-298.
- Wright, S.J. (2002) Plant diversity in tropical forests: a review of mechanisms of species coexistence. *Oecologia*, 130: 1-14.
- Yasuda, M. (2000) Evidence for food hoarding behaviour in terrestrial rodents in Pasoh Forest Reserve, a Malaysian lowland rain forest. *Journal of Tropical Forest Science*, 12: 164-173.

APPENDIX

Details of the fruiting tree species selected for the study.

Tree Species	<i>Parartocarpus venenosus</i>	<i>Eugenia grandifolia</i>	<i>Blumeodendron tokbrai</i>
Fruit characteristics	Large fruit with prickly ectocarp and thick layer of soft flesh. Medium sized seeds dispersed throughout flesh, ranging from 2-18 per fruit.	Small fruit with soft flesh, with 4 small seeds at centre.	Tough thick ectocarp, with thin layer of flesh surrounding 3 large seeds with thick testa.
Seed characteristics on the forest floor	Flesh fell away as fruit hit the floor, leaving exposed individual seeds.	Seeds remained enclosed in flesh.	Seeds remained enclosed in ectocarp
Approximate mean no. fruit dislodged after an orang-utan feeding event	100	50	50
No. of tree individuals in the study	4	5 (though with total of 6 seed data sets, as one tree was time replicated)	5
Number of sample sets per tree	4	4	4
Exact number of seeds per set	25	12	12

N.B. Although some of the seeds remain inside the fruit during their potential dispersal, for the purposes of this study they are always be referred to as seeds, not as diaspores.

UNDERSTANDING THE GROWTH STRATEGIES OF TROPICAL PEAT SWAMP FOREST TREE SPECIES: ESTABLISHING POTENTIAL RESTORATION TOOLS

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SUMMARY

In October 2005 the Sabangau Seedling Nursery (SSN) was established at the Natural Laboratory of Peat Swamp Forest, Central Kalimantan. The SSN was designed to house the Seedling Growth-Strategy experiment; to increase understanding of physiological and morphological growth characteristics of tropical peat swamp forest (TPSF) tree species. Seeds were collected from the forest and cultivated in the SSN, which recreates natural forest conditions. Seed size and weight, germination rates, optimum germination media, relative growth rates, net assimilation rate, leaf area ratio and root-to-shoot partitioning have been established for over 32 native tree species during the first 18 months of study. This paper outlines the methods under which this study has been conducted, gives an example of some of the data acquired and discusses the applications of such a study. Crucially, the data from this study highlights tree species which potentially have the necessary characteristics to become a restorative tool as seedling transplants in degraded areas.

Keywords: seedlings, relative growth rate, seeds, peatlands, regeneration.

INTRODUCTION

Tropical peatlands provide essential global, regional and local environmental services (Page *et al.*, 2002; Lyons, 2003), with high floral biodiversity. Over 300 tree species have been identified in the Sabangau catchment alone (Husson, personal communication). Indonesia supports the largest expanse of tropical peatlands in the world (Page *et al.*, 1999); however, vast areas of these peatlands are degraded, with estimated deforestation rates of 1.7% per year (Hooijer *et al.*, 2006). As this precious ecosystem is lost, the benefits of these environmental services are reversed (Page *et al.*, 2002; Smith, 2003). Subsequent to degradation and disturbance, peatlands frequently lose or reduce their ability to regenerate (D'Arcy and Graham, 2006). The peat oxidizes and erodes, and its composition and structure alters, and invasive species can come to dominate (Muhamad and Rieley 2001). Consequently, active restoration becomes the most necessary option for recovery of the ecosystem.

Seedling transplants are an important and potentially successful restorative tool, though 'most restoration groups in tropical forest areas are still in the initial stages of determining which species or species combination are more suitable to restore degraded or abandoned pasturelands' (Florentine and Westbrooke, 2004 b). Degraded

ecosystems are frequently under extreme environmental conditions, thus appropriate transplant species need to be carefully considered. The physiological and morphological growth strategies must be understood, to determine favoured habitats (Hoffman and Franco, 2003) and indicate the seedlings' ability as pioneer species (Stocky and Hunt, 1994). In order to increase understanding of native TPSF tree species and investigate potential transplant species for forest restoration of TPSF, the Seedling Growth-strategies Project (SGP) was designed. Through cultivating and studying native tree species seedlings in a natural-environment seedling nursery, one can determine the growth strategies employed by each species. 'Growth strategies' can be considered in the form of: $RGR = NAR \times LAR$

where RGR is relative growth rate; the rate at which dry matter is produced, NAR is net assimilation rate, the physiological component of RGR, showing the rate of dry matter production per unit area of leaf, and LAR is leaf area ratio, the morphological component of RGR, the quotient of total leaf area to total plant dry weight, and R:S, the root-to-shoot partitioning, the ratio between root and shoot mean RGR. Through the SGP, native TPSF tree species growth rates and morphological and physiological features can be determined, increasing forest ecology understanding, and highlighting tree species which might be used as transplant seedlings, becoming important restorative tools.

METHODS

Study site

The 'Sabangau Seedling Nursery' (SSN) was constructed at the Natural Laboratory of Peat Swamp Forest (NL), an area of protected TPSF in the upper catchment of the Sabangau River, Central Kalimantan, Indonesia. The area of forest is relatively undisturbed, though adjacent to this, between the forest and the river, is a heavily disturbed sedge area, approx. 1.5km x 30km.

Sebangau Seedling Nursery – Natural Conditions

The SSN was constructed in October 2005, to replicate natural forest conditions whilst still supporting seedling life, such that seedling growth rates would reflect those in the forest. The SSN was constructed *within* the NL forest, to follow environmental conditions. Local sterilized peat was used as the growth medium, and analyzed to ensure similarity to peat in the NL. Permeable roofing meant seedlings experienced natural rain-fall patterns, supplemented with additional watering when needed. 70% shade roofing was installed to replicate the light conditions of the broken-canopy forest.



Figure 1 SSN, constructed within the forest of the NL (left), inside the SSN (right).

Cultivating seedlings

Fruit and seeds were collected from the mixed peat swamp forest, forest edge and sedge habitats in the NL, 2-3 times per week. Tree position, date and maximum seed distance from the tree were recorded, showing tree canopy size, position within the different forest types and phenology. Seeds were brought back to the SSN and, with expert local assistance; the seeds were classified into species, stage of maturity and length of time spent on the forest floor. Ten seeds from each classification group were photographed and measured for length, wet weight and dry weight. The remaining seeds were transferred to germination trays, and germination rates recorded on different germination media (water, moist leaves or moist peat). Once germinated, the seedlings were tagged and transferred to separate grow-bags. Seedling heights were measured twice weekly, and ten seedlings were harvested after 1, 2, 3, 5, 10 and 20 weeks.

During harvesting, fresh and dry weights of the leaves, stems, and coarse and fine roots were measured, as well as total leaf area and maximum root length. The seedlings were photographed when whole and separated. Each species and classification types' growth rates were calculated using both classical analysis, with Fisher's formula (Hoffman and Poorter, 2002, software from Hunt *et al.*, 2002), and combined classical-functional analysis, RGR plotted over time (Hunt and Cornelissen, 1997). Root-shoot biomass partitioning, NAR and LAR were also calculated (Hoffman and Franco, 2003; Hunt and Cornelissen, 1997). Data were compiled into a purpose-built, professionally-designed database, design sponsored by Pulsar Business Programs.

RESULTS

Over 40 tree species have been studied (appendix 1), for seed weight variation and germination. Of these, 32 species have been grown and harvested to the 20wk growth-period. Data collected allows analysis of: RGR within the same tree species for ripe versus unripe seeds and for length of time spent on the forest floor (these factors are rarely considered in RGR studies but the data are showing significantly different RGR across these classifications). Further, the RGR of different tree species, RGR in relation to SW and final seedling biomass, NAR, LAR and R:S, explaining the morphological and physiological components of RGR, indicating the growth strategy employed by each species, and increasing understanding of fruiting patterns, abundance and germination.

This paper provides an overview of the methodology and applications for this research. Therefore, the results presented here only cover RGR across ten tree species and their relationship to seed weight. The ten species chosen were from the same classification group, 'ripe, 4-7 days on the forest floor' (differences are being observed across the RGRs of same species, but with different classifications regarding maturity and time on the forest floor). Further discussion of the data-set will be published at a later date.

RGR across tree species

RGR is displayed over time for ten different species found in TPSF (Fig. 2), their maximum RGR's range over a five-fold difference (Table 1). Of interest, the mean RGR is three times higher than a similar study of South American tropical tree species (Hoffman and Franco, 2003).

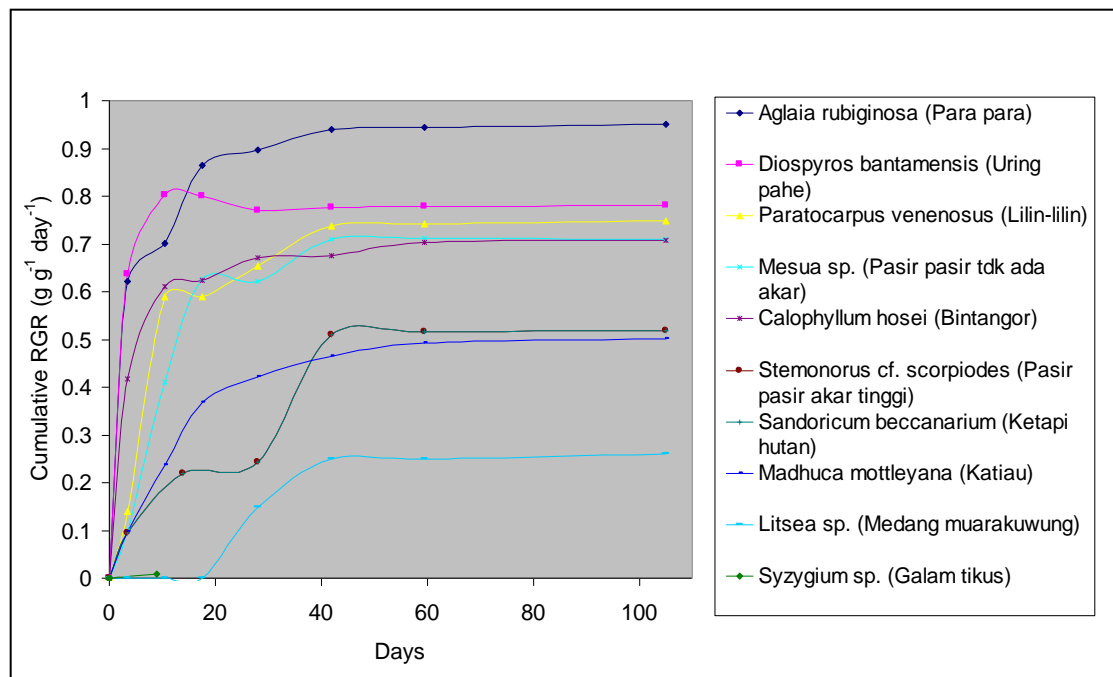


Figure 2 The cumulative RGRs of ten TPSF tree species seedlings over time, each data point represents the average RGR across ten seedling individuals.

Family	Genus	Species	Local name	SW	Max RGR
Myrtaceae	Syzygium	sp. 5 cf. E.spicata	Galam tikus	0.10	0.008
Sapotaceae	Madhuca	mottleyana	Katiau	0.28	0.139
Lauraceae	Litsea	sp. 1 cf. resinosa	Medang muarakuwung	0.24	0.149
Meliaceae	Sandoricum	beccanarium	Katapi hutan	0.28	0.265
Icacinaceae	Stemonorus	cf. scorpiodes	Pasir pasir akar tinggi	0.75	0.287
Clusiaceae	Mesua	sp. 1	Pasir pasir tdk ada akar	0.64	0.311
Clusiaceae	Calophyllum	hosei	Bintangor	0.67	0.418
Moraceae	Paratocarpus	venenosus	Lilin-lilin	0.84	0.450
Meliaceae	Aglaia	rubiginosa	Para para	5.00	0.622
Ebenaceae	Diospyros	bantamensis	Uring pahe	0.80	0.636

Table 1 The seed weights (averaged across ten seeds for each value) and maximum RGRs (attained through calculating RGR between adjacent harvest events, each harvest event containing ten seedlings) for ten TPSF tree species.

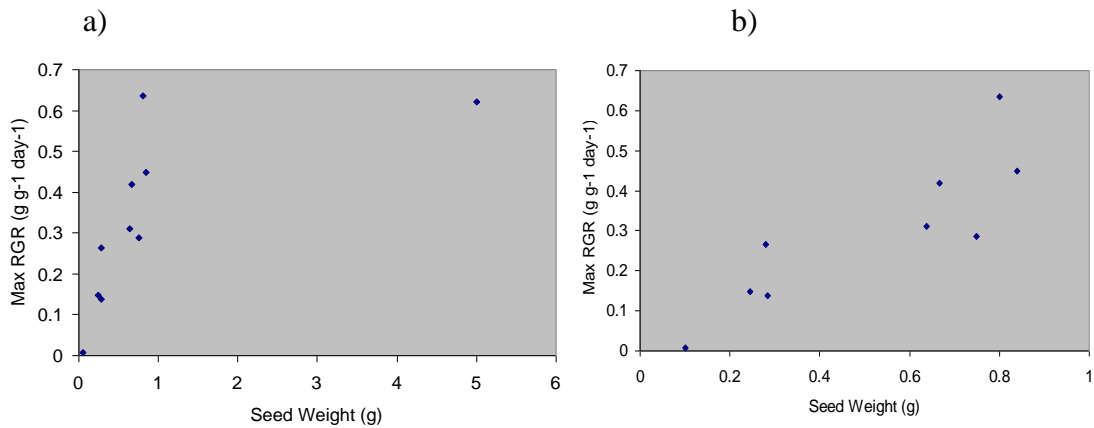


Figure 3 Showing SW correlated to max RGR for all ten TPSF tree species represented. a) showing all ten species b) showing nine species, excluding *Agليا rubignosa*, as an outlier due to large seed size.

RGR in relation to seed size

When the RGR of the ten different species is compared to seed weight, there is a positive correlation, $p = 0.05$ (Pearson's correlation), however, when the outlier of *Agليا rubignosa* is excluded, p -value = 0.003 (fig. 3).

DISCUSSION

Certain assumptions can be put forward about the ecosystem's trees' growth strategies based on present data, however, only 32 tree species of the over 200 hundred have been studied. This is because of time and space restrictions, associated with the nursery and work-load, but equally to unpredictable, non-annual phenology of the tree species. As such, this project will continue until, at least, April 2009, by which time a greater percentage of the tree species can be studied, allowing a more holistic understanding of the growth strategies associated with TPSF trees.

Despite the relatively small data-set in relation to the number of tree species still left to study, already certain features and trends are emerging, highlighting some unusual aspects of TPSF forest ecology. The average RGR of the ten species shown (the species included were effectively selected at random, and not in relation to the species' RGR) was over three times greater than a similar study in South American tropical rain forest. If this trend persists across all species, it may highlight a necessary survival technique associated only with this forest type. The high average RGR may be necessary due to the natural flooding conditions of TPSF; seedlings, upon germination, must rise above the flood level rapidly to promote survival. Alternately, due to peat's structure providing low stability for tall trees, it can be observed the canopy is often low, as the peat is not deep enough to create secure rooting for tall trees, and the canopy is often broken due to high tree fall rate (pers. obs). This may lead to more tree species being adapted towards higher regeneration rates, as gaps occur more frequently and light penetrates more easily, compared to a tall, closed-canopy forest as found in the Neotropics (Hoffman and Franco, 2003). However, for this theory to fully tested, growth rates and strategies of more mature saplings and young trees would need to be considered, as some species can alter growth strategies through different stages of growth, moving from shade-tolerant to sun-loving.

A second feature to emerge from this preliminary data-set is that seed weight correlates positively to RGR (fig.3). A similar study in the Neotropics found only low correlation between seed weight and RGR, however other studies have observed a negative correlation between seed-weight and RGR, in Britain (Hunt and Cornelissen, 1997), and similarly in the Mediterranean (Maranon and Grubb, 1993). This suggests fast-growing seedlings (pioneer species) can be small-seeded in these ecosystems, requiring little by means of early support from the seeds reserves. As the reverse is observed in this ecosystem, it suggests that fast-growing seedlings require a large reserve to achieve this, and small-seeded seedlings can only achieve low growth rates. This may be due to the naturally low nutrient availability of TPSF, such that, high RGR in seedlings can only be achieved through seed reserves.

Future work

With a more complete knowledge of TPSF tree species, the growth strategies can be related to habitat choice and potential ability to tolerate degraded zones. With this in mind, a brief overview of future applications of this work is given below:

- To create an electronic book, providing access to data collected, acting as both an identification guide, sorely needed for the tree species of this ecosystem, and include photos of seeds, seedlings, trees and fruit for each classification, with identifying features described, RGRs, and other morphological and physiological characteristics.
- Much can be learnt by correlating the data collected in this project to forest field-observations: Habitat preference can be established through setting-up seedling plots in different forest zones, under different levels of disturbance, and monitoring species abundance, recruitment and growth. These data can then be correlated to the physiological and morphological data attained from the nursery, showing the key growth-strategies necessary for the different forest environments, when the seedlings are at early growth stages. It is beyond the confines of this study to consider growth-strategies employed by sapling and young-trees, which can be different to their respective seedling strategies, but the field data can be used to reveal environmental tolerances of species in later maturity.
- By combining the data from the nursery with the field-observations, we can then begin to understand the governing growth strategies which allow species to tolerate degraded, high disturbance zones and to achieve successful cultivation in a nursery environment. Thus indicating potential transplant species to be cultivated and trialed in the adjacent degraded area, to determine success. These data would then become an important restorative tool for the TPSF, highlighting which species could become good pioneer species, able to tolerate the difficult degraded environment. Then, with these 'nurse species' creating a closed canopy, the data from the SSN again can highlight mid-successional species which can be cultivated easily and can be introduced beneath the new canopy, raising biodiversity, and re-creating natural forest conditions.

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REFERENCES

- D'Arcy, L. J. and Graham, L. L. B. (2006) The potential effects of naturally low rates of secondary seed dispersal, coupled with a reduction in densities of primary seed dispersers on forest tree species diversity in regenerating peat swamp forest. In: Rieley, J.O., Limin, S.H. and Jaya, A. *Problems of Biodiversity, Fire, Poverty and Water Management. Proceedings of the International Symposium and Workshop on Tropical Peatland* Palangka Raya, Central Kalimantan, Indonesia, 20-24 September 2005, EU RESTORPEAT Partnership, University of Palangka Raya, Indonesia and Alterra, Wageningen University and Research Centre, The Netherlands. Pp. 110-121. ISBN: 90327-0354-4.
- Florentine, S. and Westbrooke, M. (2004b) Restoration on abandoned tropical pasturelands – do we know enough? *Journal for Nature Conservation* 12, 85-94.
- Hoffman, W.A. and Franco, A.C. (2003) Comparative growth analysis of tropical forest and savannah woody plants, using phylogenetically independent contrasts. *Journal of Ecology*, 91, 475-484.
- Hoffman, W.A. and Poorter, H. (2002) Avoiding bias in calculations of relative growth rate. *Annals of Botany*, 80, 37-42.
- Hooijer, A., Silvius, M., Wösten, H. and Page, S.E. (2006) *PEAT-CO2, Assessment of CO2 emissions from drained peatlands in SE Asia*. Delft Hydraulics report Q3943.
- Hunt, R., Causton, D.R., Shipley, B. and Askew, A.P. (2002) A modern tool for classical plant growth analysis. *Annals of Botany*, 90, 485-488.
- Hunt, R. and Cornelissen, J.H.C. (1997) Components of relative growth rate and their interrelations in 59 temperate plant species. *New Phytologist*, 135, 395-417.
- Lyons, A.L. (2003) *The importance of non-timber forest products to livelihoods and conservation in the Sebangau Catchment, Central Kalimantan, Indonesia*. Report submitted to School of Development Studies, University of East Anglia.
- Maranon, T. and Grubb, P.J. (1993) Physiological basis and ecological significance of the seed size and relative growth rate relationship in Mediterranean annuals. *Functional Ecology*, 7, 591-599.
- Muhamad, N. and Rieley, J.O. (2001) Management of Tropical Peatlands in Indonesia: Mega-reclamation project in Central Kalimantan. In Rieley, J.O. and Page, S.E. (eds.) with Setiadi, B., *Peatlands for People: Natural Resource Functions and Sustainable Management*, Proceedings of International Symposium on Tropical Peatland, 22-23 August 2001, Jakarta, Indonesia. BPPT and Indonesian Peat Association, pp. 155-167.
- Page, S.E., Rieley, J.O., Shotyk, W. and Weiss, D. (1999) Interdependence of peat and vegetation in a tropical peat swamp forest. *Philosophical Transactions of the Royal Society, London, B.*, 354, 1885-1897.
- Page, S.E., Siegert, F., Rieley, J.O., Boehm, H-D.V., Jaya, A. and Limin, S. (2002) The amount of carbon released from peat and forest fires in Indonesia in 1997. *Nature*, 420, 61-65.
- Smith, V. (2002) Investigation into the human communities of the Sebangau Peat Swamp Forests, Central Kalimantan, Indonesia: Demography, attitudes and impacts. Report submitted to Oxford Brookes University. Stockey, A. and Hunt, R. (1994) Predicting secondary succession in wetland mesocosms on the basis of

autecological information on seeds and seedlings. *Journal of Applied Ecology*, 31, 543-559.

Appendix 1: List of tree species studied in the SSN (December 2005 – April 2007).

Family	Genus	Species	Local name(s)
Anacardiaceae	Camptosperma	coriaceum	Terontang
Anacardiaceae	Camptosperma	squamatum	Teras Nyating
Annonaceae	Mezzetia	umbellata	Kambalitan Hitam / Pisang pisang kecil
Annonaceae	Xylophia	fusca	Rahanjang / Jangkang
Clusiaceae (<i>Guttiferae</i>)	Calophyllum	hosei	Jinjit / Bintangor
Clusiaceae (<i>Guttiferae</i>)	Calophyllum	sclerophyllum	Kapurnaga
Clusiaceae (<i>Guttiferae</i>)	Garcinia	bancana	Manggis Hutan
Clusiaceae (<i>Guttiferae</i>)	Mesua	sp. 1	Tabaras akar tinggi / Pasir pasir akar tinggi
Dipterocarpaceae	Shorea	balangeran	Kahui / Balangeran
Ebenaceae	Diospyros	bantamensis	Uring Pahe / Malam malam
Elaeocarpaceae	Elaeocarpus	mastersii	Mangkinang
Euphorbiaceae	Blumeodendron	elateriospermum / tokbrai	Kenari
Euphorbiaceae	Neoscortechinia	kingii	Pupu Palanduk
Fabaceae (<i>Leguminosae</i>)	Archidendron	borneensis	Kacing Nyaring
Fagaceae	Lithocarpus	sp. 1 cf. dasystachys	Pampaning Bitik
Icacinaceae	Stemonorus	cf. scorpiodes	Tabaras tdk ada akar / Pasir pasir tdk ada akar
Lauraceae	Litsea	cf. rufo-fusca	Tampang
Lauraceae	Litsea	sp. 1 cf. resinosa	Medang Marakuwung
Magnoliaceae	Magnolia	bintulensis	Asam Asam / Medang limo
Meliaceae	Aglaia	rubiginosa	Kajalaki / Para para
Meliaceae	Aglaia	sp. 1	Banguang Napu
Meliaceae	Sandoricum	beccanarium	Papong / Ketapi hutan
Moraceae	Parartocarpus	venenosus	Tapakan / Lilin lilin
Myristicaceae	Knema	intermedia	Bahandang / Karandau mrah
Myrtaceae	Eugenia	spicata	Kayu Lalas
Myrtaceae	Syzygium	haviandii	Tatumbu
Myrtaceae	Syzygium	sp. 1 cf. garcinifolia	Jambu Burung
Myrtaceae	Syzygium	sp. 14	Milas
Myrtaceae	Syzygium	sp. 15	Hampuak Galaget
Myrtaceae	Syzygium	sp. 5 cf. E.spicata	Kayu Lalas Daun Kecil
Myrtaceae	Syzygium	sp. 6 cf. campanulatum	Tampohot Batang
Sapindaceae	Nephellium	lappaceum	Manamun / Rambutan hutan
Sapindaceae	Nephellium	maingayi	Kelumun Buhis
Sapotaceae	Madhuca	mottleyana	Katiau
Sapotaceae	Palaquium	cf. xanthochymum	Nyatoh Burung
Sapotaceae	Palaquium	leiocarpum	Hangkang
Sapotaceae	Palaquium	pseudorostratum	Nyatoh Bawoi
Sapotaceae	Palaquium	sp. 3	Nyatoh Burung
Tetrameristaceae	Tetramerista	glabra	Ponak
Theaceae	Ternstroemia	magnifica	Tabunter

VEGETATION RESTORATION ON DEGRADED TROPICAL PEATLANDS: OPPORTUNITIES AND BARRIERS

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SUMMARY

Extensive peatlands in SE Asia have been degraded leading to on- and off-site environmental and socio-economic impacts. In order to address these problems, landscape scale restoration measures are urgently required. This paper reviews field data and on-going vegetation trials on degraded peatlands in Central Kalimantan, Indonesia. Data reveal the nature of vegetation changes that follow drainage and fire. At high levels of degradation, succession to forest is prevented and replaced by retrogressive succession to fern and sedge communities. At this stage, natural regeneration is insufficient to bring back forest vegetation and some form of human-assisted regeneration is needed in order to remove or reduce barriers to forest regeneration. We address the nature of these barriers, describe initial results from tree seedling establishment trials, and discuss potential future directions that tropical peatland restoration might take.

Keywords: Tropical peat swamp forest, degradation, vegetation restoration, regeneration barriers, seedling transplant trials

INTRODUCTION

In the last 15 years ~30Mha (25%) of Indonesia's forests have been lost. Between 2000 and 2005 annual rates of loss were 1.91%. Over a quarter of this forest area was tropical peat swamp forest (TPSF), which through extensive fires, drainage, logging and land conversion, is rapidly becoming degraded. Loss of forest cover from tropical peatlands increases peat oxidation, risk of fire and flooding and the loss of forest resources for local communities. Both locally and internationally, however, attitudes towards deforestation are changing; in 2005, a public pledge was made by the Governor of Central Kalimantan to sustainably manage TPSF in his province, whilst the 2007 Bali COP meeting saw parties agree to include positive incentives to reduce emissions from deforestation and forest degradation (REDD) in developing countries, giving a stronger momentum to both protection and restoration of tropical forest resources.

Following deforestation, TPSF degrades to sedge or fern-dominated swamp, losing its natural regeneration capabilities. In these circumstances, active restoration becomes the best option for recovery. The implementation of successful restoration, however, poses many difficulties, or 'restoration barriers', which must be overcome. Following degradation, the biophysical attributes of the ecosystem become altered, and the

changed environmental conditions can become ‘regeneration barriers’, preventing succession back to forest. A thorough understanding of the regeneration process and how this is altered with degradation is necessary in order to determine and alleviate these barriers.

To date, there have been few published SE Asian forest restoration projects, and none focusing on TPSF. This new project, initiated in C. Kalimantan, is pioneering ecological and social methods for TPSF restoration, with the ultimate aim of developing an achievable restoration action plan for degraded tropical peatlands. This paper describes the nature of the degradation processes, discusses the types of ecological barriers to forest restoration, describes initial results from tree seedling establishment trials, and discusses potential routes to developing appropriate restoration action plans for TPSF.

MATERIALS AND METHODS

Study Area: Drivers of Degradation, Barriers to Restoration

The study was carried out in C. Kalimantan province, Indonesia, in the peat-covered catchment of the River Sebangau, close to the provincial capital of Palangka Raya. This province has ~60,000 km² of peatland, but a large proportion has been degraded through a combination of logging, drainage and fire, with more than 10,000 km² of degraded peatland associated with the ex-Mega Rice Project (ex-MRP) to the south and east of Palangka Raya. In this area land cover has altered dramatically since the early 1970s, with a large reduction in primary TPSF cover, particularly from 1997 onwards, largely as a consequence of repeated fires, which are one of the principal barriers to vegetation restoration. Previous and on-going studies (Hoscilo et al. this volume; Page et al. in press) have demonstrated forested sites subject to a single, low intensity fire subsequently undergo secondary succession back to forest. With increased fire intensity and frequency, however, the numbers of tree species and of individual trees, saplings and seedlings are greatly reduced, and, at the highest levels of degradation, succession back to forest is diverted to plant communities dominated by ferns and sedges with few or no trees. Thus, increased fire frequency converts the original forest cover, which was at low risk of fire, to secondary vegetation which dries out quickly and thus burns more easily, creating a positive feedback through increased flammability. If this cycle is repeated two or three times, woody species disappear completely.

In fire-degraded areas there is also an inter-relationship between ecology and hydrology, in particular frequency and duration of surface flooding, which have been identified as additional barriers to forest restoration. In locations that have frequent flooding of long duration, tree re-establishment is prevented and the vegetation is dominated by non-woody, flood-tolerant fern species. This vegetation is largely devoid of trees, presumably because the dense growth of ferns, together with flooding, inhibits the establishment of tree seedlings. Ironically, areas that are subject to flooding are still at high risk of fire during periods of prolonged drought, since the vegetation has a high flammability.

Thus, fire and flooding have been identified as the most important ecological barriers to vegetation recovery, with secondary barriers including competition between tree seedlings and non-woody vegetation, and the lack of seed sources and dispersers.

There are, however, also social, political and economic barriers to forest restoration, some of which are addressed in the discussion section of this paper.

Field Trials

Tree seedling establishment trials are being conducted in an area adjacent to the western boundary of the ex-MRP. The study location comprises degraded peatland (sedge swamp) adjacent to intact TPSF, with a narrow transitional zone between the swamp and closed canopy forest. Trials are being conducted along parallel transects, enabling comparisons to be made between forested, transitional and degraded locations. Along these transects, the ecological conditions necessary for successful regeneration (level of competition, peat composition, availability of nutrients, light, water, mycorrhizae, and seed abundance and dispersal) are being assessed, to determine the degree of alteration in the different zones, and their impact on seedling recruitment, abundance, survival and growth. This work is on-going and the next section presents some initial results.

RESULTS

Water level

Water table in relation to peat surface, in each of the zones, was recorded monthly for 8 months. In the dry season, the forested zones were the driest, with the most degraded zone supporting a significantly higher water table. Although there is not yet a complete data set for the wet season, early results suggest that the most degraded transects have the highest water table. It was anticipated, being the most exposed, that the degraded zone would have a water table that oscillated between extremes; impairing seedling recruitment through both flooding and drought. The higher dry season water table in the degraded zone may be due to lower transpiration rates from the reduced vegetation cover. This suggests that whilst flooding may be a regeneration barrier, lack of water through the dry season is not likely to be a problem at this site.

Nutrient limitation and peat composition

Peat samples were collected along each transect and analyzed for pH, percentage of organic carbon (%org-C), percentage-Nitrogen (%N) and Phosphorus-total (P-Total). The analysis shows that: pH does not significantly alter in any of the forest zones, %org-C significantly decreases as one moves from the pristine forest, out into the more degraded areas. A reduction in org-C may be related to increased decomposition rates in the more degraded zone, or a lack of C-input through reduced vegetation biomass. There was little significant difference across the forest zones regarding %N. P-Total values were significantly lower in all degraded and transition transects when compared to the pristine forest transect. The further one moved into the degraded zone, the more significantly P-Total values were reduced. Thus, both %org-C and P-Total can be classified as 'potential regeneration barriers'.

Light intensity

As one moves out of the closed forest into the degraded zone, light intensity significantly increases both at ground level and at a height of 1m. The reduced forest vegetation of the transition and degraded zones has a more open canopy, with ground vegetation (such as grasses and ferns) not being sufficient to ameliorate this effect. Increased light intensity may have negative impacts on regenerating seedlings (photo-inhibition, wilting, drying).

Trial seedling transplants

Four hundred seedlings of *Shorea balangeran* (Dipterocarpaceae) were planted in October 2007, 80 seedlings in each forest zone. Their height and basal diameter were recorded monthly. Seedling survival is high, with fatality lower than 2%. Surprisingly, seedling growth is significantly higher in the degraded forest zones and lowest in the least degraded forest area. This tree species, which forms a component of undisturbed TPSF, was selected based on its known tolerance of disturbance and flooding.

DISCUSSION/CONCLUSIONS

In order to set about restoring an ecosystem, one must first appreciate how and why it has become degraded in the first place. Ecological restoration is a complicated, multi-faceted science, in which ecological, social, economic and political factors must all be considered. Degradation of a site can occur as a result of a number of different, intertwined causes. For example, the global economic demand for timber, the political decentralization in Indonesia that allowed concessional logging and turned a blind eye to illegal logging, the way this ostracized local communities from their land, and left them untrusting of government rehabilitation work, the continued spiraling degradation of the land left in an unattended state, leading to further fires, reduction in nutrients, reduced seed availability, and so on. By simply planting seedlings or stopping fires, we do not address the issues that led to the initial degradation. If we do not seek to understand these ‘barriers’ and develop solutions for them, restoration will be short-lived and superficial.

The above initial results, although interesting in their own right, are presented to highlight an important issue: At this specific site, the degraded zone has a higher water table in the dry season than inside the forest, it has sufficient nitrates and a tolerable pH, and some species grow better under its environmental conditions than in the pristine forest. These are not features that would have been predicted, had they not been first investigated. There are other features, such as reduced forest structure, increased light intensity, and reduced phosphate availability that do follow the anticipated pattern of reduced resource availability in the degraded area, but clearly these trends also needed to be established through investigation.

A crucial concern facing ecological restoration is the transferability of knowledge gained at any particular site to other sites. Ecological restoration, if done properly, is site-specific. The history of disturbance will be unique to that ecosystem, as will the causes for its initial and continued degradation, both social and ecological. But how can we investigate such a labyrinth of cross-disciplinary, multi-layered issues? And how can we hope to expand this restoration work to a landscape-scale, in order to make a viable impact? There is no easy answer. This paper concludes by proposing that certain guidelines and approaches could be developed, which still allow for site individuality, but which also provide a pathway to more efficient locally-based site restoration.

Through a basic knowledge of the natural history of an ecosystem and the political and social history of the area, we can propose a list of potentially altered conditions, both social and ecological. We must then investigate if they have altered, and if these alterations have indeed become ‘active regeneration barriers’. Although the answers will differ for every ecosystem and even every site, if the right questions are asked,

then the restoration barriers can be determined more efficiently and reliably. The ideal solution would be an all-for-one restoration method that could be applied to all degraded TPSF in SE Asia. In reality, however, this kind of approach would lead to short-lived restoration activities of limited relevance. The process by which we develop site-specific restoration action plans can and should be stream-lined and made more accessible and straight-forward: in the literature many suggested approaches or processes remain disjointed and separate. By beginning to understand the wide-array of potential regeneration barriers preventing the recovery of degraded TPSF, the way in which they are linked, and the way they should be investigated, brings us one step closer to achieving their recovery.

ACKNOWLEDGEMENTS

We would like to thank the brilliant team of research assistants at CIMTROP, who have helped and guided us with all our field work, especially Eben Eser and Salahuddin, who continue to plough through the degraded zone even when flood levels reach their waist. Dr. Jenny Pickerill, Univ. of Leicester continues to support the social aspects of this research and the staff of CIMTROP help hugely with all our administration.

REFERENCES

- Hoscilo A., Page S.E., Tansey K. (2008) Development of post-fire vegetation in the tropical ecosystem of Central Kalimantan, Indonesia. Proceedings of the International Peat Congress, Tullamore, Ireland (this volume).
- Page, S.E., Hoscilo, A., Wösten, H., Jauhiainen, J., et al. (in press) Ecological restoration of lowland tropical peatlands in Southeast Asia – Current knowledge and future research directions. *Ecosystems*.

THE IMPORTANCE OF ECOLOGICAL MONITORING FOR HABITAT MANAGEMENT - A CASE STUDY IN THE SABANGAU FOREST, CENTRAL KALIMANTAN, INDONESIA.

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SUMMARY

Monitoring programmes to measure biodiversity and its threat status are globally recognised as crucial elements of any protected area management programme. In order to identify problems properly, target resources and achieve sustainable conservation outcomes, a well-structured, science-based monitoring and feedback system is essential. In the northern Sabangau Forest, Central Kalimantan, we are collecting data on forest structure, biodiversity and ape density and behaviour. Here we show how these can be used to monitor the condition of the forest and provide feedback to conservation managers on the effectiveness of habitat management/conservation activities in Sabangau.

Keywords: peat swamp forest, biodiversity, monitoring, management

ECOLOGICAL MONITORING AS A CONSERVATION TOOL

The primary goal of conservation of a particular habitat is to maintain (or improve) the structure and integrity of that habitat, its plant and animal populations and the ecological processes and functions contained within. The effectiveness of conservation management actions – and the long-term success of these – must be evaluated against these objectives, which necessitates regular and rigorous scientific monitoring (Parrish *et al.*, 2003).

Monitoring programmes that include measurements of biodiversity and threat status are globally recognised as crucial elements of any protected area management program. An analysis of the effectiveness of 200 protected areas in 34 countries world-wide showed that a good monitoring and evaluation system was closely correlated to those protected areas where biodiversity was best being conserved (indeed, this had the best correlation of all variables investigated; Dudley *et al.*, 2004). Without objective measurement, conservationists cannot claim success, learn from failures, or work effectively and efficiently toward the conservation of the remaining biological diversity of the planet (Parrish *et al.*, 2003).

Many conservation programmes fail to incorporate a rigorous monitoring and evaluation component, often owing to lack of funding or inadequate expertise (e.g., Hockings *et al.*, 2000). In order to identify problems properly, target resources and achieve sustainable conservation outcomes, a well-structured, thorough and science-

based monitoring and feedback system is essential, particularly for long-term projects. The benefits of such a system come in many forms, including:

- Monitoring the effectiveness of management actions so that managers and government departments can identify problems and focus resources and efforts on addressing those problems.
- Identifying and understanding the threats facing the area (without effective monitoring only the most visible threats are apparent), the impact of those threats and the effectiveness of management strategies in preventing and mitigating the threats.
- Enabling the targeting of resources to conservation priority areas and/or problem regions.
- The ability to assess the effectiveness of conservation management programs and trial projects against a long-term dataset.
- Ensuring management plans are designed in accordance with all relevant scientific knowledge, and allowing them to be continuously assessed and altered as necessary.
- Justifying the success of specific conservation projects to grant-giving bodies and in requests for further funding.
- Obtaining essential information for inclusion in education and awareness programs.
- Judging the overall success of conservation actions in achieving its key objectives, which has implications for conservation projects elsewhere.

Monitoring biodiversity is best achieved by selecting a range of elements, processes and properties of the ecosystem, or ‘indicators’, that can be used to assess the condition of the environment or to monitor trends in condition over time (Dale and Beyeler, 2001). They can provide an early-warning system of changes in the environment, and can be used to diagnose the cause of an environmental problem or changes that cannot be measured in a more direct way (often for logistical, financial or technological reasons.) It is important to choose a representative sample of indicators and measures that characterize the ecosystem, yet are simple enough to be effectively and efficiently monitored and modelled (Dale and Beyeler, 2001). Suitable indicators include *keystone species* (those that have strong interactions with other species), *umbrella species* (those that require large areas of habitat and a wide range of ecological conditions that encompass other species), *flagship species* (those that can easily attract public support for conservation and are often the focus of conservation projects) and *resource-limited species* (those that require specific resources that may be in critically short-supply). Indicators are also found at other ecological levels, i.e. spatial distribution of communities over a landscape, species richness and evenness within a habitat, or parasite loads within organisms. A comprehensive conservation plan should thus include measures of indicators at several scales, to ensure that habitat integrity is preserved at every level (Carignan and Villard, 2002). These issues are discussed in detail by Dale and Beyeler (2001).

CASE STUDY IN THE SABANGAU FOREST, CENTRAL KALIMANTAN

The Sabangau Forest is a 568,000 ha area of tropical peat-swamp forest located between the Sabangau and Katingan Rivers in Central Kalimantan, Indonesia, which has recently been protected to conserve one of the largest and most important areas of

lowland rainforest remaining in Borneo. The Sabangau Forest supports the world's largest population of Bornean orang-utan, - 6,900 individuals in an area of 578,000 hectares of peat-swamp forest (Singleton *et al.*, 2004), and one of the largest populations of the Bornean agile gibbon, *Hylobates albibarbis* (Cheyne *et al.*, 2007). Both species are at risk throughout their range from logging, conversion of forest for agriculture, fire and hunting. Thus, the Sabangau forest is crucial for the continued survival of these species.

Although the area has recently been given protected-area status, the forest is not immune from these problems, and there are many challenges ahead. The habitat has undergone many years of disturbance, including uncontrolled illegal logging, which has resulted in drainage of the area owing to the digging of timber-extraction canals. This, in turn, has led to lowering of the water table and increased frequency and severity of forest fires (see review in Harrison *et al.*, 2007a). Exploitation of the forest and its wildlife remains a concern; particularly as many of the surrounding populace formerly relied on logging as their major source of income (Smith, 2002). Whilst protection of this region represents a major commitment on the part of the Indonesian government to protect these species and their habitat, it is only a first step towards ensuring the longer-term conservation of the Sabangau, as the long-term effects of past habitat degradation are not yet clear, but are likely to be detrimental to the long-term integrity of the ecosystem unless mitigating activities are undertaken now. Although illegal loggers have now been ejected from many areas, abandoned illegal-logging canals are still draining the ecosystem, threatening peat collapse and more fires. Blocking these canals is therefore considered to be the single most important management action to save this important ecosystem. The *Centre for International Co-operation in the Management of Tropical Peatland* (CIMTROP) manage and protect the Natural Laboratory of Peat Swamp Forest (NLPSF, 50,000 ha) in the north of the Sabangau forest. Their Patrol Team was formed in 2003 with the objectives of stopping illegal exploitation of timber and other forest resources, damming illegal logging canals and extinguishing forest fires. The next phase is for management and research bodies to collaborate closely, for implementing a successful long-term management plan for the Sabangau forest.

Habitat and biodiversity research has been carried out in the Sabangau peat swamp forest since 1993 as part of CIMTROP's international research programme. Elements of this research have been chosen to make up a suite of indicators that are being used to monitor trends over time, including aspects of forest structure and dynamics, including regeneration processes, orang-utan and gibbon population densities, ape health by monitoring urine ketone levels (Knott, 1998; Harrison *et al.*, 2007b), and relative abundances of certain bird and butterfly species that show marked responses to disturbance. A number of monitoring locations have been established in the northern section of the Sabangau Forest, an area that covers a wide spectrum of accessibility and habitat quality, is subject to varying degrees of human pressure, and is the target of conservation management activities by CIMTROP. This research is being developed into an ecological monitoring system that will provide feedback to management agencies and provides a scientific foundation for conservation management of the Sabangau Forest and its priority ape populations. To illustrate this, three methods for monitoring the area are described.

Changes in forest biomass

A simple way of monitoring forest growth is to measure the basal area of trees in permanent plots. This provides an indicator of changes in biomass, whether positive or negative. Since 2003, measurements of the basal circumference of all trees ≥ 7 cm

diameter at breast height in six forest plots (total area 0.9 ha) in the mixed swamp-forest sub-type have been made once every two years. Ten years of concession and illegal logging reduced the total basal area by ca. 20% in comparison to 1993 data (Shepherd *et al.*, 1997), but, since the cessation of logging in 2004, the forest has shown signs of recovery, with an overall increase in basal area/ha over this time (Table 1). Thus, the effectiveness of the CIMTROP Forest Patrol Unit has been demonstrated in preventing illegal logging in the northern Sabangau Forest since 2003.

Year	Basal Area (m ² ha ⁻¹)
1993	50.0
2003	38.1
2005	39.9
2007	40.1

Table 1 Changes in basal area/hectare in the Sabangau mixed-swamp forest between 1993 (pre-illegal logging) and 2007 (three years after the cessation of illegal logging).

Changes in orang-utan density

Based on our research in Sabangau, we have earlier recommended that monitoring of orang-utan and gibbon populations should be an integral part of research into the effectiveness of conservation measures in areas where these animals are found (Husson and Morrogh-Bernard, 2003; Harrison *et al.*, 2007b). This recommendation was based partly on the suitability of these species as indicators of habitat change and partly owing to their “flagship” status. Monitoring densities is important as, although there is a time lag between disturbance and changes in density, these data are easily collected, easily understood by non-experts, and ultimately indicate the overall success of the conservation project in achieving its aim (i.e., to conserve large, viable populations) (Harrison *et al.*, 2007b). Our discussion here is limited to orang-utans, as this population has been monitored since 1995.

Orang-utan density is estimated by counting nests along straight-line transects (van Schaik *et al.*, 1995). Orang-utans make a new nest each night for sleeping and sometimes another nest during the day for feeding or resting. The perpendicular distance from the transect to the nest is measured and orangutan nest density estimated using the computer programme DISTANCE. Nest density can be converted to animal density using locally-obtained nest-building parameters (Morrogh-Bernard *et al.*, 2003). This is a quick, cost-effective method that uses indicators of presence, as opposed to actual counts of animals (which are very hard to see). Thus, orang-utan nest density is a suitable indicator of abundance that can be compared between sites and to monitor trends over time. Although orang-utans are long-lived animals with a long life history, and thus relatively slow to respond to disturbance, they are one of the main foci for conservation in the region and thus important to monitor.

We found dramatic changes in annual estimates of orang-utan density from 1995-2007 in the Sabangau mixed-swamp forest (Figure 1). Density declined dramatically between 1996 and 1999, owing to heavy illegal logging that reduced the availability of their preferred fruiting trees and displaced some individuals out of the diverse, food-rich mixed-swamp habitat into the depauperate low-pole habitat. These factors ultimately caused many orang-utans to die of starvation. Since 2004 and the cessation of logging and hunting activities, the orang-utan population in this habitat has started to increase, probably in response to the recovery of the forest and decreased human

disturbance, as orang-utans will return to old disturbed areas when human disturbance has ended (Morrogh-Bernard *et al.*, 2003).

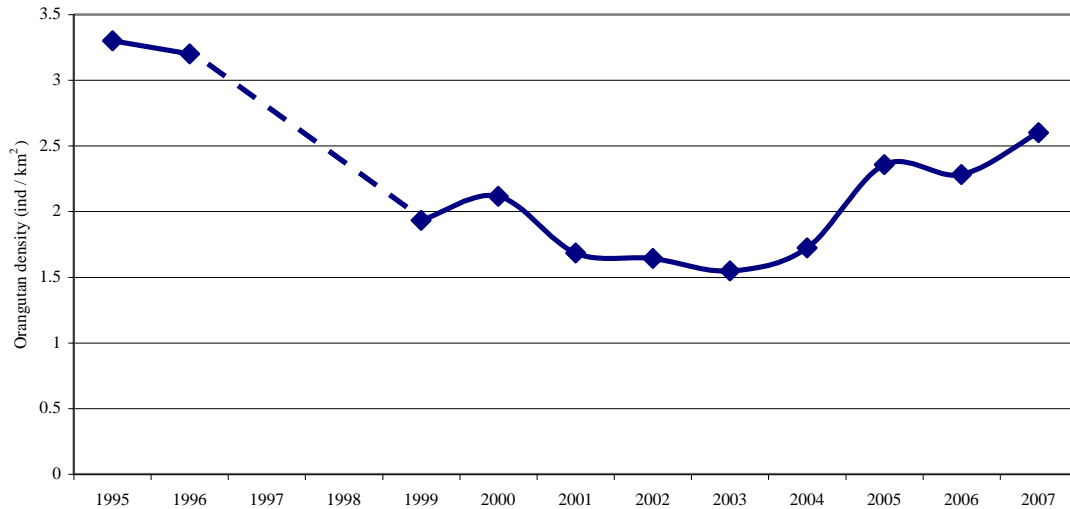


Figure 1 Changes in orangutan density in the Sabangau mixed-swamp forest between 1995 and 2007. No surveys were carried out in 1997 or 1998.

Bird indicator species

The Sabangau has 201 species of bird recorded. Birds are a good group to use as indicators of forest growth and recovery as (i) several species show consistent responses to disturbance and forest recovery; (ii) many species have short life-histories and small ranges, and thus show early and measurable responses to changes in forest structure; (iii) most species are easy to detect by identifying their songs and calls; and (iv) different species show different responses to disturbance and forest recovery. Since 2005, we have surveyed relative bird abundance along transects in areas of different disturbance levels. Fourteen common species show significant preference for either disturbed forest ('positive indicators' – Figure 2) or undisturbed forest ('negative indicators' – Figure 3).

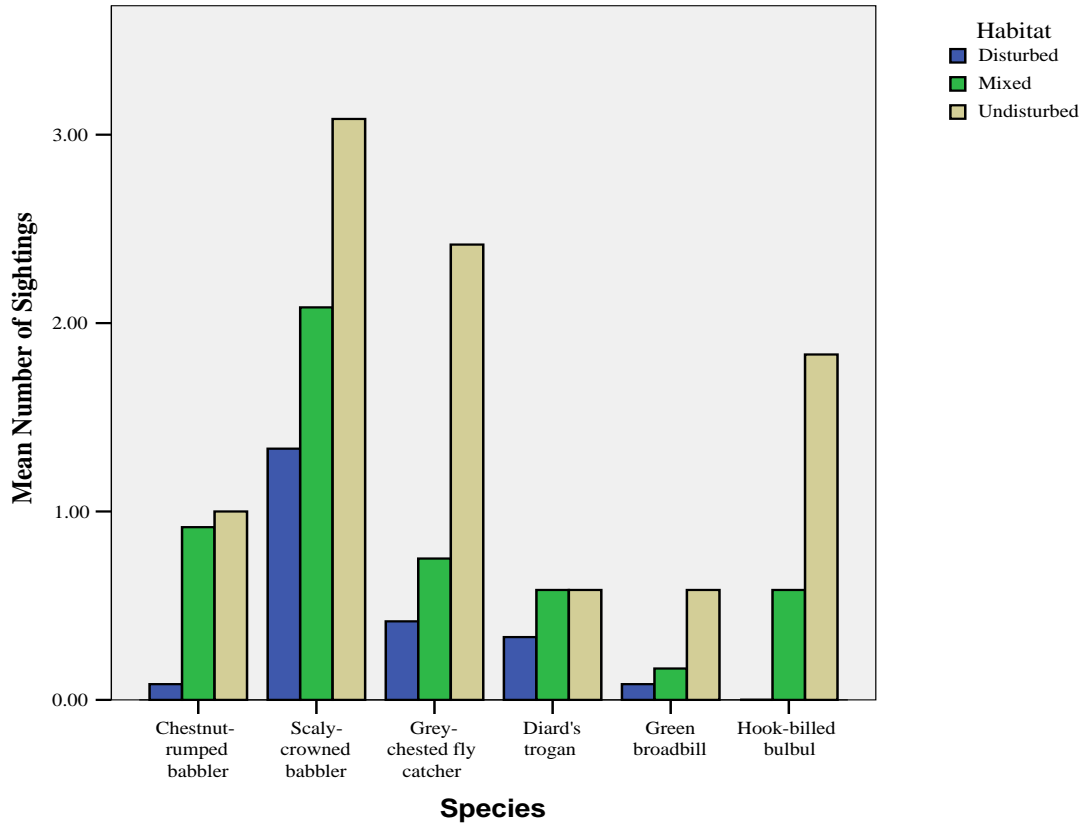


Figure 2 Bird species that show significant preference for undisturbed forest and thus act as positive indicators of forest quality.

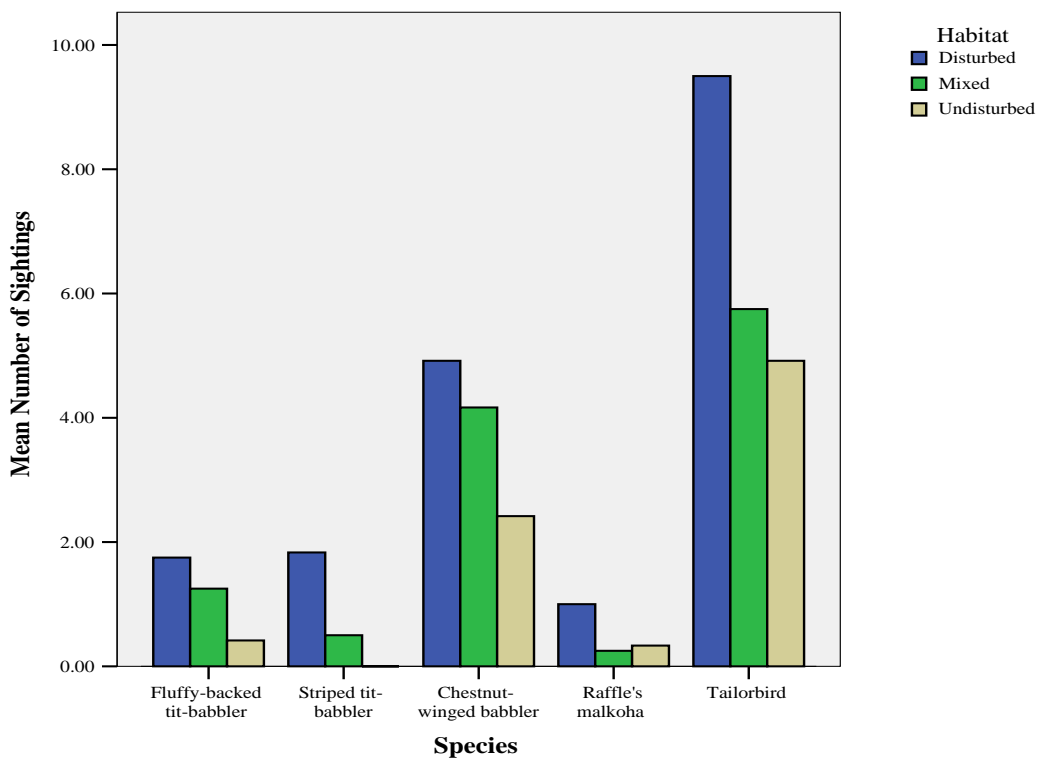


Figure 3 Bird species that show significant preference for disturbed forest and thus act as negative indicators of forest quality.

CONCLUSIONS

Ecological monitoring is frequently neglected in protected-area management world-wide, but is crucially important to a project's success. Conservation projects need to have objective measurements with which to assess the success of the project and to adapt to changes, in order to properly manage the area and its species in the long term. Naturally, species and ecosystems manage themselves very successfully, but in this day and age, no tropical ecosystems are truly devoid of human interference and, consequently, conservation management is required. The Sabangau Forest is no exception. By monitoring changes in habitat quality and selected faunal indicator species, such as birds and primates, we will improve our ability to assess the effectiveness of conservation activities in the region and, hence, to justify further conservation efforts. To date, this research indicates that CIMTROP's conservation activities are aiding the forest's recovery, but restoring the area to its original, natural state will take continued investment of time and resources, particularly for damming canals, the top conservation priority for the area. .

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REFERENCES

- Carignan, V. and Villard, M. (2002). Selecting indicator species to monitor ecological integrity: a review. *Environmental Monitoring and Assessment*, 78, 45-61.
- Cheyne, S.M., Thompson, C.J.H., Phillips, A.C., Hill, R.M.C. and Limin, S.H. (2007). Density and Population Estimate of Gibbons (*Hylobates albibarbis*) in the Sabangau Catchment, Central Kalimantan, Indonesia. *Primates*, 49 (1), 50-56.
- Dale, V.H. and Beyeler, S.C. (2001). Challenges in the development and use of ecological indicators. *Ecological Indicators*, 1, 3-10
- Dudley, N., Belokurov, A., Borodin, O., Higgins-Zogib, L., Hockings, M., Lacerda, L. and Stolton, S. (2004). How effective are protected areas? A preliminary analysis of forest protected areas. A report prepared for the Seventh Conference of Parties of the Convention on Biological Diversity, February 2004. WWF International, Gland, Switzerland.

- Harrison, M. E., Cheyne, S. M., Sulistiyanto, Y. and Rieley, J. O. (2007a). Biological effects of smoke from dry-season fires in non-burnt areas of the Sabangau peat swamp forest, Central Kalimantan, Indonesia. In: Rieley J. O. Banks C. J. and Radjagukguk B. (Eds). *Carbon-climate-human interaction on tropical peatland. Proceedings of The International Symposium and Workshop on Tropical Peatland*, Yogyakarta, 27-29 August 2007, EU CARBOPEAT and RESTORPEAT Partnership, Gadjah Mada University, Indonesia and University of Leicester, United Kingdom. www.geog.le.ac.uk/carbopeat/yogyaproc.html
- Harrison, M. E., Cheyne S. M., Morrogh-Bernard, H. and Husson, S. J. (2007b). What can apes tell us about the health of their environment? A review of the use of orang-utans and gibbons as indicators of changes in habitat quality in tropical peat swamp forests. In: Rieley J. O. (Ed) *Proceedings of the International Symposium and Workshop on "Restoration and Wise Use of Tropical Peatland"*, Palangka Raya, Indonesia, September 21-24 2005. pp. 104-107
- Hockings, M., Stolton, S. and Dudley, N. (2000). Evaluating effectiveness: A framework for assessing the management of protected areas. IUCN, Cambridge, UK.
- Morrogh-Bernard, H., Husson, S.J., Page, S.E. and Rieley, J.O. (2003). Population status of the Bornean orang-utan (*Pongo pygmaeus*) in the Sebangau peat-swamp forest, Central Kalimantan, Indonesia. *Biological Conservation*, 110(1), 141-51.
- Husson, S.J. and Morrogh-Bernard, H.C. (2004). Orang-utan population dynamics in the Sabangau ecosystem, Central Kalimantan. Report for WWF Indonesia.
- Parrish, J.D, Braun, D.P. and Unnasch, R.S. (2003). Are we conserving what we say we are? Measuring ecological integrity within protected areas. *BioScience*, 53(9), 851-860
- Shepherd, P.A., Rieley, J.O. and Page, S.E. (1997). The relationship between forest structure and peat characteristics in the upper catchment of the Sungai Sebangau, Central Kalimantan. In: Rieley, J.O. and Page, S.E. (eds.). *Biodiversity and Sustainability of Tropical Peatlands*. Samara Publishing, Cardigan, U.K., pp. 191-210.
- Singleton, I., Wich, S., Husson, S., Stephens, S., Utami-Atmoko, S., Leighton, M., Rosen, N., Traylor-Holzer, K., Lacy, R. and Byers, O (2004). Orang-utan Population and Habitat Viability Assessment: Final Report. IUCN/SSC Conservation Breeding Specialist Group, Apple Valley, MN, USA.
- Smith, V. (2002). Investigation into the human communities of the Sebangau peat swamp forests, Central Kalimantan, Indonesia: Demography, attitudes and impacts. MSc thesis, Oxford Brookes University, Oxford.
- van Schaik, C.P, Azwar and Priatna, D. (1995). Population estimates and habitat preferences of the orang-utan based on line transects of nests. In: Nadler, R.D., Galdikas, B.M.F., Sheeran, L.K. and Rosen, N.(eds.) *The Neglected Ape*. Plenum Press, New York and London, pp. 129-47

**Restoration of the Hydrological Integrity and its Impact on Carbon
Fluxes**

THE ROLE OF DRAINAGE IN THE WISE USE OF TROPICAL PEATLANDS

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SUMMARY

The Indonesian Government has identified the coastal zones of Borneo as a major region for agricultural development. Owing to a scarcity of agricultural land, there is an increasing interest to invest in the development of lowland peat swamps. Drainage is needed to make these waterlogged peat swamps suitable for agriculture or other land use. As soon as the peat swamps are drained the process of irreversible subsidence commences. This subsidence is a well-known and hard-to-overcome constraint to the development and use of tropical peatlands. Drainage and fires associated with the agricultural development and logging release increasing amounts of carbon to the atmosphere. The dilemma is how to strike a balance between two contrasting needs, namely, intensive drainage in order to produce more food and less intensive drainage to avoid irreversible damage to these fragile eco-systems. In this paper, a new water management strategy for the sustainable use of tropical peatland is proposed. In this strategy, emphasis shifts from drainage to water control. The challenge therefore is to strive for a balance between water levels allowing optimal crop production and water levels minimising peat subsidence. Under the new system, water levels in the drainage system will be maintained at the highest feasible level. These high levels have implications for the design, implementation and operation of the water management system. It will result in a water management system with narrowly spaced shallow drains in combination with an intensive network of control structures. It should be remembered, however, that subsidence cannot be completely arrested; it is the price one has to pay for utilising lowland peat swamps.

Keywords: tropical peat, hydrology, drainage, water management, Indonesia

INTRODUCTION

To be able to feed the growing world population and to banish hunger, food production needs to be doubled in the next 25 years. In south-east Asia, where fertile land has become scarce, agriculture development more and more focuses on marginal soils such as peatlands, acid sulphate soils, and steep land. Peatlands in south-east Asia cover about 27.1 Mha, or about 10% of the total land area (Hooijer *et al.*, 2006). About one quarter of the world's tropical peatlands (11 million hectares) occur in Borneo. These peatlands, which are waterlogged most time of the year, are dome-shaped. It should be realised that because of the dome-shape topography, peat domes cannot be irrigated by gravity from the surrounding rivers. The only source of water is rainfall. The rainfall is not distributed evenly over the year (Ritzema and Wösten, 2002). The average dry season (monthly rainfall <100 mm) can last for 3 to 4 months. Under these conditions the water table depth can fall to one metre or more below the

peat surface (Takahashi *et al.*, 2002). Without water conservation, this can lead to severe and persistent moisture deficits in the surface peat layer and thus to increased oxidation and risk of fire.

The Indonesian Government has identified the coastal zones of Borneo as a major region for agricultural development. The lowland peat swamps of Borneo are purely rain-fed and waterlogged most times of the year. Drainage is needed to make these waterlogged lands suitable for agriculture or other land uses. Many development projects on tropical peatlands have failed through a lack of understanding of the natural functions of these complex ecosystems. The leading principle of the existing water management practice is based on fulfilling the drainage requirements, namely, avoiding flooding by the evacuation of excess rainfall within a certain period of time. Furthermore, it is assumed that this excess rainfall is mainly removed by surface runoff. Thus, the design principles for drainage of peatlands are similar to those for mineral soils, although the soil and hydrological characteristics differ greatly. Compared to mineral soils, peat has a much higher infiltration capacity, drainable pore space and hydraulic conductivity, but a lower capillary rise, bulk density and plant-available water (Wösten *et al.*, 2003). Another major difference is the subsidence behaviour of peat; it is partly caused by oxidation and is never-ending. Oxidation leads to CO₂ emission, which under Borneo conditions, is estimated to be in the order of 26 tonnes per hectare per year. In addition to the loss of peat by oxidation, the excessive subsidence rates result in a pronounced drop in the elevation of the land reducing the efficiency of the drainage system. To avoid flooding and waterlogging problems during the monsoon season, frequent deepening of the system is required (Figure 1). The resulting progressive lowering of water levels triggers off increased subsidence and so on. In Western Johore, Peninsular Malaysia, for example, it is estimated that the low water levels in the drainage system, caused by uncontrolled drainage, increase the overall subsidence by approximately 30 per cent (DID and LAWOO, 1996). The mineral substratum under peat soils is often sulphidic. Once the peat has disappeared, the mineral subsoil, which are often sulphidic, will surface. The available pyrite will oxidise and acid sulphate soils with very low pH values will form (Kselik *et al.*, 1993). This continual subsidence process threatens the sustainable use of peat areas (Rieley *et al.*, 2002). To sustain the use of lowland peat swamps a new approach in water management, based on controlled drainage, is proposed. In this paper, the hydrology of the tropical peat swamps of Borneo is discussed and, based on the specific characteristics of this peatland hydrology, a new water management approach is presented. The paper is based on experiences obtained in the utilisation of peatlands in Malaysia (DID, 2001, Ritzema *et al.*, 2003), The Netherlands (Ven, 1996) and other parts of the world (de Bakker and van den Berg, 1982).

THE HYDROLOGY OF THE TROPICAL PEATLANDS OF BORNEO

Hydrology is an important (if not the most important) factor in the formation and functioning of peat swamp ecosystems. The hydrology of a peat swamp depends on the climate, topographic conditions, natural subsoil, and drainage base. Any changes in the hydrology, especially those from the introduction of drainage, will have - often irreversible - effects on the functioning of these fragile ecosystems. Only a sound understanding of the hydrology of peat swamps will make it possible to develop and manage them in a more sustainable way.

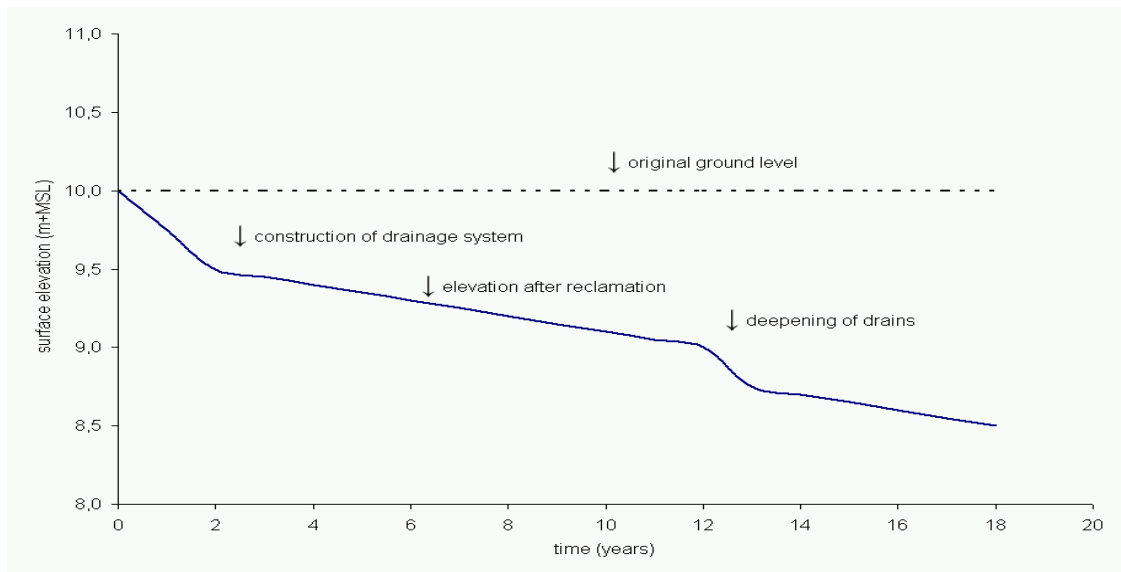


Figure 1 The everlasting subsidence results in a continuously lowering of the land surface (After Eggelsman, 1982).

Water balance in tropical peatland

The majority of the lowland tropical peat swamps are completely rain-fed. Water flow from upland areas does not enter them. The rainfall either evaporates or is transported from the swamps as near surface run-off, inter-flow, or groundwater flow. Under unsaturated conditions, almost all of the rainfall infiltrates owing to the high hydraulic conductivity (up to 30 m per day) of the surface (approximately first 1 metre) peat layer (Takahashi *et al.*, 2002). The high hydraulic conductivity, combined with a relatively low hydraulic gradient in the relatively flat peatlands, results in a rapid discharge of rainfall through the top peat layer towards the surrounding rivers or drainage channels (Figure 2).

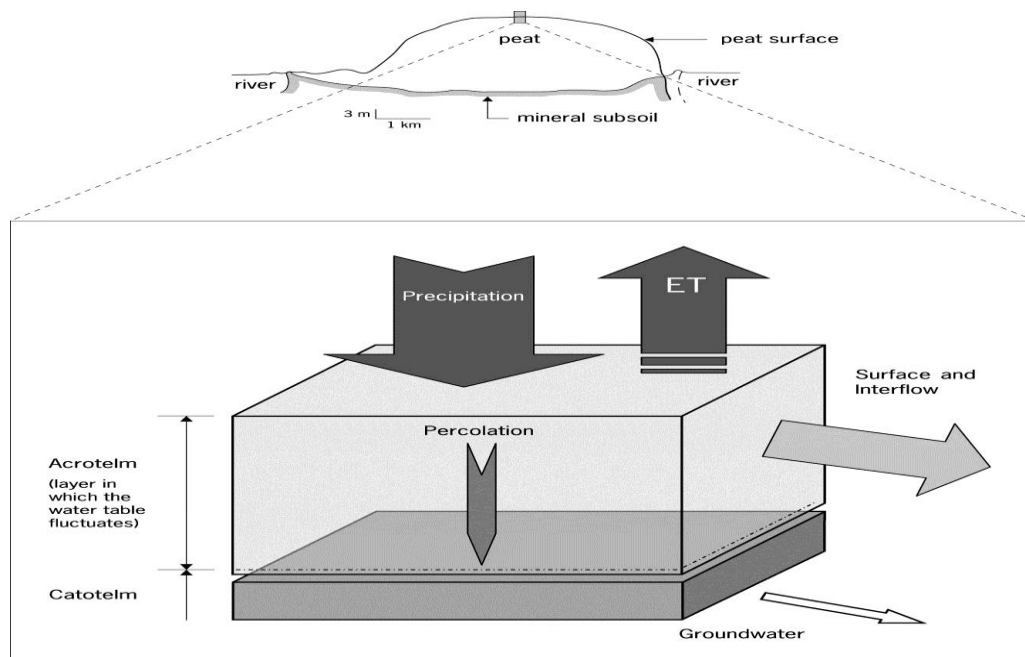


Figure 2 Water balance in a tropical peatland.

The general water balance of a peat swamp can be expressed as follows:

$$P = E + Q + \Delta S$$

where:

- P total rainfall (m)
- E total evapotranspiration (m)
- Q total discharge (m)
- ΔS change in storage (m)

Under natural conditions, the water table rises with rainfall and falls as a result of evapotranspiration and the outflow of excess water. Fluctuation of water tables in a peat swamp depends mainly on rainfall because evapotranspiration and (groundwater) outflow are fairly constant. Drainable pore space, or the storage coefficient, can be as high as 0.8 (Wösten and Ritzema, 2001). In the dry season, when water levels are low, most rainfall can be stored in the surface peat layer. Even in the wettest months, the storage capacity is considerable and discharges are factors 5 to 10 times lower than in mineral soils (DID and LAWOO, 1996). During the wet season, rainfall always exceeds the combination of evapotranspiration and (ground) water run-off. Seepage through deeper peat layers is low and about 90% of the excess rainfall will run off through the top peat layer, the so-called interflow (DID, 2001). In this season, watertables will rise, creating conditions favourable for peat accumulation while, during the dry season, when rain-free periods may last for several weeks or even months, water levels often drop to a metre or more below the peat surface.

WATER MANAGEMENT

Drainability

Drainability refers to drainage by gravity, i.e. drainage without the aid of mechanical devices such as pumps. The drainage base is defined as the water level in the adjacent river or stream, below which natural drainage by gravity cannot be achieved (Figure 3). For conveyance losses an additional hydraulic head of at least 20 cm per kilometre should be added.

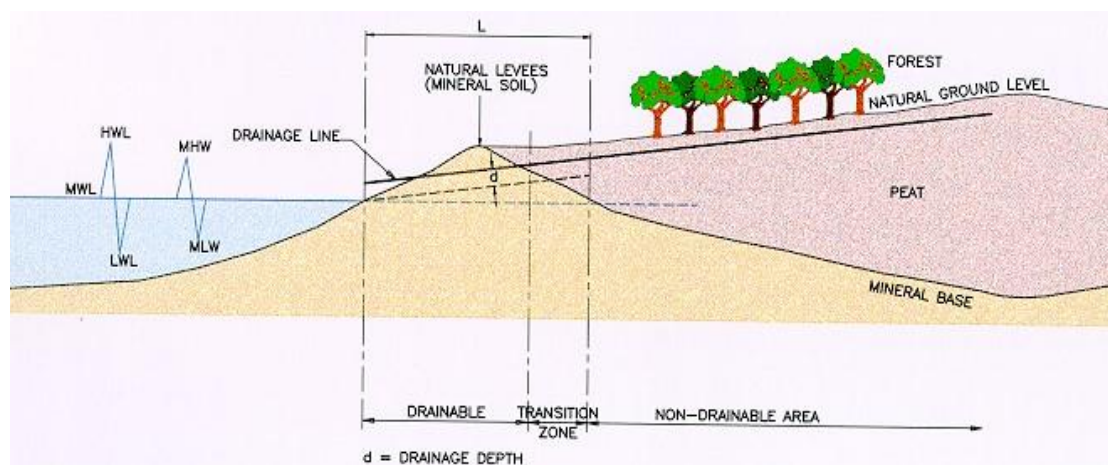


Figure 3 The water level in the adjacent river or stream determines the drainability of a peat swamp

In Indonesia, four types of tidal lands are commonly distinguished in coastal areas (Figure 4). The classification, which is mainly based on the potential for irrigation, is based on the water levels in the main rivers:

- Class A: Areas between mean low tide and mean neap tide. These areas appear close to the sea. The potential for irrigation and drainage is good because there is sufficient tidal fluctuation to allow a daily flooding and drainage. Gravity drainage is possible when the water level in an area is higher than the (outside) water level in the river. In lower-lying areas, drainage may be possible only during low tides. Control structures and embankments are needed to prevent flooding during high tide. Inside the area, storage capacity is required to store excess water until it can be discharged during low tide.
- Class B: Areas between mean neap tide and mean spring tide. Irrigation is only possible during springtide. Absence of daily flooding requires water conservation measures. Daily drainage is always possible.
- Class C: Area above spring tide. No tidal flooding, permanent drainage. In these areas drainage of excess rainfall is always possible due to absence of high water levels in the canals.
- Class D: Area outside the influence of daily tide. No tidal flooding, limited drainage during periods of high river flows. The water table drops during the dry season when evaporation exceeds rainfall.

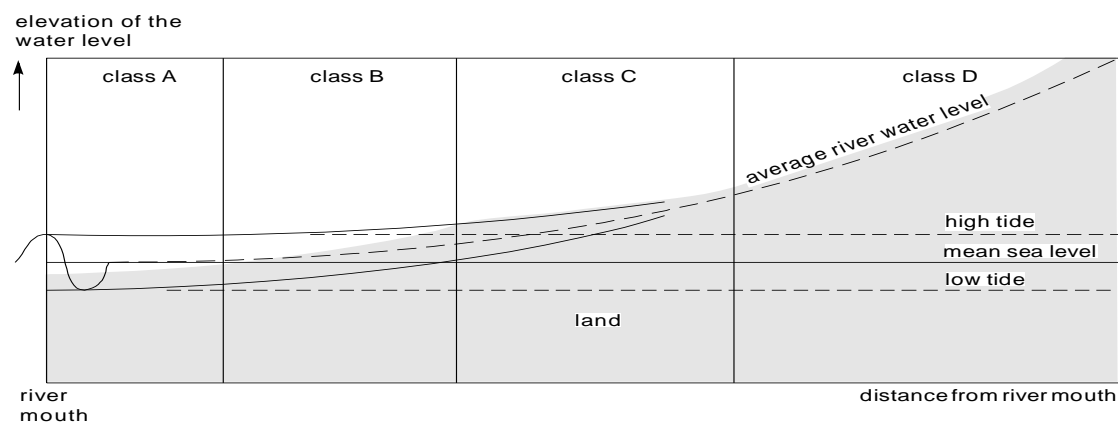


Figure 4 Tidal land classification in Indonesia (AARD and LAWOO, 1992)

Most of the peat swamps in Indonesia are class D and gravity drainage is possible because of their dome-shaped morphology. Drainage, however, results in subsidence and gravity drainage can only continue till the elevation of the land drops below the drainage base. Uncontrolled drainage – and the subsequent excessive subsidence – could put an end to this quickly: depending on its original thickness of the peat layer it may take 50 to 750 years before the overlaying peat soil has subsided so much that gravity drainage is no longer possible (Wösten *et al.*, 2003). After the elevation of the land has dropped below the drainage base, the drainability becomes problematic: gravity drainage and further subsidence will cease. The land will become waterlogged and unsuitable for agriculture. The only option is pumped drainage, which at present is not economically feasible, but it might be in future. Then, on a limited scale, it might be economical for crops with a very high rate of return (e.g. horticultural crops). The alternative is to give the land back to nature.

An Improved Water Management Strategy for Tropical Peat Swamps

The strategy for the new water management approach is based on the principle that peat is a precious resource that should be handled with care to prolong its life. This can only be achieved if there is a shift from the concept of unrestricted removal of excess water to controlled drainage. This integrated water management principle combines drainage, irrigation and water conservation. Drainage is needed during the monsoon season to control the watertable and to remove excess surface and subsurface water from the land. Irrigation, which in this case is called sub-irrigation or inverse drainage, is needed to supply water through capillary flow during dry spells. And water conservation is needed to control the water table at a higher level throughout the year to avoid excessive subsidence and to reduce the risk of fire. Thus a water management system in peatland has three functions, i.e.:

- Removal of excess (surface and subsurface) water during the monsoon season
- Control of the (ground)watertable, and
- Conservation of the water during dry periods.

These functions are somewhat conflicting: on the one hand removal of excess water requires unrestricted outflow conditions and on the other hand the control of the water table and water conservation can only be achieved by restricting the outflow. The water management requirements also vary within a year. Water table control is required the whole year around, with removal of excess water only during periods with excess rainfall, whilst water conservation is essential during prolonged dry periods. Borneo has two seasons: in the dry season, rainfall is lower or equal to evaporation and water conservation is required. In the wet or monsoon season, rainfall exceeds evaporation and drainage is needed to remove the excess rainfall. On top of this, there are short periods of extreme rainfall requiring an extra drainage capacity. To fulfil these conflicting needs, controlled drainage is required. Two conditions have to be considered:

- To maintain the watertable at a level that is low enough to enhance the agricultural use and, at the same time, high enough to sustain the peat. This watertable criterion will determine the spacing of the drains. It should be based on the drainage requirement during an average wet season.
- To remove excess rainfall during extreme events. This discharge criterion will determine the capacity of the drains (dimensions) and should be based on an extreme (e.g. one-in-5 year rainstorm) rainfall event.

The design should also take into account the specific soil hydraulic characteristics of peat, i.e. the very high infiltration rate, storage capacity and permeability. Because of these characteristics, excess rainfall is not removed as surface runoff but mainly as interflow and (to a smaller extent) groundwater runoff. The change from surface to interflow and groundwater runoff has a significant effect on the discharge: model simulations for a similar peat area in Western Johore, Peninsular Malaysia, showed a reduction of the peak discharge by more than 100% (Ritzema et al., 1998). For conditions in Borneo, with its humid climate and prolonged periods of rather uniform rainfall, the steady-state approach (e.g. the Hooghoudt Equation, see for example Ritzema, 2007) can be used to calculate drain spacing. The simplicity and the limited requirement of input data of this approach make it very suitable.

Structures are needed to control the drainage. Because peat is so permeable, structures with small head differences are recommended. The dynamic storage capacity in the drainage system is small compared to the recharge by excess rainfall and the

corresponding discharge. Therefore it is possible to use the steady-state approach for the design (Beekman, 2006). Structures act as barriers to prevent the flow but water cannot be stored for long periods as it will seep away through the surrounding peat. Computer simulations show that a cascade of closely spaced dams is most effective for water control (Figure 5) (Ritzema *et al.*, 1998).

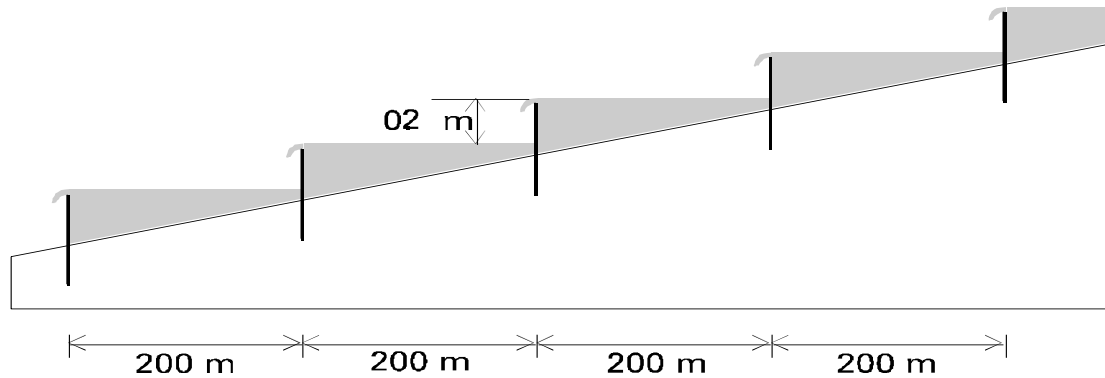


Figure 5 A cascade of closely spaced control structures is needed to maintain high water levels in the drain during the dry season (Ritzema *et al.*, 1998).

The distance between the structures depends on the gradient of the peat dome (Beekman, 2006). In the central part of the dome, the slope is often less than 0.5 m km^{-1} , increasing to more than 2 m km^{-1} near the edges. Consequently, the distance between structures in the central part of the dome can be as far apart as 1 to 2 km, but this must be much less towards the edges. As the structures are intended as water control rather than water impoundment structures, they do not have to be watertight and their construction can be relatively simple. Structures have to be adapted to the specific characteristics of tropical peat, in particular its very high hydraulic conductivity (Wösten and Ritzema, 2001) and low load bearing capacity (Salmah, 1992). In Block C, structures, constructed of locally available peat and timber, are successful in raising upstream water levels. An additional benefit of using peat, which has a low bulk density, is that expensive foundations are not needed.

The above considerations result in a water management system with narrowly spaced drains in combination with an intensive network of control structures. A consequence of this high intensity system is that the percentage of the area occupied by the water management system is high: between 15 and 20% compared to less than 5% in mineral soil areas. The layout of the water management system should also make use of the dome-shaped topography of the peat lands. Field drains should be located parallel to the contour lines and collector drains perpendicular to these. The best location for water storage, needed to replenish the groundwater during prolonged dry periods, is in the centre of the peat dome (Figure 8).

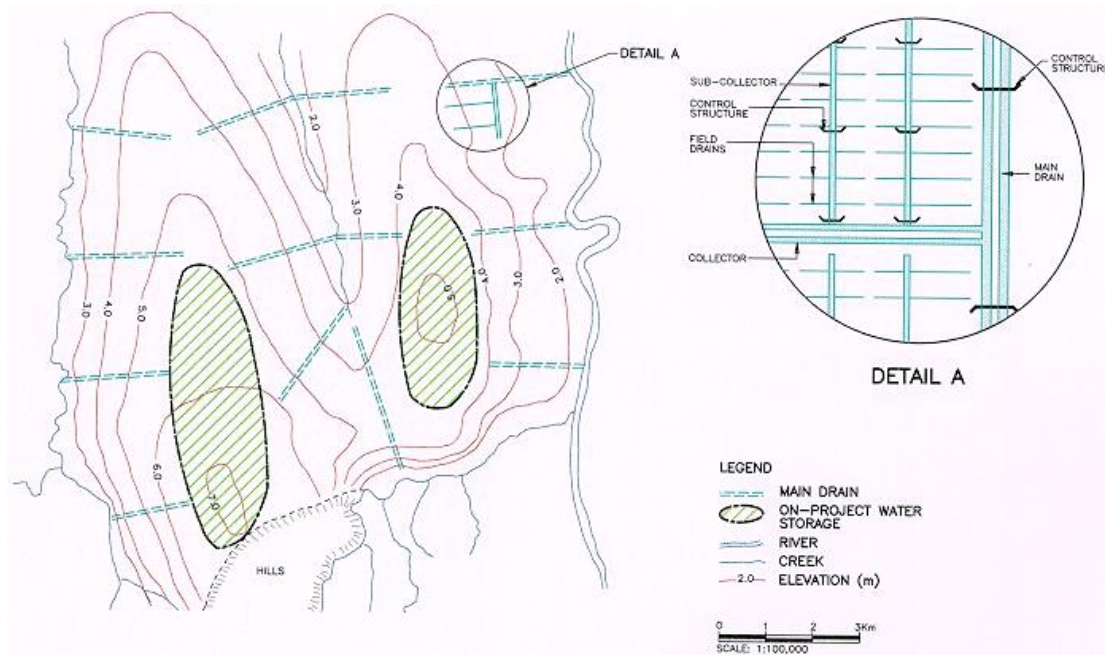


Figure 8 Typical layout of a drainage system in which the centre of the peat-dome can be used to store water

CONCLUSIONS AND RECOMMENDATIONS

To sustain the lowland peat swamps of Borneo, a new approach in water management has been developed. In this approach, the emphasis has shifted from removal of excess rainwater to water control. The challenge is to strive for a balance between water levels allowing optimum crop production and water levels minimising peat subsidence. Furthermore, the system is designed using the unique characteristics of peat: its huge infiltration, water-holding capacity and permeability. This will result in a system with closely-spaced, shallow drains in combination with an intensive system of control structures. Although the concept is clear, applying it effectively will take time. What are the best methods to use? What are the best structures to control the water level and how do you operate those structures? It's a process of optimisation that, e.g. in The Netherlands and other countries in Northern Europe, has been going on for centuries (Ven, 1996 and de Bakker and van den Berg, 1982). Also in Borneo, this process will take years. It will only be successful if the principles and practices of sustainable 'wise use', especially with respect to hydrology and water management are taken into account (Rieley and Page, 2005). And only when all organisations working in lowland peat swamps of Borneo join hands, the implementation of the recommended approach will lead to a success in sustaining one of Borneo's precious resources: its lowland peat swamps.

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This paper could not have been written without the data and support provided by these projects.

REFERENCES

- AARD and LAWOO, (1992) *Acid Sulphate Soils in the Humid Tropics: Water Management and Soil Fertility*. Agency for Agricultural Research and Development and Land and Water Research Group, Jakarta, Indonesia, 284 pp.
- Beekman, W. (2006) *Modelling of open water flow in tropical peatlands in Central Kalimantan - the effect of peat dams on open water flow and its consequences for water regulation measurements*. MSc Thesis, Wageningen University. Hydrology and Quantitative Water Management Group, Wageningen, The Netherlands, 75 pp.
- De Bakker, H., van den Berg, M.W. (1982) *Proceedings of the Symposium on Peatlands below Sea Level*. ILRI Publication 30, Wageningen, 296 pp.
- DID (2001) *Water Management Guidelines for Agricultural Development in Lowland Peat Swamps of Sarawak*. Kuching, Sarawak Department of Irrigation and Drainage, 116 pp. + annexes.
- DID and LAWOO (1996) *Western Johore Integrated Agricultural Development Project, peat soil management study*. Department of Irrigation and Drainage, Kuala Lumpur, Malaysia and Land and Water Research Group, Wageningen, The Netherlands, 100 pp.
- Eggelsmann, R. (1982) Water Management of Northwester German Peatlands. In: H. de Bakker and M.W. van den Berg. *Proceedings of the symposium on peat lands below sea level*. ILRI Publication 30, pp. 122-129.
- Hooijer, A., Silviu, M., Wösten, H. and Page, S.E. (2006) PEAT-CO₂, Assessment of CO₂ emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943.
- Kselik, R.A.L., Smilde, K.W. Ritzema, H.P. Subagyono, K. Saragih, S. Damanik, M. and Suwardjo, H. (1993) Integrated research on water management, soil fertility and cropping systems on acid sulphate soils in South Kalimantan, Indonesia. In: D.L. Dent and M.E.F. van Mensvoort (eds.), *Selected papers of the Ho Chi Minh City Symposium on acid sulphate soils*. ILRI Publication 53: pp. 177-194.
- Rieley, J.O. and Page, S.E. (eds.). 2005. *Wise Use of Tropical Peatlands - Focus on Southeast Asia*. Wageningen, ALTErrA, 168 pp. + appendices.
- Rieley, J.O. and Page, S.E. with Setiadi, B. (eds). (2002) *Peatlands for People: Natural Resource Functions and Sustainable Management, Proceedings of the International Symposium on Tropical Peatland, 22-23 August 2001, Jakarta, Indonesia*, BPPT and Indonesian Peat Association. 271 pp.
- Ritzema, H.P. (2007) Subsurface flow to drains. In: H.P. Ritzema (Editor-in-Chief), *Drainage Principles and Applications*. ILRI Publication 16, Third Edition, Wageningen, pp. 263-304.
- Ritzema, H.P. and Wösten, J.H.M. (2002) Water Management: The Key for the Agricultural Development of the Lowland Peat Swamps of Borneo. *Proceedings International Workshop on Sustainable Development of Tidal Areas, July 22, 2002, ICID, Montreal*, pp. 101-113.
- Ritzema, H.P., Hassan, A.M.M. and Moens, R.P. (1998) A new approach to water management of tropical peatlands: a case study from Malaysia. *Irrigation and Drainage Systems* 12,123–139.

- Ritzema, H.P., R.A.L. Kselik, Tom K.F. Chong and Tie Yiu Liong. (2003) A New Water Management Approach for Agricultural Development of the Lowland Peat Swamps of Sarawak. In: Chew, Dr. D. and Sim Ah Hua (Ed.). *Integrated Peatland Management for sustainable development. A Compilation of Seminar Papers*. Sarawak Development Institute, Sarawak, Malaysia, pp. 243-253.
- Salmah, Z. (1992) *Water management in deep peat soils in Malaysia*. PhD Thesis, Silsoe College, Cranfield Institute of Technology, U.K.
- Takahashi, H., Shimada, S., Ibie, B.I., Usup, A., Yudha and Limin, S.H. (2002). Annual changes of water balance and a drought index in a tropical peat swamp forest of Central Kalimantan, Indonesia. In: Rieley, J.O., Page, S.E. with Setiadi, B. (eds), *Peatlands for People: Natural Resource Functions and Sustainable Management, Proceedings of the International Symposium on Tropical Peatland, 22-23 August 2001, Jakarta, BPPT and Indonesian Peat Association*, pp. 63-67.
- Tie, Y.L. and Esterle, J.S. (1991) Formation of lowland peat domes in Sarawak, Malaysia. *Proceedings of the International Symposium on Tropical Peatland*. Kuching, Sarawak, pp: 81-90.
- Ven, G.P. (1996) *Man-made Lowlands. History of water management and land reclamation in the Netherlands*. Matrijs, Utrecht, The Netherlands, 1993, 293 pp.
- Wösten, J.H.M. and Ritzema, H.P. (2001) Land and water management options for peatland development in Sarawak, Malaysia. *International Peat Journal*, 11, 59–66.
- Wösten, J.H.M., Ritzema, H.P., Chong, T.K.F. and Liong, T.Y. (2003) Potentials for peatland development. In: Chew, Dr. D. and Sim Ah Hua (Ed.). *Integrated Peatland Management for sustainable development. A Compilation of Seminar Papers*. Sarawak Development Institute, Sarawak, Malaysia, pp: 233-242.

ASSESSING THE WATER BALANCE OF TROPICAL PEATLANDS BY USING THE INVERSE GROUNDWATER MODELLING APPROACH

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SUMMARY

The understanding and proper management of the groundwater system are key factors for sustainable land development and effective soil and nature conservation in tropical peatlands. To assess the water balance in tropical peat swamps, a methodology based on a groundwater-balance approach was developed. Two groundwater modelling packages, MODFLOW and SIMGRO, were applied to quantify the groundwater recharge by assessing the water balance in three peat swamps in south-east Asia. As water flows in tropical peatlands are extremely difficult to measure, the models were calibrated using rainfall and groundwater levels. This inverse modelling approach required fewer data than the traditional water-balance method.

Keywords: hydrology, tropical peatland, hydrology, water balance, groundwater modelling.

INTRODUCTION

To be able to feed the growing world population and to banish hunger, food production needs to be doubled in the next 25 years. In south-east Asia, where fertile land has become scarce, agriculture development more and more focuses on marginal soils such as peatlands, acid sulphate soils, and steep land. Peatlands in south-east Asia cover about 27.1 Mha, or about 10% of the total land area (Hooijer et al., 2006). These peatlands, which are waterlogged most time of the year, are dome-shaped. Both the Indonesian and Malaysian Governments have identified their coastal peat swamps as major regions for agricultural development. These lowland peat swamps are purely rain-fed and waterlogged most times of the year (Ritzema and Wösten, 2002). Drainage is needed to make these waterlogged lands suitable for agriculture or other land uses. The resulting subsidence process threatens the sustainable use of the fragile ecosystems (Rieley *et al.*, 2002). Many development projects on tropical peatlands have failed through a lack of understanding of the natural functions of these complex ecosystems. It will only be successful if the principles and practices of sustainable 'wise use', especially with respect to hydrology and water management are taken into account (Rieley and Page, 2005).

The understanding and proper management of the groundwater system are key factors for sustainable land development and effective soil and nature conservation in tropical peatlands. The tropical peatlands in Indonesia and Malaysia are, generally, characterised by elevated rainfall figures, which largely exceed the potential evapotranspiration. The infiltration capacity of the peat soils, together with the transmissivity, do not permit the discharge of all excess precipitation and large volumes of water are, therefore, discharged by surface runoff (including interflow)

and surface water courses. Only a small portion of the precipitation excess recharges the groundwater. The groundwater recharge pattern, the geometry and the hydraulic properties of the soils determine the groundwater regime of the peatlands. Any land development may impact on the groundwater regime, which may then trigger a number of derivative impacts, such as soil subsidence and environmental degradation. It is, therefore, imperative to analyse and assess the groundwater system in any peatland development or conservation scenario.

The form of a peat dome can be considered to reflect the form of a saturated water mound (Ingram, 1982). As groundwater flows in tropical peatlands are extremely difficult to measure, the models are calibrated using rainfall and groundwater levels. This inverse modelling approach required fewer data than the traditional water-balance method (Boonstra and Bhutta, 1996).

MATERIALS AND METHODS

A wide variety of groundwater models are presently available. In the ongoing research on peatlands in Malaysia and Indonesia two groundwater modelling packages are being applied, MODFLOW and SIMGRO. The hydrological model SIMGRO (SIMulation of GROundwater and surface water levels) is a distributed physically-based model that simulates regional saturated groundwater flow, unsaturated flow, actual evapotranspiration, irrigation, stream flow, groundwater and surface water levels, and groundwater abstraction (Querner, 1997; Van Walsum, 2004). The model is used within the GIS environment Arcview (user interface ALTERRAQUA). This allows the use of digital geographical information, such as soils, maps, land use, water courses, etc., that can be converted in to input data. Further use is the graphical presentation and analysis of results and/or specific input parameters. MODFLOW is a (pseudo-)3D groundwater modelling package, developed by the U.S. Geological Survey, which is nowadays one of the most widely used packages. The model is based on the *finite-difference* calculation technique and is capable to simulate the effects of wells, rivers, drains, and other groundwater recharge (or discharge) functions (www.modflow.com). A major challenge in using the groundwater models in the tropical peat swamps of SE-Asia is that there is generally a lack of (reliable) data sets, especially long-term data records. For this research, the PWWIN 5.0-79 simulation package was selected because it offers good pre- and post-processing options, requires not too much input data, is well documented and can easily be extended with additional modules (Ritzema *et al.*, 2003).

MODFLOW was used to simulate the groundwater flow in the Balingian area, a tropical peat dome of about 10,000 ha in the Central Region of Sarawak, Malaysia (3⁰ 00' N, 112⁰ 36' E). The Government of Sarawak (Malaysia) has identified the populated coastal zone of Sarawak as a major region for agricultural development. In total, 2 million hectares of coastal lowlands will be developed for oil palm, forest plantation, sago, aquaculture, paddy, and miscellaneous crops including vegetables (Ritzema *et al.*, 2003). It is estimated that between 300,000 and 535,000 hectares of the proposed agricultural area is on peat, located mainly in the Central Region. The land-use in the Balingian area is characterised by a smallholder sub-sector, mainly sago, subsistence padi, coconut and peri-urban horticulture, and a large-scale oil palm plantations. Besides the agricultural land-use, some parts of the dome are still in their natural state. E.g. tropical peat forest (Ritzema *et al.*, 2004).

SIMGRO was used to model the Air Hitam Laut (meaning “Black Water flowing to the Sea”) catchment area, located in the eastern lowlands of Jambi Province, Sumatra Indonesia ($1^{\circ} 42' - 2^{\circ} 05' \text{S}$, $103^{\circ} 52' - 104^{\circ} 34' \text{E}$). The central part of this catchment (220 000 ha) is occupied by Berak National Park, which is under threat due to illegal logging and the conversion into oil palm plantations and agricultural lands of the surrounding areas (Wösten *et al.*, 2006). SIMGRO was also used to study the catchment of Sungai (=river) Sabangau in Central Kalimantan, Indonesia ($2^{\circ} 15' - 3^{\circ} 06' \text{S}$, $113^{\circ} 33' - 114^{\circ} 01' \text{E}$). This area consists of both the relatively intact Sabangau catchment, the last remaining, large continuous area (13,000 km²) of dense peat swamp forest in Borneo and the degraded Block C of the former Mega Rice Project (Wösten *et al.*, 2006; Wösten *et al.*, 2008).

Two conflicting conceptualizations of peatland hydrology currently exist: “shallow-flow” and “groundwater flow” hypotheses (Reeve *et al.*, 2000). The shallow flow model assumes mainly flow through the uppermost layer (acrotelm) and neglects vertical flow. In the groundwater flow models this vertical flow is more important. In the simulations, the peat domes were schematized as a one-layered, unconfined aquifer with the mineral subsoil as the bottom boundary. The mineral subsoil was considered to be impervious. The top boundary was the soil elevation of the peat layer, which in the waterlogged peat soils, is also the elevation of the groundwater level. The hydraulic conductivity is an important parameter in peat land hydrology. Ingram (1982) assumed a uniform hydraulic conductivity throughout the profile, but others argue that the hydraulic conductivity decreases with depth, see e.g. (Armstrong, 1995).

RESULTS

For Balingian, the model was calibrated using the recharge as input and the elevation of the groundwater table as output (Grobbe, 2003). The hydraulic conductivity of the peat domes is high, but varies considerably with the type of peat and the degree of humification (Wösten and Ritzema, 2001). For the model simulation, the horizontal hydraulic conductivity in the peat layer was assumed at 30 m/d, based on long-duration pumping test data (Ong and Yogeswaran, 1992). Using these hydraulic conductivity values the simulated groundwater levels were far too high. A sensitivity analysis conducted for the horizontal hydraulic conductivity showed that the hydraulic conductivity had to be increased to unrealistic high values ($> 180 \text{ m/d}$) to obtain acceptable groundwater levels, thus the value of the hydraulic conductivity was left unchanged. Subsequently, a value of the recharge was determined using the inverse modelling package PEST, which is part of the PMWIN programme. Results indicate that the total amount of recharge, i.e. around 40 mm/year or about 1% of the total rainfall, is considerably lower than found in previous studies (around 220 mm/year or 6% of the total rainfall, (SWRC, 1997), but more in agreement with results found in European peat domes (Van der Schaaf, 1999). Sensitivity analysis of the horizontal hydraulic conductivity shows that the assumed value (30 m/d) is quite realistic.

The hydrology of the Air Hitam Laut and the Sebangau watersheds were modelled with the SIMGRO. To use SIMGRO, a Digital Elevation Model (DEM) of the peat surface was created using radar imagery (Wösten *et al.*, 2006). The model was calibrated using measured and calculated groundwater levels at representative sites in the watershed, measured and calculated discharge rates in the catchments and

calculated and observed flooding patterns as deduced from radar images (Siderius, 2004; Clymans, 2006). An analysis showed that model simulations were not so much affected by hydraulic conductivity, but were very sensitive for precipitation and evapotranspiration, drainage levels and resistance, runoff fractions and storage.

DISCUSSION

The groundwater recharge is difficult to quantify. The direct measurement of groundwater recharge is almost impossible. Water balance studies showed that the groundwater recharge is only a small component compared to evapotranspiration and surface runoff. As a consequence, groundwater recharge can only be determined tentatively through water balances. Existing water balances show that the groundwater recharge amounts to 6% of the precipitation (SWRC, 1997). The groundwater model of the Balingian area, Sarawak, Malaysia, was calibrated with only 1.1 % of the rainfall (representing 41 mm/year) (Grobbe, 2003). This area is characterised by high rainfall figures (3700 mm per year). The Balingian model was calibrated for a steady-state situation.

The peatlands of the Sungai Sebangau catchment in Central Kalimantan, Indonesia, were modelled with SIMGRO. A period of almost 9 years was simulated, including 8 entire calendar years (1994-2001). The groundwater recharge was determined for these 8 years. Although that these values should be interpreted with caution (given that in some years a significant change in storage was calculated), indications are that the groundwater recharge is dependent on the precipitation (Figure 1). The calculated annual groundwater recharge varies from 80 to 100 mm. The figure shows that the groundwater recharge would be approximately 2.5 % in the case of 3700 mm precipitation (such as in Balingian). This value is reasonably in line with the calibrated value of 1.1 % (with the MODFLOW model).

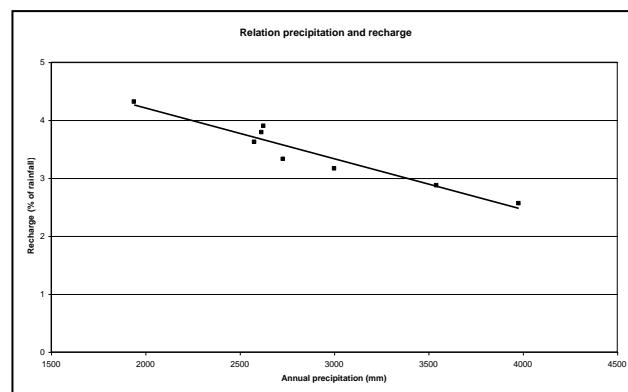


Figure 1 Groundwater recharge Sungai Sebangau catchment (SIMGRO model)

The water balances of the unsaturated zone, as calculated by SIMGRO (Sungai Sebangau catchment), show that the interception and surface runoff are minor in comparison with the evapotranspiration and percolation term. The 30-days moving averages of daily water balances (Figure 2A) and the quarterly water balances (Figure 2B) shows that almost all precipitation excess percolates into the soil (N.B: this is not the groundwater recharge). These graphs were also generated for 5 representative sub-

catchments as well as 5 representative nodal points, all showing the same pattern. The modelling of the unsaturated zone, therefore, does not give much additional information. This may be different when simulations with deeper groundwater are conducted (e.g. scenario simulations).

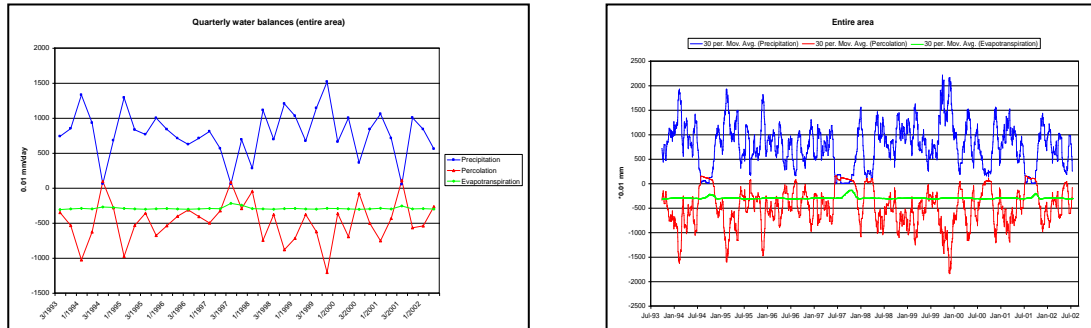


Figure 2 Daily (A) and Quarterly (B) water balances of the unsaturated zone

The water balances of the saturated zone, as calculated by SIMGRO (Sungai Sebangau catchment), show that most of the percolated water is discharged by the surface water system (3 different surface water systems were defined). The 30-days moving averages of daily water balances (Figure 3) shows that almost all percolation from the unsaturated zone is discharged by the surface water system and that only a minor quantity recharges the groundwater (N.B: this is the leakage term).

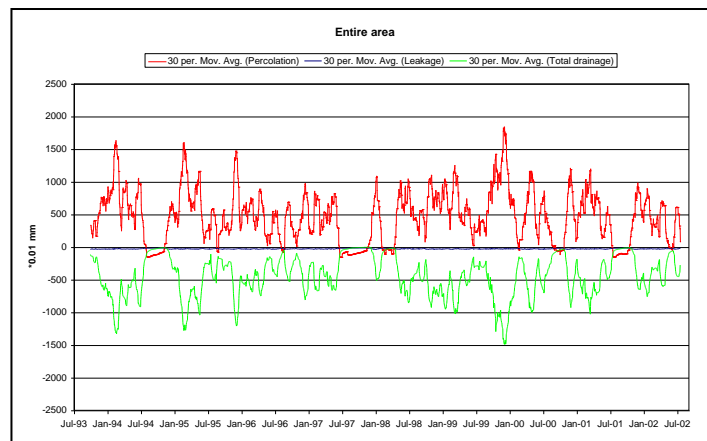


Figure 3 Water balances saturated zone (entire area).

CONCLUSION

Two groundwater modelling packages, MODFLOW and SIMGRO, were applied to quantify the groundwater recharge by assessing the water balance in three peat swamps in south-east Asia. Although actual field data was scarce, the initial results are rather promising: the models were calibrated by simulating groundwater table fluctuations based on actual rainfall data. Inverse modelling was used to access the recharge to the groundwater. The simulations showed that the model were not so much affected by hydraulic conductivity, but were very sensitive for precipitation and

evapotranspiration, drainage levels and resistance, runoff fractions and storage. Although the hydraulic conductivity is high, the gradients in hydraulic head are small and thus also the groundwater flows. Thus fluctuations in the watertable are mainly influenced by processes in the unsaturated zone. Both models need accurate data on the elevation, a more accurate DEM will improve outcomes. A major difference between the two models is the groundwater recharge from precipitation. In MODFLOW this value is principally determined by model calibration. In SIMGRO the unsaturated zone is simulated through a reservoir model of the root zone. The capillary flux from the groundwater to the root zone is dependent of the groundwater depth. SIMGRO, therefore, requires daily values of the rainfall and evapotranspiration. The model also requires the soil physical properties (calculate capillary fluxes and the storage coefficient). With this information, SIMGRO *calculates* the groundwater recharge. In MODFLOW the interaction between the groundwater and surface water is described by two recharge/discharge relations: (i) rivers (both recharge and discharge of groundwater are possible), and (ii) drains (only groundwater discharge). The water levels (drain levels) are constant during each 'stress period', i.e. the water levels are not influenced by groundwater inflow or outflow into/from the surface water system. In SIMGRO the surface water system is integrated with the groundwater model. Five different surface water systems can be described. The surface water level is calculated by the model.

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The research activities presented in this paper are conducted in the framework of the projects “Research into drainage and water management guidelines for agricultural development in coastal peat swamps of Sarawak”, “Promoting the river basin and ecosystem approach for sustainable management of south-east Asian lowland peat swamp forest” and “Restoration of tropical peatland to promote sustainable use of renewable natural resources/RESTORPEAT”. This paper could not have been written without the data and support provided by these projects.

REFERENCES

- Amstrong, A.C., 1995. Hydrological model of peat-mound form with vertically varying hydraulic conductivity. *Earth Surface Processes and Landforms* 20, 473-477.
- Boonstra, J., Bhutta, M.N., 1996. Groundwater recharge in irrigated agriculture: the theory and practice of inverse modelling. *Journal of Hydrology* 174, 357-374.
- Clymans, E. 2006. Hydrological modelling for protection and restoration of degraded tropical peatlands, Wageningen University, Wageningen.
- Grobbe, T. 2003. REPEAT: Decision Support System for Water Management Strategies in Tropical Peatlands. , Larenstein University, Velp.
- Hooijer, A., Silvius, M.J., Wösten, J.H.M., Page, S., 2006. PEAT-CO2, Assessment of CO2 emissions from drained peatlands in SE Asia. Delft Hydraulics, Delft, pp. 41.
- Ingram, H.A.P., 1982. Size and shape in raised mire ecosystems: a geophysical model. *Nature* 297, 300-303.

- Ong, B.Y., Yogeswaran, M., 1992. Peatland as a resource for water supply in Sarawak. In: Aminuddin, B.Y. (Ed.), *Tropical Peat: proceedings of the Int. Sym. on Tropical Peatland*, 6-10 May, 1991. Malaysian Agricultural Research and Development Institute, Kuching, pp. 255-268.
- Querner, E.P., 1997. Description and application of the combined surface and groundwater flow model MOGROW. *Journal of Hydrology* 192, 158-188.
- Reeve, A.S., Siegel, D.I., Glaser, P.H., 2000. Simulating vertical flow in large peatlands. *Journal of Hydrology* 227, 207-207.
- Rieley, J.O., Page, S.E., Setiadi, B., 2002. Peatlands for People: Natural Resource Functions and Sustainable Management. *Proceedings of the International Symposium on Tropical Peatland*, 22-23 August 2001. BPPT and Indonesian Peat Association, Jakarta, pp. 271.
- Rieley, J.O., Page, S.E. (Eds.), 2005. *Wise Use of Tropical Peatlands - Focus on Southeast Asia*. ALTERRA, Wageningen.
- Ritzema, H.P., Wösten, J.H.M., 2002. Water Management: The Key for the Agricultural Development of the Lowland Peat Swamps of Borneo. *International Workshop on Sustainable Development of Tidal Areas*. International Commission on irrigation and Drainage, Montreal, pp. 101-113.
- Ritzema, H.P., Grobbe, T., Chong, T.K.F., Wösten, J.H.M., 2003. Decision Support System for Peatland Management in the Humid Tropics. 9th International Drainage Workshop, 10-13 September 2003. Alterra-ILRI, Utrecht.
- Ritzema, H.P., Veltman, D., Wösten, J.H.M., 2004. A system to support decision making for peatland management in the humid tropics. In: Päivänen, J. (Ed.), *Wise use of peatlands*, 12th Int. Peat Congress, 6-11 June 2004, Vol. I, Tampere, Finland, pp. 720-725.
- Siderius, C., 2004. Modelling of hydrological processes of the Air Hitam Laut watershed and the impact of various land use scenarios. Water for food and ecosystems programme project on: 'Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peatswamp forests'. Alterra, Wageningen.
- SWRC, 1997. *Sarawak Water Resources Study Projects - Final Report*. PS Konsultant, Montgomery Watson, Australia, and the Centre for Water Research (CWR), Sarawak Water Resources Council.
- Van der Schaaf, S. 1999. Analysis of the hydrology of raised bogs in the Irish Midlands: a case study of Raheenmore Bog and Clara Bog, Wageningen University, Wageningen.
- Van Walsum, P.E.V., 2004. SIMGRO 5.0.1, theory and model implementation. Alterra, Wageningen, pp. Alterra Rep. No. 913.1, 96.
- Wösten, J.H.M., Ritzema, H.P. 2001. Land and Water Management Options for Peatland Development in Sarawak. *International Peat Journal* 11, 59-66.
- Wösten, J.H.M., Hooijer, A., Siderius, C., Rais, D.S., Idris, A., Rieley, J.O. 2006. Tropical peatland water management modelling of the Air Hitam Laut catchment in Indonesia. *Intl. J. River Basin Management* 4, 233-244.
- Wösten, J.H.M., Clymans, E., Page, S.E., Rieley, J.O., Limin, S.H., L. 2008. Peat-water interrelationships in a tropical peatland ecosystem in Southeast Asia. *Catena* 73: 212-224.

PEAT - WATER INTERRELATIONSHIPS IN A TROPICAL PEATLAND ECOSYSTEM IN SOUTHEAST ASIA

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SUMMARY

Implications of groundwater level fluctuations were studied using a hydrogeological modelling approach for adjacent relatively intact and degraded peatland in Central Kalimantan, Indonesia. Ideally, to prevent subsidence and fire, groundwater levels should be maintained between 40 cm below and 100 cm above the peat surface. Calculated groundwater levels for different years and for different months within a single year showed that these levels can drop lower than the critical threshold of 40 cm below the peat surface whilst flooding of more than 100 cm above the surface was also observed. The relatively intact peatland showed resilience towards disturbance of its hydrological integrity whereas the degraded peatland was susceptible to fire.

Keywords: hydrogeological modelling; peat subsidence; fire susceptibility; peat humification; peatland restoration

INTRODUCTION

The study area is the catchment of Sungai (= river) Sabangau in Central Kalimantan, Indonesia. Sg. Sabangau is a blackwater river that originates in, and drains, the last remaining, large continuous area (13,000 km²) of dense peat swamp forest in Borneo. The area between the Sg. Sabangau and the Sg. Kahayan is 'Block C' of the former Mega Rice Project area. Since the study location consists of both the relatively intact Sabangau catchment and the degraded Block C of the former Mega Rice Project, it is possible to compare two contrasting peatland landscapes in terms of their fire susceptibility. Annual precipitation for the period 1994 – 2004, used in the hydrogeological modelling fluctuates considerably (Takahashi *et al.*, 2004). Over this 11 year period, 1997 was the driest year with 1848 mm rainfall, 2003 was a 'normal' year with 2570 mm rainfall and 1999 was the wettest year with 3788 mm rainfall. In unsaturated tropical peatlands, almost all of the rainfall infiltrates owing to the high hydraulic conductivity of the surface peat layer (Takahashi and Yonetani,

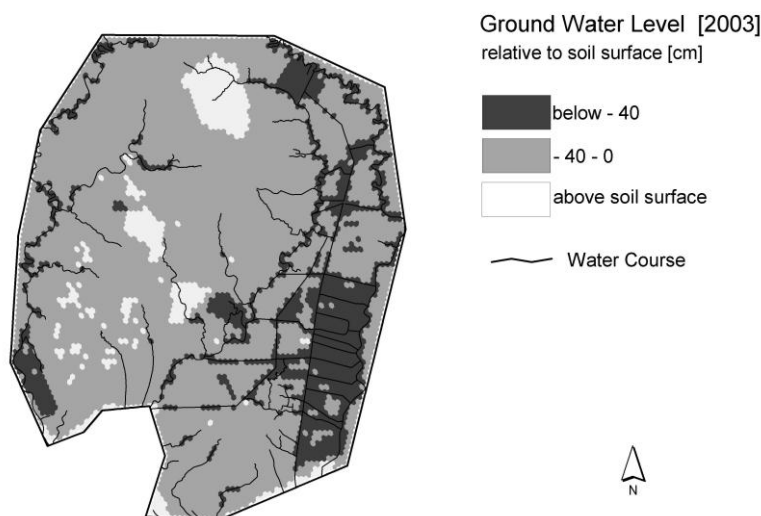
1997). When the groundwater level in tropical peat drops below 40 cm from the surface, which under hydrostatic equilibrium is equivalent to a pressure head of -4 kPa, the moisture content of the barely humified top layer decreases from about 0.90 cm³ cm⁻³ at saturation to about 0.50 cm³ cm⁻³ at a pressure head of -4 kPa (Rieley and Page, 2005), thus making it susceptible to fire (Takahashi *et al.*, 2003; Usup *et al.*, 2004).

MATERIALS AND METHODS

The soil elevation map prepared by the Indonesian National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL, 1997) was used to generate a DEM. The physically-based SIMGRO (SIMulation of GROundwater flow and surface water levels) model was used to simulate water flow in the saturated zone, unsaturated zone, river channels and over the peat surface (Dik, 2004). The hydraulic conductivity and also the moisture retention relationship of the peat is strongly influenced by the degree of humification of the peat. Based on hydraulic conductivity measurements using the pumping test method as reported by Ong and Yogeswaran (1992) and by Takahashi and Yonetani (1997) the peat profile in this study is schematized in a two layer system consisting of a fibric to hemic peat top layer (0-100 cm) with an average saturated hydraulic conductivity of 30 m d⁻¹ and a deeper, sapric peat layer with an average saturated hydraulic conductivity of 0.5 m d⁻¹. The two layer system applied in this study is consistent with the ‘acrotelm’ or surface layer and ‘catotelm’ or deeper layer concept as used to stratify boreal and temperate peatlands (Ingram, 1978). Differences in peat thickness and hydraulic conductivity result in hydraulic transmissivities (cumulative thickness multiplied with conductivity) ranging from 30 to 40 m² d⁻¹.

RESULTS

Groundwater levels calculated for July in the non El Niño year 2003 (map at top of Fig. 1) reveal that 23% of the study area was below the critical threshold of 40 cm and thus at high fire risk. In July 1999, however, the area at risk was only 2% (map at bottom of Fig. 1).



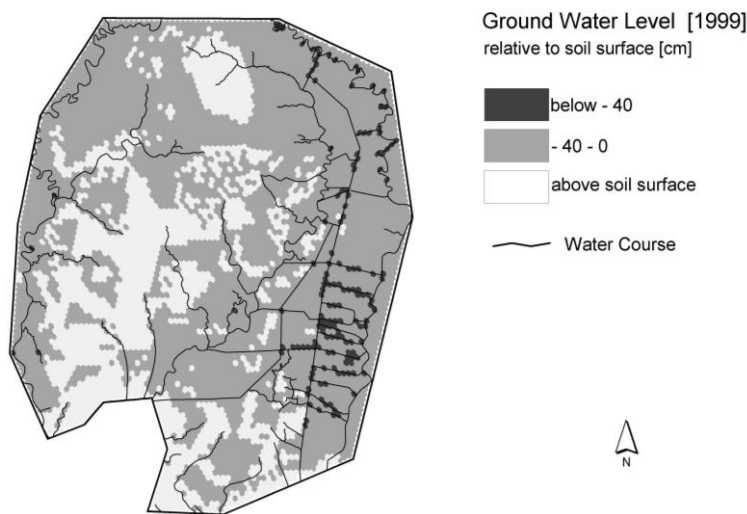


Figure 1 Calculated groundwater levels in the study area for the month of July in the normal year 2003 with 2570 mm rainfall (top) and in the wet year 1999 with 3788 mm rainfall (bottom).

In contrast, 40% of the area was prone to fire in July 1997 (El Niño year) showing that there is considerable variation in fire risk from year to year depending upon annual rainfall, length of the dry season and consequent depth of the groundwater level below the peat surface. Comparison of the relatively intact peat swamp forest in the Sabangau catchment with the degraded peatland in Block C shows that in the 3 years, 1997, 1999 and 2003, groundwater levels were lower in the latter and therefore the associated fire risks were higher. This highlights the negative effect of the drainage canals on peatland hydrology in Block C that are leading to enhanced peat oxidation, subsidence and loss of stored carbon (Page *et al.*, 2002). The calculated groundwater levels for the 15th day of every month (Fig. 2) show that from January to May they seldom dropped below 40 cm.

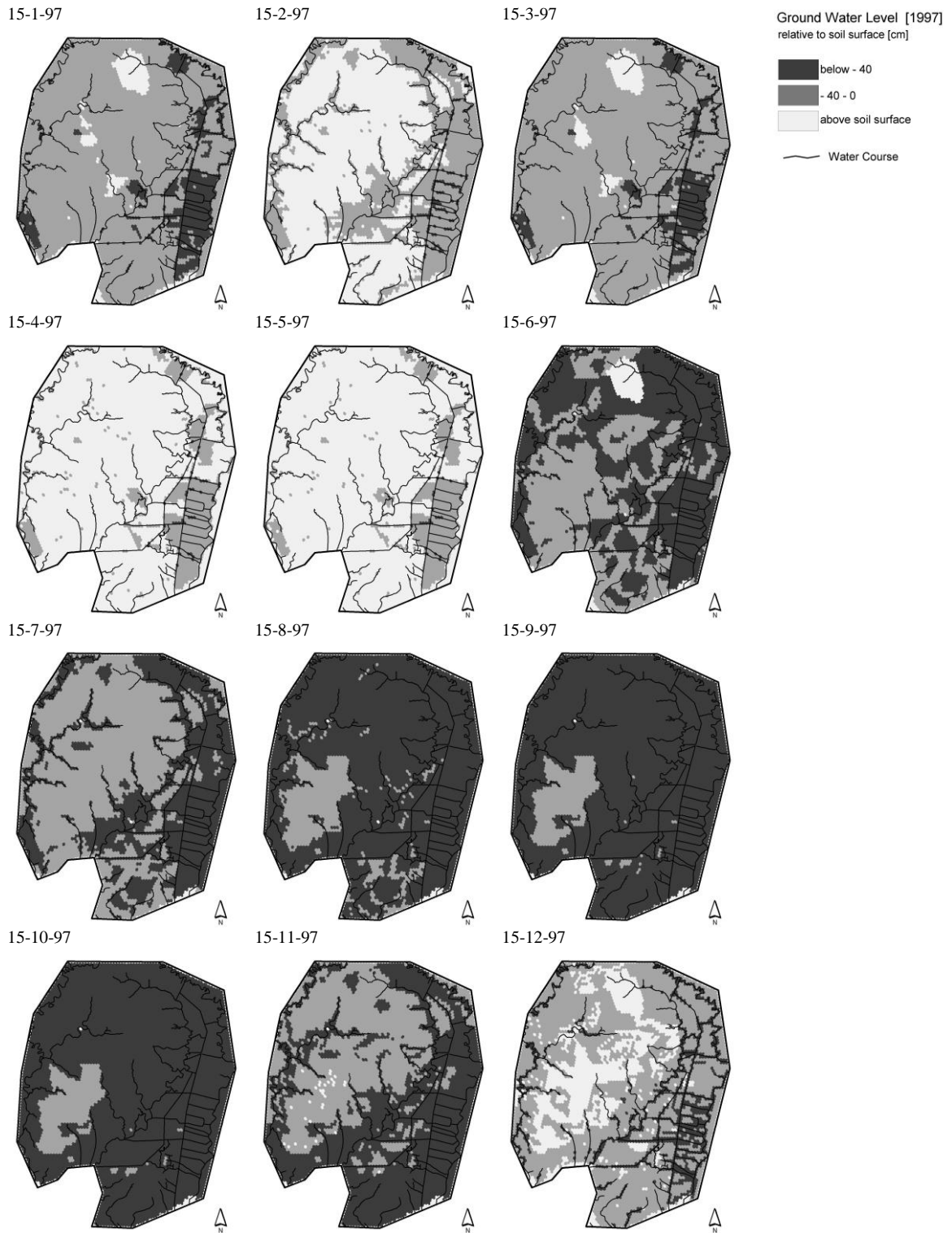


Figure 2 Calculated groundwater levels in the study area for the dry year 1997 at every 15th day of the month.

Flooding occurred in February, April and May but from June onwards groundwater levels dropped progressively and sharply, with the result that water levels were below the 40 cm critical threshold in 91% of the area by October and therefore susceptible to fire. By the same time, 33% of the area had groundwater levels deeper than 100 cm

below the surface making these an extreme fire risk. By November and December groundwater levels had started to rise once more resulting in some flooding in December. Groundwater level rise occurs some time after the rain commences owing to water retention within the dry surface peat as the water reservoir recharges (Fig. 2). From Fig. 2 it is also evident that the Sabangau catchment returned to its original hydrological status in December 1997, whereas Block C remained drought affected and thus susceptible to fires for longer. Maps of groundwater levels can thus be used in land utilisation and restoration planning, for example, to indicate where hydrological restoration efforts should be targeted, as well as in fire hazard warning systems.

CONCLUSION

This study shows that water management is a key element in the wise use of peatlands. In dry years groundwater levels drop below the critical threshold of 40 cm. Deep groundwater levels mean an increased subsidence of the peat by oxidation as well as an increase in fire susceptibility. Both oxidation and fire transform peatlands from carbon sinks under pristine conditions into carbon sources with important local, regional and global consequences under drained conditions. In wet years, flooding depth and flooding duration have adverse consequences for the restoration potential of peatlands. Ideally, groundwater levels should vary between 40 cm below and 100 cm above the land surface. Comparison of the adjacent relatively intact Sabangau catchment and the degraded Block C area reveals that in their natural state, tropical peatlands show sufficient resilience to disturbance provided their hydrological integrity is maintained or restored. Once they are in a degraded state, however, tropical peatlands become an increasingly fragile ecosystem that is likely to disappear.

ACKNOWLEDGEMENT

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REFERENCES

- BAKOSURTANAL (1997). National Coordinating Agency for Surveys and Mapping, Jakarta, Indonesia. www.bakosurtanal.go.id
- Dik, P.E. (2004). *SIMGRO 4.1.2 User's Guide*, Alterra-Report 913.3 ISSN 1566-7197, Alterra, Green World Research, Wageningen.
- Ingram, H.A.P. (1978). Soil layers in mires: function and terminology. *Journal of Soil Science* 29, 224-227.
- Ong, B.Y. and Yogeswaran, M. (1992). Peatland as a resource for water supply in Sarawak. In B.Y. Aminuddin, S.L. Tan, B. Aziz, J. Samy, Z. Salmah, Siti Petimah, S.T. Choo (eds.), *Proceedings of the International Symposium on Tropical Peatland, Kuching, Sarawak, May. 1991*, pp. 255-268. Ministry of Agriculture Malaysia.
- Page, S.E., Siegert, F., Rieley, J.O., Böhm, H-D.V., Jaya, A. and Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia in 1997. *Nature* 420, 61-65.

- Rieley, J.O. and Page, S.E. (2005). *Wise Use of Tropical Peatlands: focus on Southeast Asia*. Alterra, Wageningen University and the EU INCO STRAPEAT and RESTORPEAT Partnerships, Wageningen, the Netherlands, ISBN: 90327 0347 1, 266 pp. www.restorpeat.alterra.wur.nl
- Takahashi, H. and Yonetani, Y. (1997). Studies on microclimate and hydrology of peat swamp forest in Central Kalimantan, Indonesia. In J.O. Rieley and S.E. Page (eds.), *Biodiversity and Sustainability of Tropical Peatlands*, pp. 179-187. Samara Publications, Cardigan, United Kingdom.
- Takahashi, H., Usup, A., Hayasaka, H. and Limin, S.H. (2003). Estimation of ground water levels in a peat swamp forest as an index of peat/forest fire. *Proceedings of the International Symposium on Land Management and Biodiversity in Southeast Asia, Bali, Indonesia, 17-20 September 2002*, pp. 311-314. Hokkaido University Japan and Indonesian Institute of Sciences.
- Takahashi, H., Usup, A., Hayasaka, H., Kamiya, M., Limin, S.H. (2004). The importance of ground water level and soil moisture of subsurface layer on peat/forest fire in a tropical peat swamp forest. In J. Päivänen (eds.), *Wise Use of Peatlands. Volume 1. Proceedings of the 12th International Peat Congress, Tampere, Finland, 6-11 June 2004*, p. 760. International Peat Society.
- Usup, A., Hashimoto, Y., Takahashi, H. and Hayasaka, H. (2004). Combustion and thermal characteristics of peat fire in tropical peatland in Central Kalimantan, Indonesia. *Tropics* 14, 1-19.

WATER MANAGEMENT FOR MULTIPLE WISE USE OF TROPICAL PEATLANDS

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SUMMARY

Land use changes and associated fires change profoundly the hydrology of tropical peatlands and thus affect the functioning of entire river basins. A hydrological model was used to calculate the effects of drainage on groundwater levels, peat surface morphology and river flows for the Air Hitam Laut watershed in Jambi Province, Sumatra, Indonesia. The model was used to predict consequences of three possible scenarios: i) expansion of oil palm plantations upstream, ii) expansion of agriculture downstream and iii) continuing fire damage. Continued drainage for oil palm plantation development will result in a decapitated and reduced river basin. Reduced river discharge has a detrimental affect upon conservation of the Berbak National Park in the centre of the watershed and agriculture and fisheries in the coastal zone. Expansion of agriculture downstream causes peat subsidence, resulting in exposure of underlying, acid sulphate soils and intrusion of saline sea water. Continuing fires will increase considerably the area of permanently flooded land and thus constrain peatland restoration options.

Keywords: catchment modelling; scenario analysis; peat subsidence; land use change; fire.

INTRODUCTION

Peat swamp forests are characterized by their occurrence on organic substrates where the vegetation itself provides the material for the formation of the peat. Poor drainage, permanent waterlogging, high rainfall, and substrate acidification are conditions in which plant residues accumulate faster than they decay (Brady, 1997). Peat swamps are recognized as important reservoirs of biodiversity, carbon and water, and they exhibit a large range of important ecological and natural resource functions (Andriessse, 1988; Page and Rieley, 1998). This study focusses on the basin of the Air Hitam Laut (meaning “black water flowing to the sea”) River located in Jambi province, Sumatra, Indonesia (Figure 1). The river bisects Berbak National Park, which was established as a Ramsar site because of its representativeness of peat swamp forest habitats in Southeast Asia (Giesen, 2003; Silvius et al. 1984; Van Eijk and Leenman, 2004). In the early 1990s Berbak National Park made up about 30% of the remaining relatively undisturbed peat swamp forest in Sumatra, but over the last decades the area has been affected increasingly by fire. In 1981/82, fires in Berbak occurred mainly in peat swamp forest areas affected by coastal agricultural encroachments and illegal logging but, in 1992 and 1997/98, fires destroyed over 16,000 ha of primary forest in the core zone of the National Park. Hydrology is a key factor in the ecology of this increasingly threatened habitat, and thus water (and water

management) plays a key role in maintaining its support functions (Wösten and Ritzema, 2001; Hooijer, 2005; Siderius, 2005). The hydrology of the Air Hitam Laut river basin was studied using the SIMGRO (SIMulation of GROundwater flow and surface water levels) model. Considerable emphasis has been put on collecting the data required to input to this model, including elevation of the river basin (DEM), groundwater levels and rainfall. The calibrated and validated model is used to evaluate consequences of three possible scenarios:

1. Expansion of oil palm plantation upstream
2. Expansion of agriculture downstream and
3. Continuing fire damage.

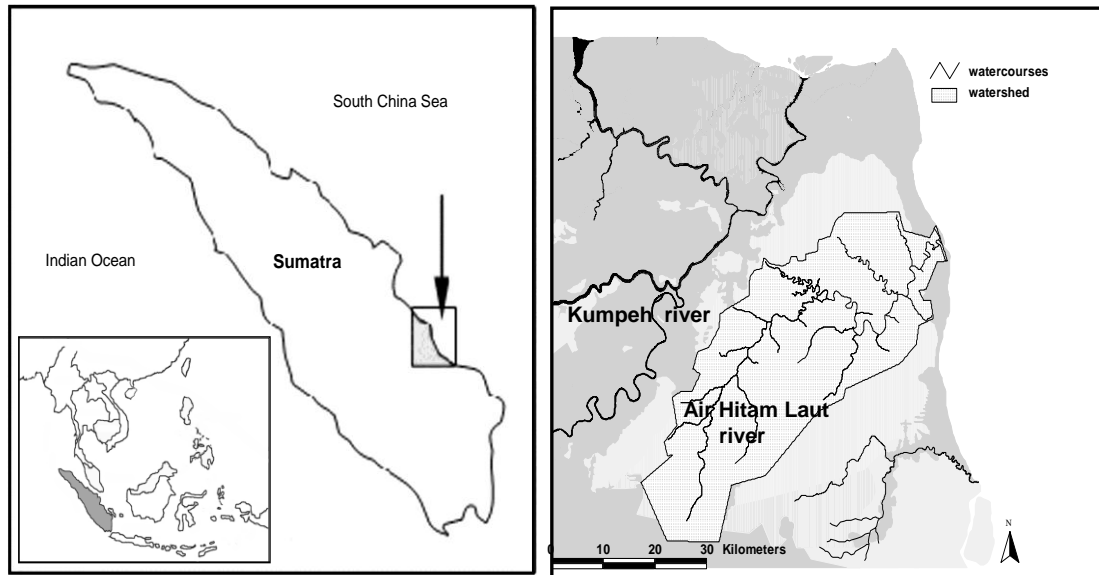


Figure 1 Location of the Air Hitam Laut watershed.

SCENARIO 1: EXPANSION OF OIL PALM PLANTATION UPSTREAM

Expansion of oil palm plantations in the upstream area of the Air Hitam Laut River basin is ongoing and may eventually cover the whole upstream area. Oil palm requires up to 70 cm drainage and thus induces subsidence of the peat surface. Figure 2 shows clearly the impact of 50 years of drainage and associated peat subsidence as calculated by the SIMGRO model. It demonstrates that peat elevation inside the plantation will be lowered by as much as 3-4 metres as a result of continuous drainage. Such subsidence will result in reduced water flow towards the Air Hitam Laut River as the gradient in that direction becomes less and less. As a consequence, the direction of drainage from the plantation area will gradually shift from the Air Hitam Laut River towards the lower-lying Kumpeh River (Figure 3). Eventually the whole upstream area will be decoupled from the Air Hitam Laut watershed and become part of the Kumpeh watershed. This will result in a great reduction in the amount of water entering Berbak National Park. Decoupling of the upstream area will also result in considerably decreased discharge rates of river water entering the downstream coastal area leading to a serious decrease in agricultural production.

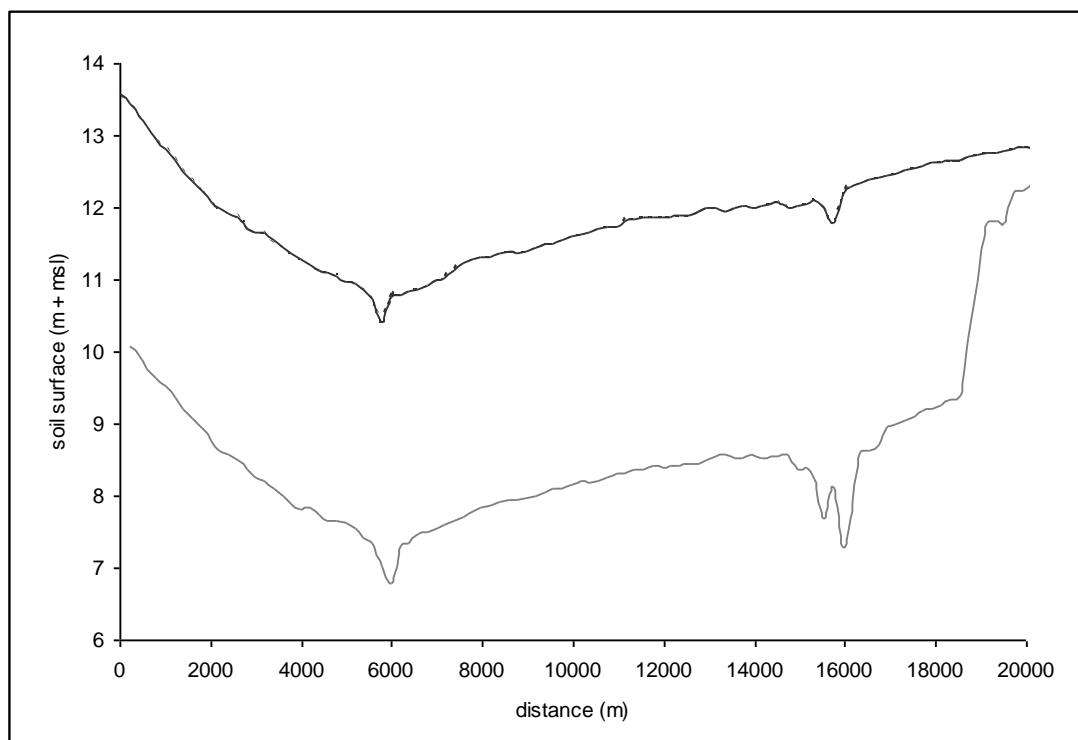


Figure 2 Cross section of peat surface elevation in the upstream area in the present situation (black line) and after 50 years of drainage and associated subsidence (gray line) for oil palm cultivation.

SCENARIO 2: EXPANSION OF AGRICULTURE DOWNSTREAM (COAST)

Areas under agricultural use downstream in the Air Hitam Laut River basin expanded in response to population growth in the coastal zone. An average subsidence over the whole area of about 4.5 cm/year will result in a total subsidence of more than 2 meters of peat after 50 years. Thus peat in the agricultural area will have totally disappeared after 50 years in about 1/3 of the area, whereas 50% will have only a thin layer of peat left. The mineral subsoil in the agricultural area is located at an elevation of approximately 3 m above mean sea level. Because the mineral subsoil is of marine origin and contains pyrite it is very likely that problems related to the occurrence of acid sulphate soils (now already encountered by the local people) will also increase in the future. Decreased discharge rates of river water caused by expansion of oil palm plantations in the upstream area will also increase the negative effects of salt sea water intrusion in the coastal agricultural areas. Both impacts will make agricultural production in the coastal zone more difficult and less sustainable.

SCENARIO 3: CONTINUING FIRE DAMAGE

Fire damage in the Air Hitam Laut watershed is difficult to predict, but no matter what fire prevention measures are taken, fires are likely to occur in the future. To show the impact of peat fires a new surface map (DEM) was constructed simulating the situation after more large areas have been burned. In the preparation of this map, areas were selected that had a groundwater level deeper than 1 m below soil surface during the long dry period in the El Niño year 1997. These areas are considered to be

prone to fires and they are most likely to burn in a future dry year. The assumption is made that fires will cause a lowering of the surface elevation of the affected areas by 1 metre. The combination of these newly burned areas with the already burned ones results in a new surface map (DEM). This new DEM was used to calculate groundwater levels and flooding patterns. The impact on the hydrology and more important on the flooding extent shows that the deeply flooded areas with more than 1.5 m inundation will increase by almost a factor 5. This will seriously constrain peatland restoration possibilities.

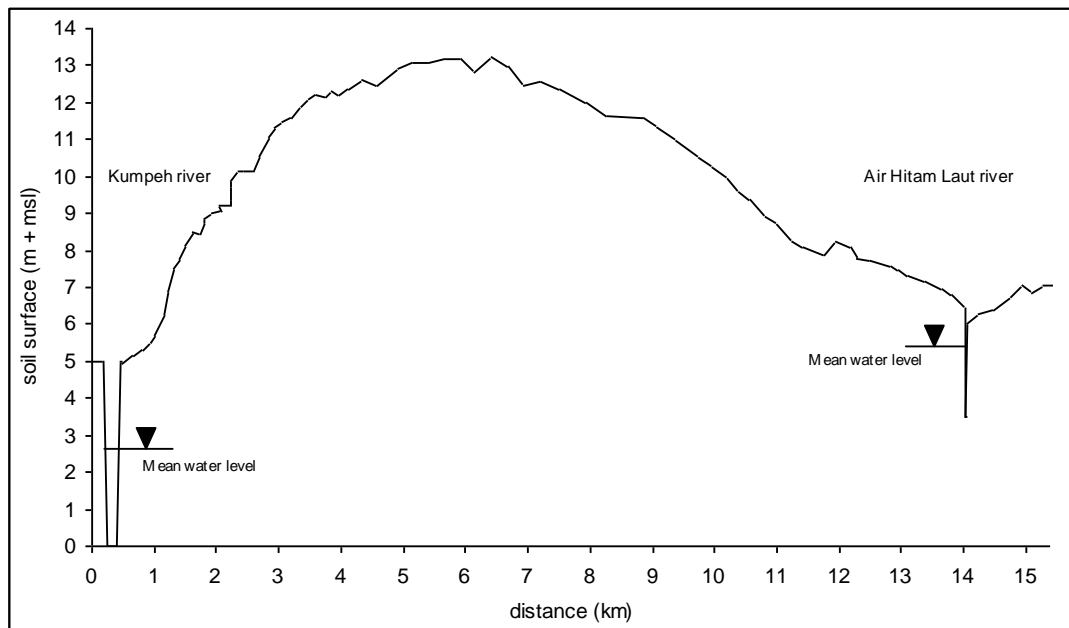


Figure 3 Cross section of peat surface elevation between the Kumpeh and Air Hitam Laut Rivers.

DISCUSSION AND CONCLUSION

The many human induced land use changes observed in the Air Hitam Laut River basin all cause groundwater levels to be lowered as a result of drainage. This has negative consequences in terms of increased soil subsidence and fire susceptibility. Restoration and conservation of peat swamp forests in the Berbak National Park necessitate restoring the hydrological integrity of the river basin in order to maintain groundwater levels at or close to soil surface. Sustainable development of agriculture along the coast requires maintenance of the dynamic hydrological balance of the Air Hitam Laut River basin. The envisaged land-use changes in the upper part of the Air Hitam Laut River basin pose a huge and hitherto unknown threat to downstream human livelihoods and biodiversity. The hydrological model has helped to reveal this threat before it is too late to reverse it. Actions, however, require conservation of the peat swamp forest in the upstream area and immediate cessation of further land conversion to agriculture that requires drainage. For restoration and conservation to be sustainable they need to be accompanied by economic measures to improve the livelihoods of local people and by effective law enforcement.

REFERENCES

- Andriesse, J.P. (1988) Nature and Management of Tropical Peat Soils. FAO Soils Bulletin 59, Rome.
- Brady, M.A. (1997) Effects of vegetation changes on organic matter dynamics in three coastal peat deposits in Sumatra, Indonesia, in: J.O. Rieley and S.E. Page (Eds), Biodiversity and Sustainability of Tropical Peatlands, pp. 113-134. Samara Publications, Cardigan, United Kingdom.
- Giesen, W. (2003) Causes of peat swamp forest degradation in Berbak National Park and recommendations for restoration. Water for food and ecosystems programme project on: "Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peat swamp forests". ARCADIS Euroconsult, Arnhem, the Netherlands.
- Hooijer, A. (2005) Hydrology of tropical wetland forests: recent research results from Sarawak peat swamps, in: M. Bonell and L.A. Bruijnzeel (Eds) Forest, water and people in the humid tropics, pp. 447-461. (United Kingdom: Cambridge University Press).
- Page, S.E. and Rieley, J.O. (1998) Tropical peatlands: a review of their natural resource functions, with particular reference to Southeast Asia, *International Peat Journal*, 8: 95-106.
- Siderius, C. (2005) A hydrological model of the Air Hitam Laut watershed and the impact of various land use scenarios. Water for food and ecosystems programme project on: "Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peat swamp forests", Alterra, Wageningen, the Netherlands.
- Siegert, F., Ruecker, G., Hindrichs, A. and Hoffman, A.A. (2001) Increased damage from fires in logged forests during droughts caused by El Niño, *Nature*, 414: 437-440.
- Silvius, M. J., Simons, H.W. and Verheugt, W.J.M. (1984) Soils, vegetation, fauna and nature conservation of the Berbak game reserve, Sumatra, Indonesia. Research Institute for Nature Management, Arnhem, the Netherlands.
- Van Eijk, P. and Leenman, P.H. (2004) Regeneration of fire degraded peat swamp forest in Berbak National Park and implementation of replanting programmes. Water for food and ecosystems programme project on: "Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peat swamp forests", Alterra, Wageningen, the Netherlands.
- Wösten, J.H.M. and Ritzema, H.P. (2001) Land and water management options for peatland development in Sarawak, Malaysia. *International Peat Journal*, 11, pp. 59-66.

CARBON FLUX CONTROLS AND LAND USE CHANGE IN TROPICAL PEATLAND

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SUMMARY

Tropical peat swamp forest forms one of the most efficient carbon-sequestering ecosystems and important carbon stores. Some peatlands, even in natural condition, are in steady-state and no longer accumulating peat. Others, especially drained peatlands, are undergoing degradation and form a marked C-source. One of the most important abiotic factors influencing peatland C-balance is hydrology. Rainfall in excess of evaporation is the predominant peat hydrology-regulating parameter because evaporation and (groundwater) outflow are fairly constant in pristine tropical peatland. Peat drainage decreases water holding capacity, and thus speeds up formation of oxic conditions and carbon loss from the peat. Temporal CO₂ fluxes were studied in five land use types including non drained forest, drainage affected forest, deforested site, regrowing forest and non cultivated agricultural land in Central Kalimantan, Indonesia. Gaussian regression models were tested on the gas flux data and *in situ* collected water table data in order to study differences in peat surface CO₂ emissions in relation to ground water and land use type. Optimum and highest CO₂ emissions were scattered across a deeper and broader ground water range in the four drainage affected sites compared to non drained forest. The maximum CO₂ fluxes were smaller if there was no fresh organic material input into peat.

Keywords: carbon dioxide, gas flux, land use change, water table, tropical peat

INTRODUCTION

Vast wood containing tropical peat deposits are the result of long-term ecosystem carbon sequestration from the atmosphere. In Indonesia alone, the estimated current peat carbon (C) store is 26 – 50 Gt (Page *et al.*, 2002). Some peatlands, even in a natural condition, are in a steady-state and no longer accumulating peat. Others, especially drained peatlands, are undergoing degradation which can be seen as gaseous carbon loss and peat subsidence.

Peat decay processes have a strong influence on the hydraulic conductivity and moisture retention characteristics of the peat (Rieley and Page, 2005). Pristine peat swamp forest water movement takes place mostly in the shallow seasonally oxic surface peat layer that has high hydraulic conductivity (Takahashi and Yonetani 1997). In such a forest the surface may be flooded for at least nine months of the year. Below the water fluctuation zone peat is relatively well decomposed, has a lower hydraulic conductivity, and forms the main water storage in the ecosystem. Peat deposits charge with water in the wet season and releases it slowly in the dry season.

In drainage affected areas, at the onset of the dry season, water floods out of the surface peat rapidly because the water is conducted efficiently to the drainage system. Under uncontrolled drainage, water table fluctuation can be over 1.5 m annually.

In forest ecosystems, most of the carbon fixed in photosynthesis is released quickly back to the atmosphere in plant respiration, but surplus is stored in ecosystem labile living and dead organic matter, especially as peat. The balance between the rates of net C-sequestration in photosynthesis and C-release in organic matter decay determines when the system C-reservoir decreases, is in equilibrium, or increases. It has been shown that high leaf area index (LAI) and soil ground water conditions are essential for net C-sequestration in peat swamp forest ecosystem (Suzuki *et al.*, 1999; Hirano *et al.*, 2007). Land reclamation changes fundamental components of tropical peat soil-atmosphere carbon exchange participating machinery, *i.e.* vegetation and peat hydrology, and thus enhances C-losses from the ecosystem.

Data availability concerning tropical peat CO₂ fluxes and their biological controls are still limited (e.g. Chimner, 2004; Jauhiainen *et al.* 2004, 2005; Melling *et al.* 2005), and variation in environmental conditions (especially in peat hydrology), peat-, and vegetation characteristics make comparisons between datasets difficult. In drained areas there is lack of datasets including long-term soil water levels, time periods after drainage, and different crop systems. Studies on total ecosystem carbon balance are most limited (e.g. Suzuki *et al.*, 1999; Hirano *et al.*, 2007).

This paper aims to fill the gaps in existing information concerning the tropical peat related GHG dynamics in relation to peat hydrology. The study is based on peat surface CO₂ flux data, and subsequent non linear regression model analysis in five sites with differing characteristics of hydrology and vegetation.

MATERIALS AND METHODS

Study sites

The study was carried out in the catchment of the River Sebangau, ~20 km southeast from Palangka Raya city in Central Kalimantan, Indonesia. Sites located near each others at about 10 km radius included nondrained selectively logged peat swamp forest (NDF), drained selectively logged peat swamp forest (DF), drained clear felled but recovering forest (RF), drained, clear felled, burned site (DB), and agricultural land (AL).

The NDF site was located west of the River Sebangau and the DF site east from the river. Both forests were selectively logged for the most valuable trees in 1990's. Forest floor was formed largely from a mixture of vegetation-free base ground (hollows) and about 10 – 30 cm high hummocks forming locations for trees and seedlings. The DF, RF and DB sites were drained in the mid 1990s by a large canal drainage system. Vegetation at the regrowing RF site was up to 10 m high stand of tree seedlings growing on relatively flat peat. The RF and DB sites were fire affected in 1997. Fires struck the DB site again in 2002 while smouldering fire created about 20–30 cm deep depressions, where ferns now occupy the high surfaces. The crop-free agricultural land was drained during the 1980s and was formerly managed by surface peat burning and fertilization for growing vegetables. The AL site water table was controlled and maintained at ~-30 cm.

Gas flux measurement methodology

Gas flux measurements were made at each site during wet and dry seasons at least for 2 year periods between 1999 and 2006. Sub-sites were selected from about 100 – 500

m distances, where 3 – 5 sample-plots were selected for gas flux measurements from soil base ground (depressions). On sites with prominent micro-topographical differences, additional 4 – 8 sample plots were established on high surfaces (hummocks). For details of applied closed chamber methods, see Jauhiainen *et al.*, (2004, 2005). Automated water table loggers installed in one depression at each site recorded peat water table. During the gas flux measurements water table was measured with an audible buzzer apparatus from wells next to each sub-plot. Non linear Gaussian regression model of the form $y = a * \exp [-0.5 * ((x - x_0) / b)^2]$, was fitted on the CO₂ data from each sub-site, and water table was applied as an explanatory factor. See Table 1 for explanations of the parameters. Mean gas fluxes were used for the forest site hummocks because of high variation in gas fluxes and poor goodness of fit with the soil water table.

RESULTS

Water table had less influence on soil CO₂ fluxes on NDF and DF hummocks where live root biomass, and thus root respiration, were high. Mean CO₂ emissions in the forest hummocks were comparable with the respective highest depression CO₂ emissions (Table 1). Optimum CO₂ emission resulting from ground water table range [*b*] was broad and the maximum CO₂ flux [*a*] was in deeper water table in DF, RF and DB sites but with high water table fluctuation in comparison to NDF site owing to stable hydrology (Table 1, Jauhiainen *et al.*, 2005). In the drained DB and AL sites maximum CO₂ fluxes [*a*] were found to be smaller if there was no fresh organic material input (Table 1). This was also the case when drainage depth (AL site) was controlled (Table 1).

Parameter	NDF Depres-sion ^{*)}	DF depres-sion ^{**)}	RF base ground	DB depres-sion	DB high surface	AL base ground
[<i>a</i>] (mg m ⁻² h ⁻¹)	659 – 691	818 – 1151	906 – 965	481 – 620	339 – 600	266 – 345
[<i>x</i> ₀] (cm)	-30 – -35	-58 – -104	-94 – -141	-50 – -75	-78 – -110	-55 – -78
[<i>b</i>] (cm)	21 – 22	61 – 80	57 – 77	36 – 43	54 – 71	29 – 47
(<i>n</i>)	34 – 41	17 – 24	21 – 31	18 – 21	46 – 264	41 – 62
R ²	0.80 – 0.83	0.191 – 0.823	0.44 – 0.61	0.33 – 0.71	0.07 – 0.35	0.28 – 0.57
Sites (<i>n</i>)	3	5	3	4	4	3

^{*)} For the NDF site hummocks, mean CO₂ fluxes on three sub-sites (n= 303 – 337) were 472±12 – 637±16 g m⁻² h⁻¹ (mean flux ± standard error). ^{**) For the DF site hummocks, mean CO₂ fluxes on five sub-sites (n= 222 – 292) were 698±159 – 1078±258 g m⁻² h⁻¹ (mean flux ± standard error).}

Table 1 Nonlinear regression model parameters for base ground (depression) CO₂ fluxes in five land use types. In the model, *a* is the maximum CO₂ flux, *x*₀ is optimum water table and *b* is tolerance in water tables around the maximum flux. Number of samples and goodness of fit are shown. For the two forest sites hummocks, mean CO₂ fluxes are shown.

DISCUSSION

In this small spatial scale study, C-loss through fires and leaching by groundwater flow were not considered although regionally and on long-term scales they have important roles in the carbon balance of tropical peatlands. Net carbon sequestration in tropical peat necessitates combination of high vegetation biomass (C-sequestration potential) and near soil surface water table, while drainage and disturbances (fire related haze) can increase C-losses (Suzuki *et al.*, 1999; Hirano *et al.*, 2007). In replacement ecosystems net ecosystem C-sequestration is unlikely to be attained because of low biomass volume, frequent biomass cropping, deposited litter is not conserved in waterlogged conditions owing to a usually low water table regime, fertilization enhancement of peat humification, fires, *etc.*

In this study peat surface CO₂ emissions were noted to be convergent with the ecosystem level study observations of Suzuki *et al.*, (1999) and Hirano *et al.*, (2007) in the forest sites. Soil CO₂ efflux which contributes largely to total ecosystem respiration, was largely controlled by water table and differed with micro-topography. In non-drained forest the water table is stable and remains relatively high, so soil respiration is drastically inhibited when the ground is almost flooded or water table drops below the normal fluctuation depth in the peat profile. High live root biomass in hummocks increases root respiration and results in high CO₂ emissions irrespective of water table depth as was noted in this study and also by Hirano *et al.*, (2007).

Soil CO₂ emission optimum was noted to shift on drainage affected areas where long-term wider and deeper water table conditions have enhanced organic matter decomposition in the air-exposed peat profile. If the vegetation cover is sparse and there is no marked input of fresh organic matter in peat, CO₂ emissions from soil will in the long run decrease. The DB and AL sites indicate conditions in which carbon sequestration is low and peat decomposition, after prolonged and deep peat profile exposure to air, is already slowing down owing to the lack of easily decomposable substrate.

Continuous C-loss in the drained sites will eventually cause loss of most of the peat resource. Carbon losses by oxidation in degraded peat, such as DB and RF sites, are exacerbated by fires which not only destroy the above-ground biomass but also penetrate into the underlying peat, resulting in greatly increased atmospheric emissions of carbon gases and particulate matter, impairs hydrology through loss of the water regulation functions, causes loss of seed bank and tree roots in surface peat, and damages human health and livelihoods through loss of resources provided by vegetation and creates toxic haze from burning peat and vegetation. Haze has been noted to decrease the available amount of photosynthetically active radiation and therefore gross primary production in the vegetation (Hirano *et al.*, 2007). Without a protective layer of vegetation or plant litter, the peat surface is prone to erosion by wind and water.

Soil gas fluxes cannot be used as a measure of the maintenance of peat carbon deposits, which require continuous and sufficient biomass allocation into waterlogged peat for prolonged periods. The best C-sequestration potential systems (forests) have likely higher emission rates in comparison to drained sparsely vegetated sites if the decomposition and vegetation root respiration originated CO₂ is not separated. This is one of the reasons why both sequestered and released carbon (*i.e.* ecosystem level C-balance) needs to be known in order to quantify the role of tropical peat ecosystems as carbon sinks and the extent to which they are carbon stores or sources. Carbon sequestration cannot be achieved in drained peat because drainage exposes the surface peat profile to oxic conditions, and thus increases C-loss through decomposition.

Carbon sequestration potential is still possible in the DF site, but is not achieved under current drainage conditions at the site (Hirano *et al.*, 2007).

CONCLUSIONS

Soil respiration optimum location range in respect to ground water level reflects the typical hydrological conditions, and thus the land hydrological near-history. To reduce peat CO₂ emissions the water level should be kept near to the surface for as long as possible throughout the year. Stand-level measurement of CO₂ flux is needed to fully reveal peatland ecosystem carbon balances.

REFERENCES

- Chimner, R.A. (2004) Soil respiration rates of tropical peatlands in Micronesia and Hawaii. *Wetlands*, 24, 51-56.
- Hirano, T., Segah, H., Harada, T., Limin, S., June, T., Hirata, R. and Osaki, M. (2007) Carbon dioxide balance of a tropical peat swamp forest in Kalimantan, Indonesia. *Global Change Biology*, 13(2), 412-425. DOI: 10.1111/j.1365-2486.2006.01301.x
- Jauhiainen, J., Jaya, A., Inoue, T., Heikkinen, J., Martikainen, P. and Vasander, H. (2004). Carbon Balance in Managed Tropical Peat in Central Kalimantan. In: Päivänen, J. (ed.) *Proceedings of the 12th International Peat Congress, Tampere 6 – 11.6.2004*. International Peat Society, Jyväskylä, pp. 653-659.
- Jauhiainen, J., Takahashi, H., Heikkinen, J.E.P., Martikainen, P.J. and Vasander, H. (2005) Carbon fluxes from a tropical peat swamp forest floor. *Global Change Biology* 11, 1–10, doi: 10.1111/j.1365-2486.2005.01031.x
- Melling, L., Hatano, R., Kah Joo Goh (2005) Soil CO₂ flux from three ecosystems in tropical peatland of Sarawak, Malaysia. *Tellus*, 57(1), 1-11.
- Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.-D.V., Jaya, A. and Limin, S. (2002) The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, 420, 61-65.
- Rieley, J.O. and Page, S.E. (eds) (2005) *Wise use of tropical peatlands*. ALTEERRA and the EU INCO - STRAPEAT and RESTORPEAT Partnerships, 237 pp. www.strapeat.alterra.nl
- Suzuki, S., Ishida, T., Nagano, T. and Waijaroen, S. (1999) Influences of deforestation on carbon balance in a natural tropical peat swamp forest in Thailand. *Environmental Control in Biology*, 37, 115-128.
- Takahashi, H. and Yonetani, Y. (1997) Studies on microclimate and hydrology of peat swamp forest in Central Kalimantan, Indonesia. In: Rieley, J.O. and Page, S.E. (eds), *Biodiversity and Sustainability of Tropical Peatlands*. Samara Publishing, Cardigan, pp. 179-187.

EFFECT OF HYDROLOGICAL RESTORATION ON DEGRADED TROPICAL PEAT CARBON FLUXES

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SUMMARY

Large areas of tropical peat have been drained, resulting in an abrupt change in the carbon sequestration and storing potential. Hydrological restoration by dam construction was made in drainage affected peat swamp forest and deforested burned peat area in Central Kalimantan (Indonesia) in order to slow down water outflow. Peat carbon dioxide fluxes were analyzed both for pre- and post-restoration peat water table level conditions. In forested areas the contribution from autotrophic CO₂ production can be high, but oxidation of deposited litter is faster in drainage affected forest than in undrained forest. Restoration of peat hydrology may not instantly affect the reduction of peat CO₂ flux rates in forests owing to difficulties in creating near peat surface water table level conditions, and because forest soil results in high autotrophic CO₂ production. In open degraded areas near soil surface maintained water table level can potentially reduce CO₂ loss from decomposition but carbon loss cannot be stopped until ecosystem C losses are exceeded by vegetation net carbon sequestration.

Keywords: carbon dioxide, land use, peat swamp forest, restoration, water table

INTRODUCTION

Tropical peat swamp forest forms one of the most efficient carbon (C) sequestering and storing ecosystems because it combines substantial biomass production capacity and dead biomass conservation in nutrient-poor, waterlogged peat. The estimated current peat carbon store in Indonesia is 26–50 Gt (Page *et al.* 2002). Large areas of tropical peat have been drained, resulting in an abrupt and permanent shift in the ecosystem carbon balance from sink to source (e.g. Page *et al.* 2002; Hirano *et al.* 2007). Decomposition of drained peatlands in Indonesia is estimated to cause 632 Mt yr⁻¹ CO₂ emissions (range 355–874 Mt yr⁻¹), which will likely increase every year for the first decades of the next century unless peatland use practices are changed (Hooijer *et al.* 2006). One of the largest degraded areas on tropical peatland (about 1 Mha) was created in 1996–1998 by the Mega Rice Project (MRP).

The main objectives of this study are to: (1) determine soil CO₂ dynamics and cumulative fluxes in relation to peat hydrology in drainage affected forest and deforested tropical peat, (2) determine major patterns in the annual peat WTL conditions after hydrological restoration of drainage affected peat, and (3) to evaluate the effect of hydrological restoration on CO₂ fluxes.

METHODS

Study site

Two measurement sites were located near each other in the northeast corner of the ex-MRP area, about 20 km southeast of Palangka Raya City in Central Kalimantan Province of Indonesia (Fig. 1). The area is split by two open canals, 25 m wide and 3.5–4.5 m deep. Measurement sites included drainage affected, selectively logged peat swamp forest (DF), and deforested, drained, burned peatland (DBP). The DF site had been cleared of its commercially most valuable timber prior to 1998. The forest floor microtopography included about 10–20 cm high hummocks with adjoining unvegetated depressions with about 50:50 surface ratio. Hummocks were largely formed from tree bases and other vegetation growing on them. The deforested site was treeless as a result of clear felling and consequent fires. The vegetation on the deforested site was dominated by ferns that had colonizing the higher surfaces. About 20–30 cm deep depressions, created by smoldering fires, had remained unvegetated possibly because of excessive wetness during rainy seasons. The mean peat thickness in the area was about 4 metres. The climate is characterized by 24–27°C temperatures, high humidity and high rainfall (overall average ~2800 mm) intensity.

Data collection and processing

Two gas flux monitoring transects oriented perpendicular to the canal direction were established about 1.1 km apart from each other in the selectively logged forest and deforested sites. Both transects consisted of five subplots at about 50 m intervals. Gas flux monitoring on the sites was carried out between April 2004 and December 2006 at intervals of about 2–3 weeks. In June–August 2005, seven dams were constructed in the study area canal system bordering an area of about 13 km² (Fig. 1). Water table level loggers (Keller, DCX-22) installed in one depression at the most far-off subplots from the canal recorded peat WTL on the sites. During gas flux measurements, WTL was measured with an audible buzzer apparatus from wells on each subplot.

Two methods were applied for the gas flux measurements. A closed chamber technique was applied for measuring CO₂ on depressions (method described in Jauhainen *et al.* 2005). In this, four air samples were collected at 5-minute intervals from aluminum frames closed air-tightly by a 37 dm³ headspace during a 20-minute incubation period. Evacuated glass vials (12 ml) were used for sample storing by filling each vial with 20 ml of the sample air. For CO₂ analysis a gas chromatograph (Agilent 6890N) equipped with a flame ionization detector (FID) was used. The other method applied for measuring CO₂ emissions from hummocks and high surfaces was a portable infrared gas analyzer (PP Systems, model EGM-4) connected to a 30 cm diameter soil respiration chamber that enclosed the peat surface during 81-second incubation periods.

Carbon dioxide fluxes were calculated from a linear change of gas concentration inside the closed chamber as a function of measurement time. Non-linear regression models were fitted to CO₂ data from each subplot, and WTL was applied as an explanatory factor (see Table 1). The 3–5 most representative subplots on both microtopographical surface types, based on *R*² values, were selected for further analysis. Gas fluxes at respective diurnal WTLs were summed together to produce cumulative gas fluxes for one year periods. Cumulative fluxes on hummocks and depressions were proportioned to microtopography surface ratio (50:50) on both sites.

Mean gas fluxes were used for the DF site hummocks because goodness of fit for modeled gas fluxes with WTL in hummocks was low.

RESULTS

Peat water table level

Deforested (DBP) site WTL annual mean, minimum (-21 vs. -33 cm), median (-14 vs. -26 cm), and mean 4-month dry season WTL (-40 vs. -52 cm) were higher after canal blocking. In the forested DB site, annual mean (-43 vs. -47 cm), minimum (-100 vs. -155 cm), and median (-35 vs. -39 cm) WTL were also higher after canal blocking. In general, the greatest difference in the peat WTL was found in the annual minimum WTL, which was 55 cm higher in the forest and 68 cm higher in the deforested site after restoration (Fig. 1). Precipitation during the one-year period before restoration was 3215 mm in comparison to 2857 mm rainfall after restoration, and timing of dry and wet seasons was comparable during the two years.

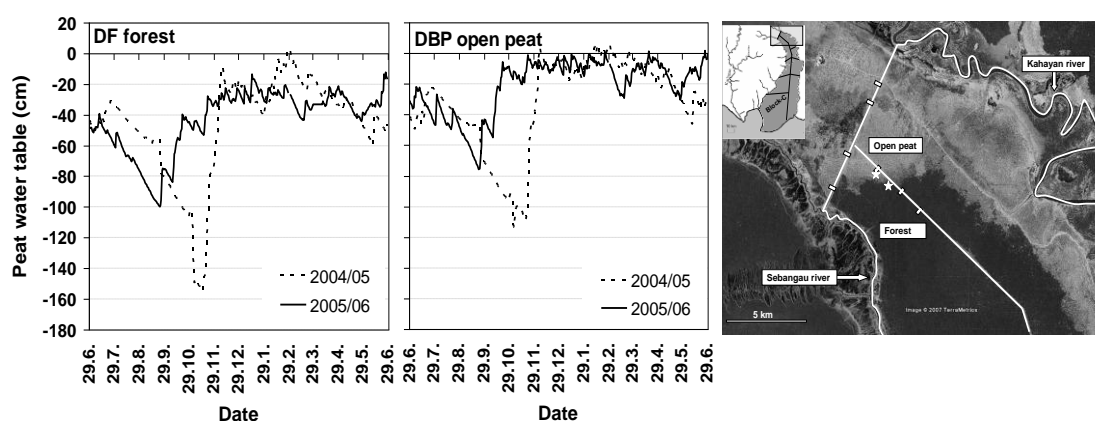


Figure 1 Soil water table level in drainage affected selectively logged forest (DF) and in deforested (DBP) site depressions before (2004/05) and after (2005/06) drainage canal blocking. Map of the study site on right.

Regression models

All gas flux data for each subplot were pooled together in the regression analyses since the GHG fluxes did not differ markedly ($P > 0.05$) at comparable soil water table level conditions before and after restoration. CO_2 flux maximum rates in the DF site depressions were clearly higher in comparison to the clear-felled site (Table 1). The WTL resulting in the maximum CO_2 flux in the DF depressions was deeper and covered wider WTL range than in the DBP site.

Parameter	DF depression ^{*)}	DBP depression	DBP high surface
Gaussian equation for CO ₂ form of $y = a * \exp [-0.5 * ((x - x_0) / b)^2]$			
[a] (mg m ⁻² h ⁻¹)	818 – 1151	481 – 620	339 – 600
[x0] (cm)	-58 – -104	-50 – -75	-78 – -110
[b] (cm)	61 – 80	36 – 43	54 – 71
Samples (n)	17 – 24	18 – 21	46 – 264
R ²	0.191 – 0.823	0.33 – 0.71	0.07 – 0.35
Sub sites (n)	5	4	4
^{*)} For the DF site hummocks, mean CO ₂ fluxes on five sub-sites (n= 222 – 292) were 785 – 1078 g m ⁻² h ⁻¹			

Table 1 Nonlinear regression model parameters for CO₂ fluxes in drainage affected selectively logged peat swamp forest (DF) and deforested, drained, burned peatland (DBP). In the Gaussian model for CO₂, [a] is the flux maximum, [x0] is the optimum WTL, and [b] is the tolerance in WTL's around the maximum flux. Number of samples and goodness of fit are shown.

Cumulative gas fluxes

Annual cumulative CO₂ fluxes differed between the DF and DBP sites at (P < 0.001) level between hummocks and high surfaces, and (P < 0.01) level in depressions. By using the 50:50 surface ratio in microtopography, cumulative fluxes between the sites differed (P < 0.001) during both years (Table 2). There were no marked differences (P > 0.05) in the hummock/high surface or depression cumulative gas balances in either of the sites between year before and after restoration.

Site	Period (365 d)	Depression CO ₂ (g m ⁻² y ⁻¹)	Hummock CO ₂ ^(*) (g m ⁻² y ⁻¹)	Combined depression and hummock CO ₂ (g m ⁻² y ⁻¹)
DF	2004/05	7005±1582	7605±1242	7305
	2005/06	7283±1787	7605±1242	7444
DBP	2004/05	2969±235	2593±309	2781
	2005/06	2809±278	2406±236	2608
^(*) Flux model was not applied to the DF site hummocks. Relative annual WL conditions: 2004/05 (before restoration), 2005/06 (after restoration).				

Table 2 Soil annual CO₂ fluxes in drainage affected selectively logged peat swamp forest (DF) and deforested, drained, burned peatland (DBP). Gas fluxes (mean ± standard error) for the depressions, and fluxes with (50:50) surface ratio for depressions and hummocks, are shown.

DISCUSSION

CO₂ fluxes

Hummocks in the DF site are in an elevated position in forest floor microtopography which creates sufficiently moist conditions in surface peat and therefore makes them appropriate for root growth and seedling germination. Hummock surfaces resulted in high CO₂ emission rates even in nearly waterlogged conditions, which is largely (not quantified in this study) from autotrophic root respiration of trees. In bare forest floor

depressions gas fluxes responded more clearly to peat WTL which is proposed to result from the smaller share of autotrophic respiration in comparison to emissions from organic matter decomposition. Comparable gas flux response in hummocks and depressions has been found in an undrained peat swamp forest, but with about $320 \text{ mg m}^{-2} \text{ h}^{-1}$ lower maximum CO_2 flux rate in comparison to DF site (Jauhiainen *et al.* 2005). Tree roots in the DF site need to extend deep in the peat and cover a spatially large area in order to secure water availability in dry conditions, which may increase proportionally litter deposition in oxic situation in deeper peat layer, and thus contribute to the resulted high CO_2 loss maximum that was resulted in deep WTL conditions and covered a wide WTL range in the model.

Lower CO_2 fluxes at the sparsely vegetated BDP site, in comparison to the forest, can be explained by low root respiration and low deposition of fresh litter into peat. After clear felling a large amount of fresh debris remains in and on the surface peat, but if the subsequent litter deposition is low, decomposition rate slows down over time (Wösten *et al.* 1997). CO_2 flux maximum in fern dominated high surfaces at the site was about $100 \text{ mg m}^{-2} \text{ h}^{-1}$ lower compared to depressions, which indicates low root respiration contribution to the fluxes and relatively low microbial activity in peat near the surface. High exposure to sun may promote over-heating and over drying in high surfaces, which probably reduces microbial activity in the uppermost peat profile. In the DBP site CO_2 emission was highest when the depth of the oxic peat profile was relatively wide (WTL deep), and this likely reflects conditions in which oxic peat horizon depth and peat moisture conditions are optimal for aerobic decomposition.

Drainage affected forest cumulative CO_2 effluxes were among the highest measured in tropical peat ($\sim 2000 \text{ g CO}_2\text{-C m}^{-2}$). Forest floor CO_2 emissions of a comparable scale have been detected in Sarawak ($2130 \text{ g C m}^{-2}\text{y}^{-1}$) by Melling *et al.* (2005). Undrained peat swamp forest floor CO_2 emissions have varied between $953\text{--}1200 \text{ g C m}^{-2} \text{ y}^{-1}$ (Inubushi *et al.* 2003; Jauhiainen *et al.* 2005). The DBP site annual CO_2 efflux ($711\text{--}758 \text{ g C m}^{-2} \text{ yr}^{-1}$) are somewhat higher than annual $\text{CO}_2\text{-C}$ emissions from agricultural uncultivated peat (526 g C m^{-2}) in the same area (Jauhiainen *et al.* 2004), but it is lower than in more voluminous vegetation-covered oil palm (1540 g m^{-2}) and sago plantation (1110 g m^{-2}) soil emissions (Melling *et al.* 2005).

Peat water table level and gas fluxes

The peat swamp forest main water storage is in permanently waterlogged subsurface peat below the usual water fluctuation zone. This peat is relatively well decomposed and has lower hydraulic conductivity compared to the more permeable surface peat (Takahashi *et al.* 2002). Water runoff through the top horizon was more efficient in the DF forest site which still had a 15–30 cm deep highly porous, fibric horizon on top. High WTL conditions prevailed longer in the DBP site because the peat is characterized by a collapsed peat macro-pore structure, and it is well decomposed and compacted up to the peat surface. Therefore dams can act as barriers restricting water outflow during the dry season especially in the forest area, and thus decrease depth and duration of the lowest water level conditions.

Restoration of peat hydrology may not instantly effect the reduction of peat CO_2 flux rates in forests owing to difficulties in creating near peat surface WTL conditions in porous peat, and because forest soil results in high autotrophic CO_2 production. The main positive outcome from nearer peat surface stabilized hydrological conditions is likely created by enhanced C-storing potential through avoided drought stress and

maintained sufficient net photosynthesis in the vegetation (Hirano *et al.* 2007). This would increase litter deposition and duration of recently deposited litter in a decomposition slowing, waterlogged environment also near the peat surface, while the deeper carbon stores would not be exposed to oxic conditions. In clear felled sites higher WTL did not show any immediate response in the cumulative CO₂ flux. However, peat C losses can be expected to decrease with long term stabilized near peat surface hydrology conditions. Instant benefit from higher WTL is greater water availability for vegetation that promotes forest regeneration potential.

CONCLUSIONS

Uncontrolled drainage causes enhanced dead biomass oxidization in peat owing to increased thickness of the aerobic peat profile, which leads to peat subsidence. Long term waterlogging is difficult to achieve in peat that has porous surface peat. In drainage affected forested areas, the contribution from autotrophic CO₂ production can be high, but oxidation of deposited litter is faster than in undrained forest. The main positive outcome from higher WTL conditions in forest is likely to be improved ecosystem level C-storing potential through avoided drought stress and thus maintained net carbon sequestration resulting in sufficient litter deposition in frequently and long-term water logged conditions. In open degraded areas, such as the DBP site, near soil surface maintained WTL can potentially reduce CO₂ loss from decomposition but carbon loss cannot be stopped until ecosystem C losses are exceeded by vegetation net carbon sequestration. Forest regeneration is a long process, but investments into hydrological restoration are important both for reducing the fire hazard and in creating conditions for forest vegetation re-establishment.

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REFERENCES

- Hirano, T., Segah, H., Harada, T., Limin, S., June, T., Hirata, R. and Osaki M. (2007). Carbon dioxide balance of a tropical peat swamp forest in Kalimantan, Indonesia. *Global Change Biology* **13**(2), 412-425.
- Hooijer, A., Silvius, M., Wösten, H. and Page, S. (2006). *PEAT-CO₂, Assessment of CO₂ emissions from drained peatlands in SE Asia*. Delft Hydraulics report Q3943. 41 pp. Netherlands.
- Inubushi, K., Furukawa, Y., Hadi, A., Purnomo, E. and Tsuruta, H. (2003). Seasonal changes of CO₂, CH₄ and N₂O fluxes in relation to land-use change in tropical peatlands located in coastal area of South Kalimantan. *Chemosphere* **52**(3), 603-608.

- Jauhiainen, J., Vasander, H., Jaya, A., Takashi, I., Heikkinen, J. and Martikainen, P. (2004). Carbon balance in managed tropical peat in Central Kalimantan, Indonesia. In J. Päivänen (ed), *Wise Use of Peatlands - Proceedings of the 12th International Peat Congress, 6 – 11.6.2004 Tampere*, pp. 653-659. International Peat Society, Jyväskylä, Finland.
- Jauhiainen, J., Takahashi, H., Heikkinen, J.E.P., Martikainen, P.J. and Vasander, H. (2005). Carbon fluxes from a tropical peat swamp forest floor. *Global Change Biology* **11**(10), 1788-1797.
- Melling, L., Hatano, R. and Goh, K.J. (2005). Soil CO₂ flux from three ecosystems in tropical peatland of Sarawak, Malaysia. *Tellus* **57**(1), 1-11.
- Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.-D.V., Jaya, A. and Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature* **420**, 61-65.
- Takahashi, H., Shimada, S., Ibie, B.I., Usup, A., Yudha, and Limin, S.H. (2002). Annual changes of water balance and a drought index in a tropical peat swamp forest of Central Kalimantan, Indonesia. In Rieley, J.O., Page, S.E. with Setiadi, B. (eds.), *Peatlands for People: Natural resource functions and sustainable management, Proceedings of the international symposium on tropical peatland, 22-23 August 2001, Jakarta, Indonesia*, pp 63–67. BPPT and Indonesian Peat Association.
- Wösten, J.H.M., Ismail, A.B. and van Wijk, A.L.M. (1997). Peat subsidence and its practical implications: a case study in Malaysia. *Geoderma* **78**, 25-36.

RESTORATION OF HYDROLOGICAL STATUS AS THE KEY TO REHABILITATION OF DAMAGED PEATLAND IN CENTRAL KALIMANTAN

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SUMMARY

The drainage system in deep peat used for agriculture, extraction of timber and human transportation will change the peatland ecosystem. In the dome area (e.g. Block C of the former of MRP) the water table fell to 176 cm depth in the 2004 dry season. The effect of drainage was indicated by ease of wild fire spread. These impacts will change the function of peatland and is indicated by subsidence and peat loss, CO₂ emissions and vegetation change. Based on the water holding capacity of peat soil (289 - 1,057 %) and other characteristics, the key for sustainability of peatland functions is maintaining the hydrological status.

Keywords: drainage, tropical peatland, hydrology

INTRODUCTION

The importance of peatland in carbon storage is one of the important factors influencing climate change and if it is too late to save the remaining tropical peatland from destruction and restore that already damaged then various types of disasters will increase in intensity and frequency (Rieley and Page, 2005).

In Indonesia, peatland has been damaged ever since peat swamp forest exploitation for wood production in the 1970s, followed by conversion to agriculture cultivation and plantations in the 1990s. In Central Kalimantan serious damage to peat swamp forest has occurred since the Indonesian Government commenced the Mega Rice Project (MRP) in 1996 with the objective of making this area a major centre for rice production in order to compensate for reduced rice production in Java as a result of land use change, namely road construction, settlement, building and industry.

Over drainage of peatland in the MRP which has been followed by wildfire every year has resulted not only in serious loss of traditional livelihoods of the local people such as rattan collection, rubber plantation and fish ponds (*beje*), but also influenced the psychology and mentality of local communities. Therefore, when wildfires occurred around villages, people just allow them to spread because they were confused about how to solve the mistakes of Government policy that resulted in their financial loss. The support of the Indonesian Government for forest companies for the last four decades has taken away the responsibility of local communities to care for the environment surrounding them. Therefore, although land and forest around their villages occasionally go on fire, they do not care, because the owner of the area is a forest company.

CAUSES OF PEATLAND DAMAGE

Human Factor

Human Behaviour

All fire hotspots, especially in Central Kalimantan, are the result of human behaviour, intentional or un-intentional, especially, (a) burning plantation and unproductive land before planting or to control weeds, (b) starting fires for cooking adjacent to or inside the forest or discarding lit cigarettes, (c) over exploitation of forest (including illegal logging) resulting in much dry wood on the ground to be a source of fuel and (d) digging channels for transporting timber from inside the forest that leads to lowering of the water table and drying of the peat surface.

Decreased Awareness and Responsibility

Local people (especially Dayaknese), traditionally, had good knowledge of environmental functions and this is indicated through their management of shifting cultivation. They lost this awareness and responsibility, however, after the Government of Indonesia gave full responsibility for managing forests to forest companies.

Inappropriate Technology for the Carrying Capacity

Drainage System

The major factor causing peatland damage in Central Kalimantan is drainage using channels of excessively large dimensions that were constructed to prepare peatland for agriculture and transmigrant settlement. In fact they have been used mainly by illegal loggers to transport timber from the forest.

Burning peat to produce ash for fertilizer

Generally, the farmers in inland peat areas have to rely on ash as the main fertiliser input to the land for growing crops. Unfortunately, burning plant residues and rubbish on the peat surface, also sets fire to the peat.

Planting non native species

Planting of non native species requires environmental adjustment including land preparation, drainage and addition of fertilizers.

NEGATIVE IMPACTS OF DRAINAGE AND FOREST EXPLOITATION

Change of Hydrological Status

Based on observations in the inland peat area, all of the MRP channels have been draining water from the dome area to the surrounding rivers. In other words, the channels have accelerated water loss from the peatland ecosystem causing the water table to decrease, inhibiting the growth of trees, causing peat subsidence, making the peat sensitive to fire and increasing emissions of greenhouse gases. Limin (2007) reported that the water table in Block C of the former MRP decreased by 176 cm (in the dry season 2004) while peat subsidence varied between 1 and 3 cm per year. As a consequence of this lowered water table in the dry season there is increased risk of fire, leading to further increases in CO₂ emissions.

Peat sensitivity to burning and the difficulty of fire control

Decreasing the water table in tropical peatland makes the peat surface dry and the vegetation dies and becomes fire prone. In the dry season, normally the peat layer can burn to a depth of around 50 cm, but can penetrate to 100 cm in some places. Limin *et al.* (2003) reported, based on measurements made in 2002, that peat layer loss by fire averaged 22.03 cm with a maximum of 42.3 cm. Once fire has become established underground in peat, it requires 200 – 400 litres m⁻² to extinguish it. In addition, underground peat fires produce thick smoke for a long time, because of incomplete combustion (Figure 1).



Figure 1 Wild fires in Kalampong and Sabangau (2006)

Increasing CO₂ emissions

The hydrological status change in peatland promotes aerobic decomposition leading to increase in CO₂ emissions while, at the same time, acidity and nutrients are released. According to Jauhiainen (2005) the emission of CO₂ in the Natural Laboratory of Peat Swamp Forest (NLPSF) that is located in the upper catchment of Sg. Sabangau was 3493 g CO₂ m⁻² yr⁻¹ in natural forest but was 7305-7444 g CO₂ m⁻² yr⁻¹ in drainage affected forest.

Peat Swamp Forest Destruction and Loss of Traditional Livelihoods

The most significant impact of the change of hydrological status by the drainage channel system has been vegetation change in several areas of peatland. Before the MRP opened in 1996, Basarang transmigrant village, which was a centre to produce rice had to change to other crops, e.g. zallacca, pinneapple and rambutan (Figure 2). Similar effect on the livelihood of communities resulted all over the MRP when the giant channels (around 4,530 km long) were excavated in a very short time (18 months), causing all local people in the surrounding area to lose their income as their

rice fields dried up, fish traps (*beje*) were destroyed and rattan and rubber cultivation becoming unproductive and were abandoned.



Pineapples in Basarang –Kapuas

Zalacca palm in Basarang - Kapuas

Figure 2 Vegetation change in Basarang-Kapuas

RESULT OF DAMMING EXPERIMENTS

The effect on the water table of 8 dams constructed on the Kalampangan and Taruna canals in Block C the former of the MRP determined along three transects on the peat dome is shown in Figures 3 and 4 and Table 1. The dams were constructed in July and August 2005 and, as a result, the water table was elevated as far as 400 m on each side of the channel. The maximum water table increase after dam construction in October 2005 compared with October 2005 was 151 cm.

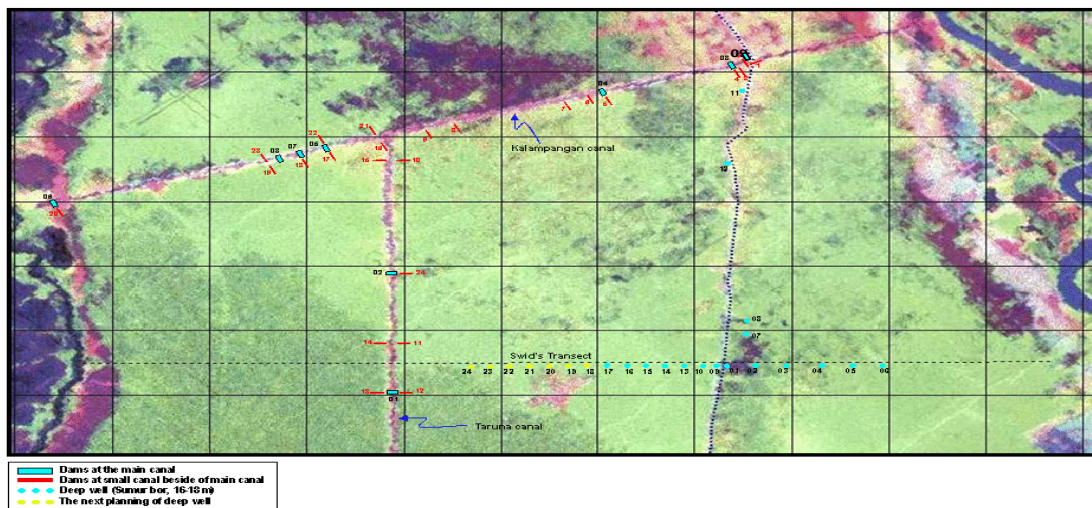
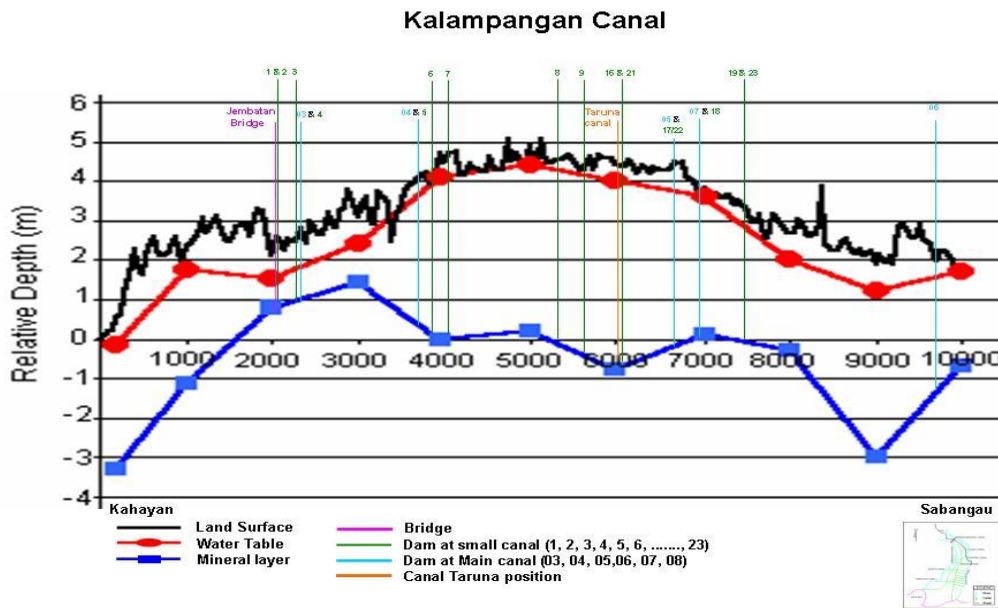


Figure 3 Position of dams at the Kalampangan and Taruna canals



Figures 4 Position of dams based on topography along the Kalmpangan canal.

The positive effect of this rewetting on vegetation re-growth was shown by the healthy condition of Tumih (*Combretocarpus rotundatus*) and Purun (*Lapironia articulata*) in the channel because water was still available during the dry season (Figure 5). Without dams, water was below the surface even in the channels in the dry season.

Year	Transect 1 Water table (m) and point no.	Transect 2 Water table (m) and point no.	Transect 3 Water table (m) and point no.
2004 vs 2005			
September	0.84 (10)	0.87 (13)	1.08 (14)
October	1.51 (13)	1.34 (13)	1.45 (13)
November	1.04 (13)	0.86 (12)	1.12 (13)
2005 vs 2006			
June	0.59 (12)	0.83 (12)	0.41 (21)
July	0.34 (7)	0.27 (12,13)	0.29 (19)
August	0.12 (18)	0.38 (11)	0.09 (21)

Table 1 The maximum difference of water table before and after dam construction.

DISCUSSION

When the peatland was opened for transmigration settlement in the south of Central Kalimantan, especially shallow peat in the coastal area and a few locations on inland peat, forest and peatland fires produced thick smoke for several months that filled the

atmosphere. Big changes occurred after the construction of a road across the peatland and a large area of peat swamp forest in order to develop inland peat for agriculture (the Mega Rice Project) since 1996. This disaster has brought about ecosystem changes to the peatland, especially the hydrological status, because drainage was required in order to build the road. All of the land along the road is in the ownership of many people who do not manage it properly, so that every year it is a source of fire. The effect of drainage on peat hydrology was shown in the channels during the dry season of 1997. During the first month at the beginning of the dry season, the channel was empty of water, a condition that affected the water table in the peatland adjacent to it. Therefore, based on experience of suppressing fire in 1997, Limin suggested to the Government to close all old channels that crossed deep peat and connected to the major rivers. Limin (2003) and Limin (2007) observed that just two weeks from the beginning of the dry season in 1997 the water in the Kalampangan Channel in Block C the former of the MRP was already below the surface. During the dry season, generally in September and October, the water table was found to be more than 100 cm from the surface, especially in the peat dome. Measurement in October 2004 showed that the water table fell to 176 cm.

Based on peatland water holding capacity, restoration of the hydrological status of tropical peatland damaged by the extensive system of channels is very important and should be a high priority. Delay in restoring the hydrological status of peatland in the MRP will lead to many kinds of disaster and will promote further vegetation changes. The effort to restore peatland damage in Block C of the former MRP by dam construction has led to a significant increase in the water table, availability of water and growth of trees in the channel compared to before establishment of the dams. Limin (2007) observed the difference in water table during the dry seasons before and after dam construction in three transects varied from 0.09 cm to 151.00 cm. Two native species grow well along the channel namely, Tumih (*Combretocarpus rotundatus*) and Purun (*Lapironia articulata*). Therefore, damming the system of channels in the peat dome is necessary, not to totally stop the water flow to other areas, but to slow down the water flow from the peatland, so that self restoration can be promoted. Without dams the water flows faster through the channels and peat domes become dry faster.

Based on peat characteristics and some examples of farmer cultivation on peatland, Limin *et al.* (2000) have suggested the peat can be used for agriculture if not more than 100 cm thick and there is clay below the peat. Peatland with a thickness of 50 cm, but underlain by sand, granite or pyrite is unsuitable for agriculture. In the restoration of damaged peatland, fire management is one of the keys to the success of peat sustainability, because fire is still a major threat in peatland areas, while the restoration of hydrological status will take a long time. Restoration of peatland cannot be achieved by physical activities alone, but must be integrated with a real program to increase human awareness of and responsibility for the environment by local people and local governments. Therefore, the mistaken regulations and technology to restore peat damage in Central Kalimantan will be a source of disaster in the future.

REFERENCES

- Jauhiainen, J., Takahashi, H., Heikkinen, J.E.P., Martikainen, P.J., Vasander, H. (2005): Carbon fluxes from a tropical peat swamp forest floor. *Global Change Biology* 11(10):1788-1797.

- Limin, S. H., Saman, T. N., Putir, P.E., Darung U., dan Layuniyati. (2000). Konsep pemanfaatan hutan rawa gambut di Kalimantan Tengah. (Concept for peatswamp forest utilization in Central Kalimantan). *Paper presented in National seminar on Management of Peatswamp Forest and Research's expose in Wetland*. Banjarmasin, 9th March 2000. CIMTROP, The University of Palangka Raya. Palangka Raya. 8pp.
- Limin, S. H., Saman, T. N. and Alim, S. (2003). Forest fire suppression activities in Kalampangan Zone and the Natural Laboratory of Peat Swamp Forest (NLPSF) in Central Kalimantan. *Presented at Hokkaido University, Sapporo, Japan, 20 March 2003*.
- Limin, S. H. (2003). Developing Public Awareness and Responsibility of Local Community through Direct Involvement in Action for Suppressing the Forest Fire. *Proceedings of the International Workshop on Human Dimension on the Management of Peatland in Southeast Asia*, Palangka Raya, pp. 15 – 28, Central Kalimantan, Indonesia, 1 – 2 December 2003. CIMTROP UNPAR, Palangka Raya.
- Limin, S. H. (2007). *Management and Development of Tropical Peatland in Central Kalimantan Indonesia*. PhD thesis. Hokkaido University, Japan.
- Rieley, J.O. and Page, S.E. (2005). *Wise Use of Tropical Peatlands: Focus on Southeast Asia*. Alterra, Wageningen University and Research Centre and the EU INCO STRAPEAT and RESTORPEAT Partnerships, Wageningen, The Netherlands. www.restorpeat.alterra.wur.nl

HYDROLOGY RESTORATION OF EX MEGA RICE PROJECT CENTRAL KALIMANTAN THROUGH CANAL BLOCKING TECHNIQUES: LESSONS LEARNED AND STEPS FORWARD

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SUMMARY

The construction of about 4,475 km of large, medium and small canals in association with the Mega Rice Project in Central Kalimantan from 1996-1998 has had a devastating impact on the hydrology throughout this area as a result of: (i) increasing surface run off through the canals, (ii) reducing water retention of existing peatland areas, and (iii) lowering the ground water table in areas surrounding the canals. This situation has led to further negative consequences such as irreversible peat drying and peat subsidence, which can lead to the depletion or complete destruction of peat owing to repeated peat fires that make rehabilitation very difficult. In an effort to overcome the hydrological problems created within the ex-Mega Rice Project, Wetlands International Indonesia in collaboration with Wildlife Habitat Canada have addressed hydrological restoration by blocking canals within the northern part of Block A. Seven dams known locally as “Tabat” have been constructed and these show evidence of hydrological recovery in terms of: (i) reducing the output of water and raising water storage along the canals; (ii) raising the ground water table in the surrounding areas so that peatland humidity can be maintained during the dry season; and (iii) improving the potential for re-vegetation around the blocking sites.

Keywords: canal blocking, dams, hydrological restoration, rehabilitation, water table, technical design

INTRODUCTION

As a result of the one million hectare Mega Rice Project (MRP) in Central Kalimantan, Indonesia around 4,473 km of primary, secondary and tertiary canals were constructed across peatland landscapes within three regencies and one municipality, namely Kapuas, Pulang Pisau, Barito Selatan and Palangka Raya. Since the project was terminated in 1999, most of the open canal network within the northern part of Block A within Mantangai sub-district has not been used effectively either for agriculture or other activities (Dohong, 2005). These canals have created hydrological disturbance as over drainage has occurred because of the large dimensions of the, threatening the sustainability of the remaining peat swamp forest in that area. Furthermore, over drainage has led to further problems such as irreversible drying, peat subsidence, and repeated peat fires notably during the dry season. Peat drying is also hindering rehabilitation of the area owing to the low survival rate of plant species (Suryadiputra et al., 2005).

Furukawa (2003) outlined other negative impacts of this open canal system in the ex-MRP as follows: (i) deep canals accelerate decomposition processes within the peat layer and oxidation may expose acid sulphate substrate that is toxic to most crops, (ii) a very long canal with a low hydraulic gradient in the flat landscape results in a very low water flow and hence peat leaching processes will be ineffective, and (iii) the accelerated drainage acceleration that occurs from both canal edges as well as under the hydraulic gradient decreases rapidly during low tide so that it will reduce the effectiveness of back water penetration of the secondary canals.

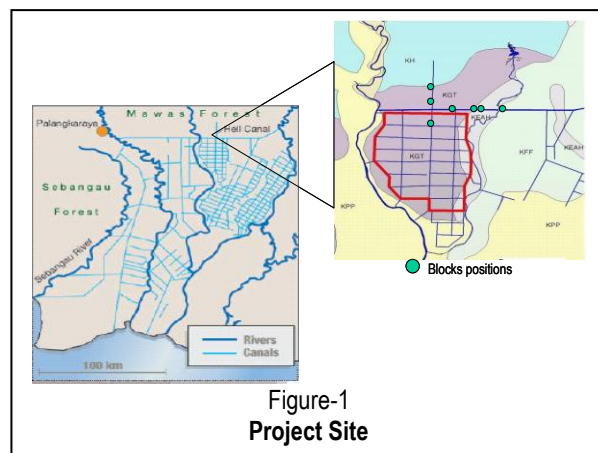
In addition, from the peat swamp forest conservation point of view, drainage and a continuous penetration of fresh water into the peatland ecosystem will raise the peat soil pH and this, in the long term, will change the peat characteristics as the natural tropical peatlands ecosystem needs high acidity and water logged conditions for its existence and sustainability.

Considering the above negative impacts, the Climate Change, Forests and Peatlands in Indonesia (CCFPI) Project has introduced intervention measures to restore hydrology in the northern part of Block A by blocking canals opened for the MRP. Following blocking some positive result were generated, notably in terms of: (1) reduction in surface water run off and increased water retention, (2) ground water table is maintained as high as possible, (3) the blocked canal could be utilized as a fire break because high water level would be maintained in the canal over a long period, (4) blocked canals could be promoted as fish ponds, which may provide new livelihood sources for local communities and (5) canal blocking is a necessary condition for rehabilitation take place.

The main aim of this paper is to present temporary hydrological results gained for almost a year of blocking activities and necessary recommended actions as steps forward.

PROJECT SITE AND METHODS OF IMPLEMENTATION

Project sites are focused on 1st and 2nd parent primary canals (PPC-1 canal and PPC-2 canal) and 7th main primary canal (MPC-7 canal), which are situated between Kapuas River and Mantangai River (Figure 1).



Technical Design, Materials Used and Construction Procedures

The first two blockings were constructed in the PPC-1 canal between February-June 2004 when two sheet piles combined with a non-woven geotextile design were applied (Figure 2a). The other five dams were constructed in PPC-2 canal and MPC-7 canal during July-September 2005 in which cases two sheet piles with chambers, combined with non-woven geotextile design were used (Figure 2b).

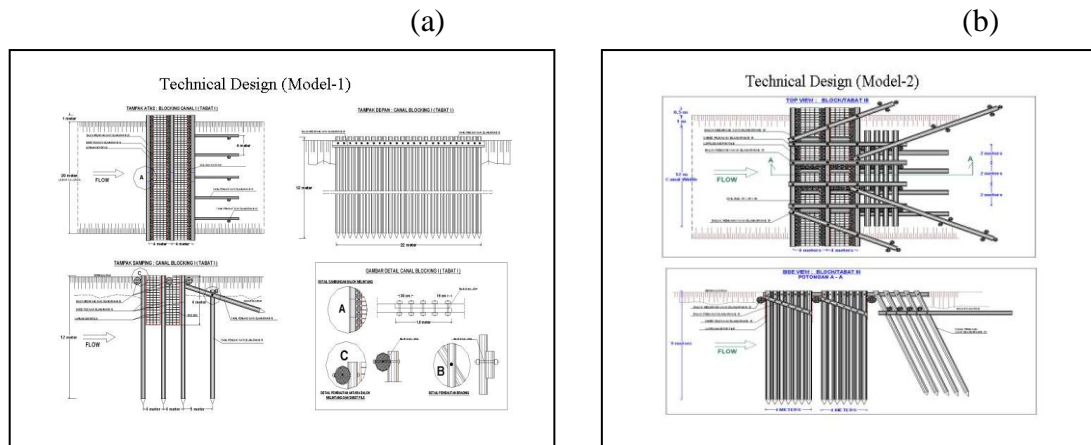


Figure 2 Dam Technical Designs

Materials that have been used for dam construction include log timbers, soil bags, geotextiles, and bolts and nuts. The following basic steps have been applied in constructing dams:

- (1) Log poles are sharpened according to necessity;
- (2) Log poles are pounded into peat soil;
- (3) Bracing system is installed;
- (4) Log poles are fasten together with bolts and nuts;
- (5) Top of poles is sawn so that they become neat and smooth;
- (6) Geotextile is laid down in front of the rows of poles; and
- (7) Soil bags are placed inside the block chambers until they reach the top of the dam.

Hydrological Monitoring

To determine hydrological changes resulting from dam construction, monitoring was focused on two hydrological aspects, namely surface water level (SWL) and ground water level (GWL). Other hydrological factors are assumed to remain constant. Rainfall data were also collected regularly to calculate the contribution of rainfall rate to the SWL. The Antecedent Rainfall Index correlation analysis was used in the following formula:

$$DL_i = c + b \times DL_{i-1} + a_0 \times R_1 + a_1 \times R_{i-1} + \dots + a_1 \times R_{i-7}$$

Where:

DL = Drain Level = SWL

c, b and a = coefficient

R = Rainfall

i = day index

In order to monitor SWL, two measurement meters were established at distances of two metres above and below Dam-1 in the PPC-1 canal. SWL data collection commenced in December 2004 and was recorded on a daily basis. Meanwhile, to measure GWL fluctuations, three PVC observation well transects, namely GWL-A, GWL-B and GWL-C, were established between Dam-1 and Dam-2 in PPC-1 and Dam-7 in the PPC-2. Each transect consisted of 8 PVC observation wells; levels were recorded on a weekly basis and data collection started in December 2004. Finally, to monitor rainfall rate, a rain gauge was positioned close to Dam-1 of PPC-1.

RESULTS AND DISCUSSION

Dam construction

Four dams have been constructed in the PPC-1 and PPC-2 canals, and three others in both southern and northern parts of MPC-1 canal. Dams constructed in the PPC-1 and PPC-2 canals have various widths between 26-28 metres; meanwhile, in the MPC-7 canal, width varies from 9.5 to 14 metres. Moreover, canal depth varies between 1.65 up to 3 metres, whereas, peat depth in the dam sites ranges from 10 up to 14 metres. Construction of Dam-1 and Dam-2 in the PPC-1 canal commenced in February 2004 and finished in June 2004 (first phase), while, construction of the other five dams on PPC-2 and MPC-7 canals took place from July up to December 2004.

Effect of dams on hydrology

Rainfall data, SWL and GWL collected and recorded for the period December 2004 up to September 2005 are shown in Figure 3.

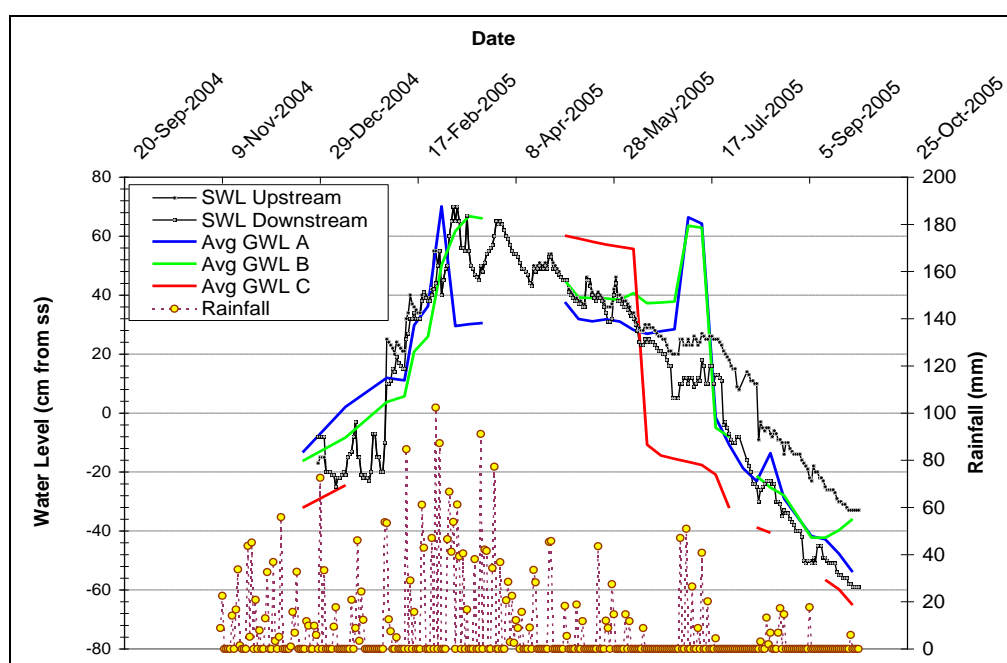


Figure 3 Rainfall, surface water levels and water tables recorded for the period December 2004-September 2005

Figure 3 shows, that in terms of SWL in Dam-1 of PPC-1, there was a significant SWL difference between downstream and upstream of Dam-1. This difference was almost 60 cm during the dry season (up to September 2005). A minimum SWL upstream of Dam-1 was not down more than 30 cm from the peat surface, whereas, SWL downstream was about 60 cm below the peat surface. Hence, there was significant difference in water storage between down and up stream of Dam-1 of the PPC-1 canal and it can be concluded that Dam-1 was effective in storing and retaining water in the PPC-1 canal during the dry season. It should be noted, however, the difference between SWL and peat surface was becoming progressively greater as we move further away from Dam-1. This means that Dam-1 has a limited capability for raising and retaining water in the PPC-1.

In addition, to measure the contribution of rainfall in raising SWL, thus, Antecedent Rainfall Index correlation analysis was applied (Figure 4) in the following form:

$$DL_i = -0.01104 + 0.990789 \times DL_{i-1} + 1.249857 \times R_i$$

The numeric approximation calculation shows that rainfall rate for respective days has contributed significantly to the SWL of PPC-1 (coefficient $a_0 > 0$), whereas, the previous 7 days rainfalls had no significant impact (coefficient of a_1 up to $a_7 = 0$). It means that rainfall occurring in the area has been released directly into the canal network as rapid surface run off and rapid groundwater flow.

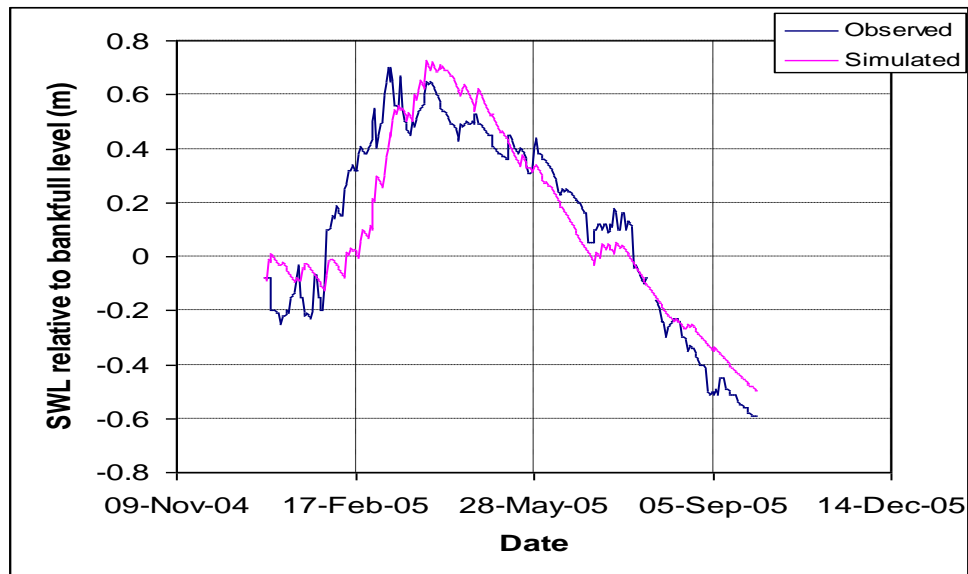


Figure 4 Surface water level of SPI-1 10 meter further up 1st block Observed and predicted with Antecedent Rainfall Index

Similarly, with regards to ground water table (GWL), Dam-1 has significant impact in raising GWL in the dam site as well as its surrounding area. However, the ability of Dam-1 to raise and retain GWL decreased significantly further away from the dam site.

Re-vegetation prospect

The impact of dams on re-vegetation has not been studied yet; however, direct observation in the field shows that new vegetation planted in the block sites has good growth as well as a high survival rate. This was observed for endemic tree species such as jelutung (*Dyera lowii*), pulai (*Alstonia* sp) and belangiran (*Shorea Belangiran*). To investigate further the impact of canal blocking on re-vegetation, it has been planed to establish special monitoring plots in the vicinity of the dam sites in the future.

CONCLUSIONS

- Canal blocking activities can be seen as a strategic measure in restoring degraded peatlands in the-ex Mega Rice Project area.

- The trial programme shows that constructed dams are effective in stabilizing hydrological properties of the site and hence, further peat degradation and depletion resulting from repeated fires and peat subsidence can be avoided.
- Canal blocking is a pre-requisite to rehabilitation activities.
- It is highly recommended that canal blocking activities are replicated and widened into larger areas within the ex-MRP, notably areas where deep and very deep peat exist.
- Research activity on the impact of canal blocking in reducing peat fire incidents is highly recommended.

ACKNOWLEDGEMENTS

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REFERENCES

- Dohong, A. (ed) (2005). Rencana Aksi: Strategi Penabatan Kanal pada Kawasan Blok A-Utara Eks Proyek Lahan Gambut Satu Juta Hektar, Kabupaten Kapuas, Propinsi Kaliman Tengah. Wetlands International-Indonesia Programme.
- Furukawa H. (2003) A Proposal for Rehabilitation of the Degraded Reclamation in Coastal Peat swamps in Indonesia: Makalah disampaikan pada acara Seminar dan Workshop Tahap II Pemanfaatan Lahan Gambut Propinsi Jambi, 17-19 Februari 2003.
- Suryadiputra, I.N.N., Dohong, A., Waspodu, R.S.B., Muslihat, L., Lubis, I.R., Hasundungan, F. and Wibisiono, I.T.C. (2005) A Guide to the Blocking of Canals and Ditches in Conjunction with Community. Climate Change, Forests and Peatlands in Indonesia Project. Wetlands International – Indonesia Programme and Wildlife Habitat Canada. Bogor.

NUTRIENT CONTENT OF RAINFALL, WATER IN CANAL AND WATER AT DIFFERENT DEPTHS IN PEATLAND IN CENTRAL KALIMANTAN, INDONESIA

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SUMMARY

Rainfall and water in a peat swamp area in Kalampangan Central Kalimantan, part of the former Mega Rice Project, Indonesia were sampled every four weeks from May 2004 to January 2007 and analyzed for total content of Ca, Mg, K, Na, and Fe. The study area has been drained since 1997. Rainfall was collected at two sites in a deforested area. Water samples were collected at three sites in a canal and six sites in the adjacent peat area. At each peatland site water samples were obtained from different depths of 50, 150 and 250 cm below the peat surface. Rainfall ranges from very acid to neutral (pH between 4.11 ± 0.01 and 6.60 ± 0.00 with average 5.12 ± 0.55). Water in the canal is very acid (pH between 3.32 ± 0.04 and 4.22 ± 0.05 with average 3.71 ± 0.19) with a predominance of Ca and K. pH of water sampled from the peat at 50, 150, and 250 cm depth in the deforested area has means of 3.98 ± 0.60 , 4.18 ± 0.36 and 4.31 ± 0.35 , respectively. In contrast, pH of water sampled from the peat at 50, 150, and 250 cm depth in the forest area has means of 3.68 ± 0.55 , 3.70 ± 0.38 and 3.92 ± 0.46 , respectively. Similarly to water in the canal, water sampled in the deforested and forest areas has a predominance of Ca and K.

Keywords: peat swamp, water sample, chemical analysis

INTRODUCTION

Several studies of tropical peat swamp forest have been carried out since the 1950s (Anderson, 1983; Rieley et al., 2005) According to these, lowland tropical peatlands are usually dome-shape (Rieley et al., 1997) and the only input of water and nutrients to them is from precipitation. Furthermore, Sulistiyanto (2004) states that an understanding of the hydrological condition in peat swamp forest is important for revealing the nutrient dynamics, especially since precipitation is the only input of water to this ecosystem and surface water flow is the only major route for nutrient losses. In the process of reclamation for agricultural purposes, extensive drainage networks were constructed across peat areas in Indonesia, including Central Kalimantan (Former ex Mega Rice Project). Drainage may cause peat domes to collapse because, without water, and owing to the very low density of the peat (Rieley et al., 1996), its low load-bearing capacity and high total porosity (Radjagukguk, 1992), peat cannot support tree vegetation or maintain the dome-shape (Kool et al., 2006). In addition, the continued growth of peat bog plants is made possible only by

nutrient input from the atmosphere, coupled with various adaptive mechanisms of bog plants (Moore and Bellamy, 1974, Marcos and Lanco, 2002). Drainage and logging cause severe damage to ombrotrophic peat domes in the surroundings of Palangka Raya, Central Kalimantan. The chemical properties of peat change upon oxidation, especially after burning. The following effects may be expected: (a) increase in acidity, owing to oxidation of pyrite in deeper mineral layers or leakage of organic acids from the peat; (b) increase in solute concentrations, resulting in release of nutrients following decomposition of the peat (Kool et al., 2006). This study evaluates changes in water chemical properties (nutrient content) at different depths in peat in both deforested and forested areas include rainfall and canal water.

MATERIALS AND METHODS

The study was carried out in the northern part of Block C of the former Mega Rice project near Kalampangan village in Central Kalimantan, Indonesia. Rainfall was collected in two fixed position rain gauges (constructed from wood and 35 litre capacity polyethylene containers fitted with 25 cm diameter plastic funnels) in a deforested area. Water samples were collected at three permanent sampling sites in a canal and six permanent sites in the adjacent peat area. The latter were established in (a) a deforested peat area (4 sites) and (b) peat swamp forest (2 sites). At each peatland site water samples were obtained from depths of 50, 150 and 250 cm below the surface. At each depth, a separate polyethylene pipe was inserted to sample each depth in the peat, making a total of 18 pipes from which water samples were taken by hand pump.

Rainfall and water samples were collected every four weeks from the end of May 2004 to the beginning of January 2007 and stored in a refrigerator (4°C) after collection, in the Analytical Laboratory, University of Palangka Raya. Next day, rainfall and water samples were filtered. Chemical analyses were carried out on the filtered samples for Ca, Mg, K, Na, and Fe using atomic absorption spectrophotometry (AAS spectra 30). Acidity of the samples (pH) was determined using a Hanna pH meter 211.

RESULTS

Rainfall

The pH of rainfall varied throughout the study period ranging from 4.11 ± 0.01 to 6.60 ± 0.00 and the mean during the study period was 5.12 ± 0.55 . The highest value obtained was on 14 September 2006 (pH = 6.60 ± 0.00) in the dry season, followed by 12 November 2004 (pH 6.38 ± 0.03) in the dry season. In contrast, the lowest value occurred on 30 March 2006 in the wet season.

The major nutrients in rainfall are Ca and K. Calcium varied throughout the study period ranging from 0.09 ± 0.02 to 3.51 ± 0.09 mg l⁻¹ and the mean during the study period was 0.72 ± 0.75 mg l⁻¹. Similarly to Ca, K of rainfall varied throughout the study period ranging from 0.04 ± 0.01 to 2.02 ± 0.02 mg l⁻¹ and the mean during the study period was 0.71 ± 0.52 mg l⁻¹. The order of magnitude of chemical elements in canal water is calcium, potassium, sodium, magnesium and iron.

Canal

The pH of canal water varied throughout the study period ranging from 3.32 ± 0.04 to 4.22 ± 0.05 and the mean during the study period was 3.71 ± 0.19 . The highest value obtained was on 18 August 2005 (pH = 4.22 ± 0.05) in the dry season, followed by 12 November 2004 (pH 4.05 ± 0.03) in dry season. In contrast, the lowest value occurred on 3 February 2005 in the wet season.

The principal nutrients in the canal water are Ca and K. Calcium varied throughout the study period ranging from 0.04 ± 0.06 to 2.91 ± 2.13 mg l⁻¹ and the mean during the study period was 1.30 ± 0.67 mg l⁻¹. Similarly to Ca, K of canal water varied throughout the study period ranging from 0.18 ± 0.02 to 1.49 ± 0.15 mg l⁻¹ and the mean during the study period was 0.75 ± 0.42 mg l⁻¹. Similarly to rainfall, the order of magnitude of chemical elements in canal water is calcium, potassium, sodium, magnesium and iron.

Deforested area

pH

Similarly to the pH of canal water, the pH of water in the deforested peatland at 50, 150, and 250 cm depth also varied throughout the study period. At 50 cm it ranged from pH 3.53 ± 0.08 to 5.93 ± 0.81 and the mean during the study period was 3.98 ± 0.60 . The highest value obtained was on 15 September 2005 (pH = 5.93 ± 0.81) in the dry season, followed by 18 August 2005 (pH 5.69 ± 1.20) also in the dry season. In contrast, the lowest value occurred on 30 March 2006 in the wet season. The pH at 150 cm ranged from 3.69 ± 0.27 to 5.36 ± 0 (only one sample available) and the mean during the study period was 4.18 ± 0.36 . The highest value obtained was on 12 November 2004 (pH = 5.36 ± 0) at the end of the dry season, followed by 14 September 2006 (pH 4.51 ± 0.93) in the dry season. In contrast, the lowest value occurred on 6 January 2006 in the wet season (pH 3.69 ± 0.27). For the 250 cm depth, pH ranged between 3.65 ± 0.16 and 5.27 ± 1.39 and the mean during the study period was 4.31 ± 0.35 . The highest value obtained was on 12 October 2006 (pH = 5.27 ± 1.39) at the end of dry season, followed by 12 November 2004 (pH 4.82 ± 0.79) also at the end of dry season. In contrast, the lowest value occurred on 6 January 2006 in the wet season (pH 3.65 ± 0.16).

Nutrients

Similarly to the calcium of canal water, the calcium of water in the deforested area at 50, 150, and 250 cm depth also varied throughout the study period. The calcium concentration of water at 50 cm depth ranged from 0.07 ± 0.04 to 4.51 ± 0.57 mg l⁻¹ and the mean during the study period was 1.93 ± 0.86 mg l⁻¹. Potassium content at 50 cm depth ranged from 0.06 ± 0.02 to 3.66 ± 1.08 mg l⁻¹ and the mean during the study period was 1.27 ± 0.88 mg l⁻¹. Sodium content at 50 cm depth ranged from 0.13 ± 0.03 to 1.46 ± 1.12 mg l⁻¹ and the mean during the study period was 0.51 ± 0.31 mg l⁻¹. Similarly to the order of magnitude of chemical elements in canal water, that at 50 cm depth in the deforested area is calcium, potassium, sodium, magnesium and iron. At 150 cm depth, the highest nutrient content of water is calcium ranging from 0.48 ± 0.32 to 5.77 ± 1.74 mg l⁻¹ and the mean during the study period was 2.24 ± 1.05 mg l⁻¹. This was followed by potassium with 0.05 ± 0.01 to 3.52 ± 3.32 mg l⁻¹ and the mean during the study period was 0.96 ± 0.76 mg l⁻¹. Sodium ranged from 0.02 ± 0.01 to 1.23 ± 0.38 mg l⁻¹ and the mean during the study period was 0.42 ± 0.30 mg l⁻¹. The lowest nutrient content is iron with a range from 0.03 ± 0.02 to 0.41 ± 0.02 mg l⁻¹ and the mean during the study period was 0.22 ± 0.10 mg l⁻¹.

At 250 cm depth, the highest nutrient content of water is also calcium with a range from 0.70 ± 0.27 to 4.33 ± 2.82 mg l⁻¹ and the mean during the study period was 2.06 ± 0.90 mg l⁻¹. This was followed by potassium with 0.09 ± 0.06 to 1.58 ± 1.10 mg l⁻¹ and the mean during the study period was 0.77 ± 0.46 mg l⁻¹. Sodium ranged from 0.07 ± 0.06 to 1.58 ± 1.10 mg l⁻¹ and the mean during the study period was 0.49 ± 0.42 mg l⁻¹. Magnesium ranged from 0.09 ± 0.02 to 0.96 ± 0.60 mg l⁻¹ and the mean during the study period was 0.34 ± 0.21 mg l⁻¹. The lowest nutrient content was iron with only 0.057 ± 0.03 to 0.48 ± 0.01 mg l⁻¹ and the mean during the study period was 0.24 ± 0.14 mg l⁻¹.

Forest area

pH

Similarly to the pH of canal water, the pH of water in forest area at 50, 150, and 250 cm depth also varied throughout the study period. The pH value of water in the forest at 50 cm depth ranged from pH 3.13 ± 0 to 5.54 ± 0 (one sample available) and the mean during the study period was 3.68 ± 0.55 . The highest value obtained was on 9 December 2005 (pH = 5.54 ± 0) in the beginning wet season, followed by 31 March 2005 (pH 4.33 ± 0) in the wet season. In contrast, the lowest value occurred on 3 February 2005 also in the wet season. The pH of water in the forest area at 150 cm depth ranged from pH 3.04 ± 0.01 to 4.89 ± 1.73 and the mean during the study period was 3.70 ± 0.38 . The highest value obtained was on 22 July 2004 (pH = 4.89 ± 1.73) in the dry season, followed by 31 March 2005 (pH 4.37 ± 0.93) in the wet season. In contrast, the lowest value occurred on 3 February 2005 in the wet season (pH 3.04 ± 0.01). For 250 cm depth in forest area, pH ranged between 3.37 ± 0.04 and 5.66 ± 1.97 and the mean during the study period was 3.92 ± 0.46 . The highest value obtained was on 9 September 2006 (pH = 5.66 ± 1.97) at the end of dry season, followed by 7 December 2006 (pH 5.03 ± 1.37) in the wet season. In contrast, the lowest value occurred on 3 February 2005 in wet season (pH 3.37 ± 0.04).

Nutrients

Similarly to the nutrient content of water in deforested area at 50, 150, and 250 cm depth, the nutrient content of water in the forest area at 50, 150, and 250 cm depth also varied throughout the study period. At 50 cm depth, the calcium concentration of water ranged from 0.16 to 3.96 mg l⁻¹ (one sample only) and the mean during the study period was 2.16 ± 1.08 mg l⁻¹. Potassium ranged from 0.17 to 1.92 mg l⁻¹ (one sample only available) and the mean during the study period was 0.89 ± 0.51 mg l⁻¹. Sodium ranged from 0.27 to 1.3 mg l⁻¹ (one sample available) and the mean during the study period was 0.63 ± 0.32 mg l⁻¹. Similarly to the order of magnitude of chemical elements in canal water, the magnitude of chemical elements at 50 cm depth in the forest area is calcium, potassium, sodium, magnesium and iron.

At 150 cm depth, the highest nutrient content of water is calcium, which ranged from 0.36 ± 0.32 to 5.43 ± 0.41 mg l⁻¹ and the mean during the study period was 2.26 ± 1.15 mg l⁻¹. This was followed by potassium that ranged from 0.05 ± 0.01 to 1.45 ± 0.83 mg l⁻¹ and the mean during the study period was 0.66 ± 0.47 mg l⁻¹. Sodium ranged from 0.3 ± 0.03 to 1.44 ± 0.83 mg l⁻¹ and the mean during the study period was 0.52 ± 0.22 mg l⁻¹. The lowest nutrient content was iron that ranged from 0.16 ± 0.06 to 0.85 mg l⁻¹ (one sample available) and the mean during the study period was 0.39 ± 0.16 mg l⁻¹.

At 250 cm depth, the highest nutrient content of water was also calcium with a range from 0.75 ± 0.15 to 4.08 ± 3.00 mg l⁻¹ and the mean during the study period was 2.14 ± 0.96 mg l⁻¹. This was followed by potassium that ranged from 0.05 ± 0.00 to $1.94 \pm$

0.91 mg l⁻¹ and the mean during the study period was 0.72 ± 0.52 mg l⁻¹. Sodium ranged from 0.23 ± 0.01 to 1.84 ± 0.21 mg l⁻¹ and the mean during the study period was 0.53 ± 0.35 mg l⁻¹. Magnesium ranged from 0.11 ± 0.06 to 0.96 ± 0.06 mg l⁻¹ and the mean during the study period was 0.39 ± 0.19 mg l⁻¹. The lowest nutrient content was iron with a range from 0.025 ± 0.02 to 0.755 ± 0.09 mg l⁻¹ and the mean during the study period was 0.38 ± 0.15 mg l⁻¹.

DISCUSSION

pH

The pH of rainfall during the study period was 5.12 ± 0.55; the pH of canal water was 3.71 ± 0.19; water pH in the deforested area at 50 cm depth (3.98 ± 0.60) was higher than in the forest area (3.68 ± 0.55). At 150 cm depth, the pH in the deforested area (4.18 ± 0.36) was higher than in the forest area (3.70 ± 0.38). Similarly to 50 and 150 cm depth, for 250 cm depth, the pH value in the deforested area (4.31 ± 0.35) was higher than the forest area (3.92 ± 0.46). These results indicate that the peat water was more acid near to the peat surface than far from the peat surface. One possible reason for this is that more organic acid is present at the top of the peat profile owing to the vegetation and decomposition process. The pH in the deforested area is higher than in the forest. The higher pH in the deforested area could be the result of the presence of ash and release of basic cations such as Ca, Mg, and K (Radojevic and Tan, 2000) from peat following burning.

Nutrients

In general, calcium, magnesium, potassium, and sodium concentrations in rainfall and canal water show higher values during the dry than the wet season. Iron does not show any distinct pattern between dry and wet seasons. These results agree with those of other workers who also found that the concentration of certain elements in rainfall was higher in the dry than the wet season, for example, magnesium and potassium (Liu et al., 2002), calcium and sodium (Veneklaas et al., 1990).

Several reasons have been suggested to explain why nutrient concentrations in rainfall and canal water are higher in dry than wet periods. The presence in the atmosphere of dust during the dry season, originating from peat burning may contain base cations (e.g. Ca, Mg, K) (Veneklaas et al., 1990) that are deposited in canal water. Moreover, biomass burning, especially at the end of the dry season, may also contribute an increased amount of some cations to the canal water (Clark et al., 1998).

The findings of this present study accord with the conclusions of Clark et al. (1998) and Prasad et al. (2000) who suggest that the majority of elements in rainfall result from biomass burning carried out by farmers near to the study areas every year at the beginning of crop cultivation, mainly during the dry season.

Comparison between deforested and forest areas at 50 cm depth indicated that the mean calcium value in the deforested area (1.93 ± 0.86 mg l⁻¹) was lower than in the forest area (2.16 ± 1.08 mg l⁻¹). For magnesium, the value in the deforested area (0.41 ± 0.13 mg l⁻¹) was lower than in the forest area (0.63 ± 0.44 mg l⁻¹). Sodium in the deforested area (0.51 ± 0.31 mg l⁻¹) was lower than in the forest area (0.63 ± 0.32 mg l⁻¹). Iron in the deforested area (0.20 ± 0.11 mg l⁻¹) was lower than in the forest area (0.31 ± 0.16 mg l⁻¹). In contrast, potassium in the deforested area (1.27 ± 0.88 mg l⁻¹) was higher than in the forest area (0.89 ± 0.51 mg l⁻¹). Unfortunately, the above averages were obtained from only half the number of total samples owing to a lack of water during the dry season at that depth.

For 150 cm depth, calcium in the deforested area ($2.24 \pm 1.05 \text{ mg l}^{-1}$) was nearly the same as in the forest area ($2.26 \pm 1.15 \text{ mg l}^{-1}$). For magnesium, the value in the deforested area ($0.35 \pm 0.18 \text{ mg l}^{-1}$) was the same as the forest area ($0.35 \pm 0.22 \text{ mg l}^{-1}$). While for sodium, the value in the deforested area was ($0.42 \pm 0.30 \text{ mg l}^{-1}$) and, in the forest area, ($0.52 \pm 0.22 \text{ mg l}^{-1}$). For iron, the value in the deforested area ($0.22 \pm 0.10 \text{ mg l}^{-1}$) was lower than in the forest area ($0.39 \pm 0.16 \text{ mg l}^{-1}$). In contrast, the value in the deforested area ($0.96 \pm 0.76 \text{ mg l}^{-1}$) was higher than in the forest area ($0.66 \pm 0.47 \text{ mg l}^{-1}$).

At 250 cm depth, calcium in the deforested area ($2.06 \pm 0.90 \text{ mg l}^{-1}$) was nearly the same as in the forest area ($2.14 \pm 0.96 \text{ mg l}^{-1}$). Similarly to calcium, potassium in the deforested area ($0.77 \pm 0.46 \text{ mg l}^{-1}$) was nearly the same as in the forest area ($0.72 \pm 0.52 \text{ mg l}^{-1}$). For magnesium, the value in the deforested area ($0.34 \pm 0.21 \text{ mg l}^{-1}$) was also nearly the same as the forest area ($0.39 \pm 0.19 \text{ mg l}^{-1}$). In contrast, iron in the deforested area ($0.24 \pm 0.14 \text{ mg l}^{-1}$) was lower than in the forest area ($0.38 \pm 0.15 \text{ mg l}^{-1}$).

Various reasons have been suggested to explain the differences in the chemical composition of water in deforested and forest areas. Lower nutrient contents (Ca, Mg, Na, and Fe) in the deforested area at 50 cm depth (acrotelm area) may result from leaching over the more than 10 years since the canal was constructed. This agrees with Crowther (1987) who found that that nutrient (Ca and Mg) losses through runoff or leaching could occur from the ecosystem. Sulistiyanto (2004) reported that Ca, Mg, Na and K were leached from a peat ecosystem in the Sabangau catchment, Central Kalimantan. Meanwhile, at 250 cm depth, almost all nutrients studied (Ca, K, Mg, and Na) were nearly the same in both deforested and forest areas. It has been suggested that at that depth the water is quite stable (catotelm area) and has been unaffected by changes that have taken place on the surface. Water does not moving laterally in the catotelm.

CONCLUSION

This study provides information on the variation of nutrient content of rainfall, peat water at different depths in deforested, forest peatland and in a canal. During the 3-year study period concentrations of all nutrients in the canal were lower than in forest and deforested area. Moreover, the results of this study highlight that nutrient concentrations in peat water at 250 cm depth were nearly the same on deforested and forest areas.

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REFERENCES

- Clark, K. L. Nadkarni, N. M., Schaefer, D. and Gholz, H. L. (1998). Cloud water and precipitation chemistry in a tropical montane forest, Monteverde, Costa Rica. *Atmospheric Environment*, 32: 1595-1603.
- Crowther, J. (1987). Ecological observations in tropical karst terrain, West Malaysia: II. Rainfall interception, litterfall and nutrient cycling. *Journal of Biogeography*, 14: 145-155.
- Kool, D. M., Buurman, P. and, Hoekman, D. H. (2006). Oxidation and compaction of a collapsed peat dome in Central Kalimantan. *Geoderma*. 131 : 217- 225.
- Liu, W., Fox, J. E. D. and Xu, Z. (2002). Nutrient fluxes in bulk precipitation, throughfall and stemflow in montane subtropical moist forest on Ailao Mountains in Yunnan, south-west China. *Journal of Tropical Ecology*, 18: 527-548.
- Moore, P. D. and Bellamy, D. J. (1974). *Peatlands*. Elek Science. London. 221 pp.
- Marcos, G. M. and Lancho, J. F. G. (2002). Atmospheric deposition in oligotrophic *Quercus pyrenaica* forest: implications for forest nutrition. *Forest Ecology and Management*, 171: 17-29.
- Prasad, V. K., Gupta, P. K., Sharma, C., Sarkar, A. K., Kant, Y., Badarinath, K. V. S., Rajagopal, T. and Mitra, A. P. (2000). NO_x emissions from biomass burning of shifting cultivation areas from tropical deciduous forest of India- estimates from ground base measurements. *Atmospheric Environment*, 34: 3271-3280.
- Radojevic, M. and Tan, K. S. (2000). Impacts of biomass burning and regional haze on the pH of rainwater in Brunei Darussalam. *Atmospheric Environment*, 34: 2739-2744.
- Radjagukguk, B. (1992). Utilization and management of peatlands in Indonesia for agriculture and forestry. *Proceedings of the International Symposium on Tropical Peatland*. Kuching. Sarawak, Malaysia. pp. 21-27.
- Rieley, J. O., Page, S. E., Limin, S. H. and Winarti, S. (1997). The peatland resource of Indonesia and the Kalimantan Peat Swamp Forest Research Project. *Proceedings of the International Symposium on Biodiversity and Sustainability of Tropical Peatlands* (Ed: J. O. Rieley and S. E. Page). Samara Publishing. Cardigan. UK. pp. 37-44.
- Rieley, J. O., Ahmad-Shah, A. A. and Brady, M. A. (1996). The extent and nature of tropical peat swamps. In *Tropical Lowland Peatlands of Southeast Asia* (Ed: E. Maltby, C. P. Immirzi, and R. J. Safford). IUCN. pp 17-53.
- Sulistiyanto, Y. (2004). Nutrient dynamics in different sub-types of peat swamp forest in Central Kalimantan, Indonesia. PhD Thesis. University of Nottingham. Nottingham. 388 pp.
- Veneklaas, E. J. (1990). Nutrient fluxes in bulk precipitation and throughfall in two montane tropical rain forests, Colombia. *Journal of Ecology*, 78: 974-992.

Fire and Land Use Change Aspects of Restoration

THE ROLE OF FIRE IN THE DEGRADATION OF TROPICAL PEATLANDS: A CASE STUDY FROM CENTRAL KALIMANTAN

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SUMMARY

Tropical peatlands in Central Kalimantan have been exposed to both extensive and intensive degradation as a result of unsustainable land management practices, which have led to widespread fires over the last three decades. Results from remote sensing analyses reveal that over the last 10 years fire frequency has increased and has now reached a yearly cycle. As a consequence of large scale, repeated fires, natural regeneration back to peat swamp forest has been replaced by retrogressive succession towards low biodiversity vegetation dominated by fire prone bushes and ferns. In a case study area of 450,000 ha, satellite images were used to determine land cover change and fire history and to assess the vegetation re-growth process.

Key words: peatlands, deforestation, fire, remote sensing, Borneo.

INTRODUCTION

Tropical ecosystems annually process about six times as much carbon through photosynthesis as humans release into the atmosphere through fossil fuel combustion (Malhi and Grace, 2000; Malhi *et al.*, 2002). Therefore, even relatively small perturbations within tropical forest ecosystems could produce significant changes in global carbon flux, the rate of climate change, biodiversity and, ultimately, human welfare (Lewis *et al.*, 2004). Peat swamp forest in Central Kalimantan (in the Indonesian part of Borneo) have been subjected to both extensive and intensive degradation owing to unsustainable land management practices, which have led to land cover change and widespread fires over the last three decades. Implementation of the Mega-Rice Project (MRP) in 1996-1998 led to substantial damage in a short time period when almost 80% of this area of approximately one million hectares, comprising mainly over-drained peatland, was heavily affected by fire during the prolonged dry season associated with the 1997/98 El Niño event. This led to loss of biodiversity, carbon and natural wetland ecological functions. The weaker El Niño event of 2002 caused further degradation of the remaining peat swamp forest and further significant loss of carbon as a result of combustion of both above ground biomass and peat. Our investigations reveal that until 2002 widespread and intensive fires were, in most cases, related to cyclical El Niño phenomena. Since 2003, however, fire has become an abnormal “natural” phenomenon in this tropical environment and the cause of wide-ranging environmental, social and health problems at both local and global scales (Davies and Unam, 1999; Rieley and Page, 2005). In order to quantify the scale of peatland degradation arising from this repeated and continuous fire activity, satellite imagery were used to investigate a project study area of nearly half a million hectares comprising Block C of the ex MRP in Central Kalimantan.

MATERIALS AND METHODS

The fire history and land cover maps for the last three decades were derived from satellite earth observation data. We have used a time-series of images obtained from several sensors, including Landsat MSS, TM, ETM+, Aster/Terra and the Digital Monitoring Constellation (DMC) covering a 32 year period (1973-2005). An analysis of more than 20 satellite images was undertaken to derive land cover maps for 1973, 1991, 1993, 1996, 2000, 2003 and 2005 as well as to obtain the spatial and temporal distribution of burn scars.

Maps showing the location of burn scars were derived by using a spatial index threshold approach combining the NDVI (Normalized Difference Vegetation Index) and dNBR (Difference Normalized Burned Ratio) (Chuvieco *et al.*, 2006; De Santis and Chuvieco, 2006). Land cover maps were based on manual segmentation of the data into 15 classes, one being recently burnt areas. A manual segmentation was shown to be the optimal approach because (i) the data were acquired from a number of sensors and at different periods of the year, covering both dry and wet seasons, (ii) pixel based automatic classification could not cope with separation of spectrally overlapping classes and specifically the heterogeneity of burned areas, and (iii) excessive haze and cloud cover further reduced the quality of the data.

RESULTS AND DISCUSSION

The classification results show that land cover alters dramatically over a 32 year period, largely as a consequence of land clearance and repeated fires. The first two decades of the study period are not so critical for land cover change, even though fire occurred in this region, especially during El Niño (ENSO) years. During ENSO-driven droughts in 1972/3, 1982/83 and 1991/2 (Aiken, 2004; Fuller and Murphy, 2006; Wyrski, 1975) fire affected only 6.9% (~31,100 ha), 7.9% (~35,600 ha) and 7.5% (~33,600 ha) of Block C, respectively (Figure 1). The next El Niño event in 1997, however, caused devastation and was the most critical for the already disturbed peatlands of Central Kalimantan because of the MRP implementation. The fires that occurred in 1997 affected 33.5% (~150,500 ha) of Block C. This was one-and-a-half times more than was burned in total over the period 1973-1996. Peat swamp forest (PSF) removal made a major contribution (84%) to the total burnt area.

A further progressive degradation of peatlands took place during the weak El Niño dry season in 2002 when fires were widespread once more, affecting 24% (~106,500 ha) of Block C. The total PSF area affected by fire in relation to the total burnt area decreased from nearly 80% in 1997, to 18% in 2002, and 2% in 2005. This indicates that the location of the fires over this time period has shifted from forest into non-forest vegetation. Moreover our analysis of fire frequency and intensity reveals that, since 2002, fire has become an inherent factor affecting the tropical peatlands ecosystem of Central Kalimantan with annual occurrence. For example, during the dry seasons of 2003/2004 and 2005 fire affected 14.3 % and 12.4% of the study area, respectively, with the majority occurring in non-forest vegetation. In 2006, fire activity was again widespread across the region, associated with a moderate El Niño event. A detailed fire frequency map indicates that many parts of Block C have burned once, twice and even three and more times over the last three decades.

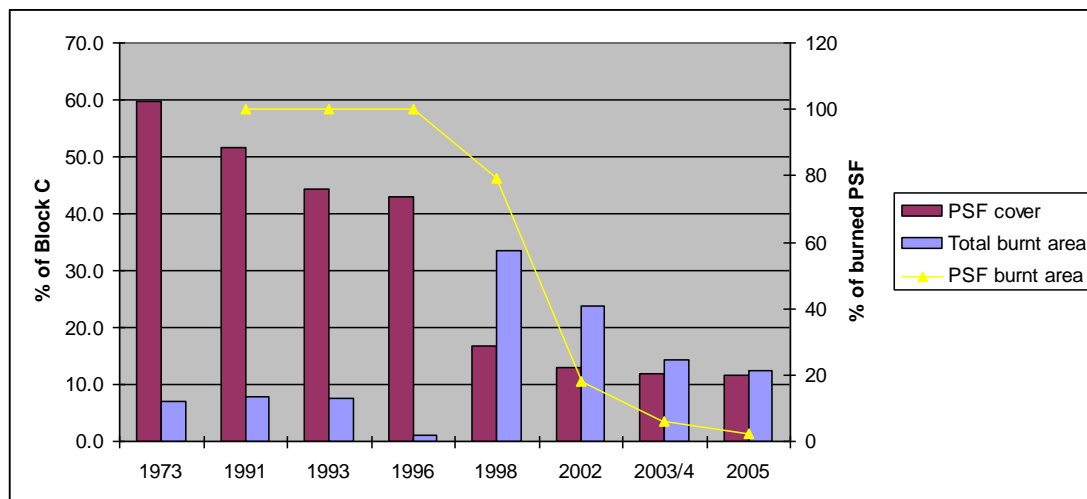


Figure 1 Percentage of changes in Block C in a) cover of peat swamp forest (PSF) b) total burnt area and c) proportion of burned PSF within the total burnt area.

There is strong evidence that fire is the major factor that is driving land cover change in Central Kalimantan. After the El Niño of 1972/3, forest occupied 72% of Block C, 60% of which was defined as peat swamp forest (i.e. mixed swamp forest on peat up to 6m thick and low pole forest on peat >6m thick) (Page *et al.*, 1999). An additional 12% was freshwater swamp forest, mangrove and heath forest. Before the great fire of 1972/73, forest cover may have been nearer 80% of Block C. The rate of loss of peat swamp forest in relation to the initial year 1973 greatly increased from 26% in the first two decades up to 72%, owing to the fire of 1997 and reached 80% in 2005. Recent estimates indicate that 80% of the peat swamp forest has been lost over the last three decades.

Additional data obtained from the study area have revealed that the massively degraded peatlands in the MRP area are constantly being exposed to fire and are unable either to resist fire or to recover naturally. Forest is being replaced by more homogeneous, lower growing plant communities dominated by bushes, ferns and sedges with very few trees. These new post-fire peatlands are more susceptible, on the one hand, to fire during the dry season and, on the other, to flooding in the wet season (Wösten *et al.*, 2006).

REFERENCES

- Aiken, S.R. (2004) Runaway fires, smoke-haze pollution, and unnatural disasters in Indonesia. *The Geographical Review*, 94, 55-79.
- Chuvieco, E., Rian'o, D., Danson, F.M. and Martin, P. (2006) Use of a radiative transfer model to simulate the post fire spectral response to burn severity. *Journal of Geophysical Research-Biosciences*, 111, 1-15.
- Davies, S.J. and Unam, L. (1999) Smoke-haze from the 1997 Indonesian forest fires: effects on pollution levels, local climate, atmospheric CO₂ concentrations, and tree photosynthesis. *Forest Ecology and Management*, 124, 137-144.
- De Santis, A. and Chuvieco, E. (2006) Burn severity estimation from remotely sensed data: Performance of simulation versus empirical models. *Remote Sensing of Environment*, 108, 422-435.

- Fuller, D.O. and Murphy, K. (2006) The ENSO-fire dynamic in insular Southeast Asia. *Climatic Change*, 74, 435-455.
- Lewis, S.L., Malhi, Y. and Phillips, O.L. (2004) Fingerprinting the impacts of global change on tropical forests. *Philosophical Transactions of the Royal Society of London, Series B* 359, 437-462.
- Malhi, Y. and Grace, J. (2000) Tropical forests and atmospheric carbon dioxide. *TREE*, 15, 332-337.
- Malhi, Y., Meir, P. and Brown, S. (2002) Forests, carbon and global climate. *Philosophical Transactions of the Royal Society of London Series a-Mathematical Physical and Engineering Sciences*, 360, 1567-1591.
- Page, S.E., Rieley, J.O., Shoty, O.W. and Weiss, D. (1999) Interdependence of peat and vegetation in a tropical peat swamp forest. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, 354, 1885-1897.
- Rieley, J.O. and Page, S.E. (Eds.) (2005) Wise Use of Tropical Peatlands: Focus on Southeast Asia. www.strapeat.alterra.nl
- Wösten, J.H.M., van Denberg, J., van Eijk, P., Gevers, G.J.M., Giesen, W.B.J.T., Hooijer, A., Idrisi, A., Leenman, P.H., Rais, D.S., Siderius, C., Silvius, M.J., Suryadiputra, N. and Wibisono, I.T. (2006) Interrelationships between Hydrology and Ecology in Fire Degraded Tropical Peat Swamp Forests. *Water Resources Development*, 22, 157-174.
- Wyrski, K. (1975) El Niño-The Dynamic Response of the Equatorial Pacific Ocean to Atmospheric Forcing. *Journal of Physical Oceanography*, 5, 572-584.

MONITORING RESTORATION MEASURES IN TROPICAL PEATLANDS USING RADAR SATELLITE IMAGERY

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SUMMARY

In the context of the ongoing climate change discussions the importance of peatlands as carbon stores is increasingly recognized in the public domain. Deforestation, drainage and peat fires are the main reasons for the release of huge amounts of carbon. Successful restoration of degraded tropical peatlands is of high interest owing to their huge carbon store and massive sequestration potential. The blocking of drainage canals by dam building has become one of the most important measures to restore the hydrology and the ecological function of peat domes. This study investigates the feasibility of using multitemporal radar remote sensing imagery for monitoring the hydrological effects of these measures. The study site is the former Mega Rice Project area in Central Kalimantan, Indonesia, where the peat drainage and forest degradation is especially intensive. First results of more than 40 ENVISAT ASAR and ALOS PALSAR images show that high frequency multitemporal radar satellite imagery can be used to detect an increase in soil moisture in the peat soil after dam construction.

Keywords: tropical peat, restoration, canal blocking, soil moisture, radar satellite

INTRODUCTION

In the past decade large areas of the Indonesian peatlands have experienced serious damage as a result of human activities such as logging and drainage. Peatland site development is often associated with the construction of drainage canals in order to make the land usable for agriculture or, more often, for oil palm and pulp wood plantations. Canals and ditches are not only built to control and lower the water level but also to facilitate access to the peat swamp forest and for transportation of timber logs. Once the peat swamp forest has been removed and the peat drained, the exposed peat oxidises owing to bacterial activity and emits carbon into the atmosphere (Rieley and Page, 2005). Furthermore, oxidation is leading to the irreversible process of peatland subsidence (PS KONSULTANT and LAWOO, 2001). Another severe consequence of drainage construction is that the peat surface becomes dry and thus susceptible to fire during the dry season. Fires in degraded peatlands can result in a quick release of huge amounts of the greenhouse gas CO₂ (Page *et al.*, 2002). These processes, which convert peatlands from being a carbon sink to a source, can only be halted by complete re-saturation of the peat with water. Owing to its very high

permeability peat acts like a sponge. Therefore, one of the most important peatland restoration measures is the blocking of drainage canals by dams, which is now widely implemented by various projects in Central Kalimantan.

The objective of this study was to investigate the feasibility of using remote sensing data for monitoring the effects of tropical peatland restoration by canal blocking. Radar imagery was selected because it is available at high temporal frequency and it is sensitive to changes in soil moisture. In general, vegetation or soil with a high moisture content returns more energy back to the radar sensor, i.e. higher σ^0 value, than if it is dry (Lillesand and Kiefer, 1994). Several studies have demonstrated the relationship between σ^0 and surface soil moisture content under varying terrain conditions (e.g. Ulaby *et al.*, 1982; Hashim *et al.*, 2002; Paloscia *et al.*, 2005). Study site was the former Mega Rice Project area (Ex-MRP) in Central Kalimantan, Indonesia, where with the presence of about 4,500 km drainage canals peat drainage and forest degradation is especially intensive (Fig. 1).

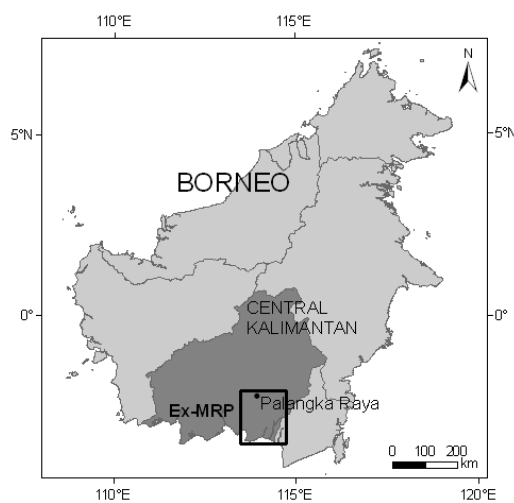


Figure 1 The former Mega Rice Project area (Ex-MRP), located in the Indonesian province of Central Kalimantan, is the study site.

MATERIALS AND METHODS

Figure 2 shows the location of eleven dams which were investigated to determine their peat rewetting effectiveness. The dams southeast of the town of Palangka Raya were constructed between July and September 2005 within the KEYTROP and RESTORPEAT project under the leadership of the University of Palangka Raya. The other dams, some are blocking the main canal going from west to east, were built between March 2004 and January 2005 within the CCFPI project mainly by Wetlands International (Suryadiputra *et al.*, 2005). Furthermore, water level data collected by automatic loggers since April 2004 at three locations in the Ex-MRP Block C were made available by the KEYTROP project (see Fig. 2). A time-series of 25 ENVISAT-ASAR radar images, acquired between July 2004 and October 2007, was investigated by change detection methods. In addition 18 PALSAR scenes, acquired by the ALOS satellite since July 2006 were analysed. All radar images were geocoded, calibrated to radar backscatter values (σ^0) and speckle filtered. When measuring changes in peat moisture it is important to consider the actual weather conditions during the time of radar image acquisition. Precipitation data collected by the Tropical Rainfall Measuring Mission (TRMM), which merges high quality microwave and infrared precipitation data, were used for this purpose. The data has a 3-hour temporal and a $0.25^\circ \times 0.25^\circ$ spatial resolution (see Fig. 2).

There are several advantages of satellite Synthetic Aperture Radar (SAR) data: (1) large scale data collection, (2) cloud penetration and (3) dependence on the dielectric constant which is dependent on the presence of moisture in soil and vegetation (Lillesand and Kiefer, 1994). However, SAR backscatter is also influenced by other surface parameters such as roughness which makes it often difficult to interpret. To assess SAR data quality, preliminary investigations on the sensitivity of the ASAR backscattering coefficient σ^0 to precipitation and in situ water level measurements were carried out. Test areas of the size 200 m x 400 m, located close to the dams, were analysed before and after dam construction as well as reference areas in undrained regions.

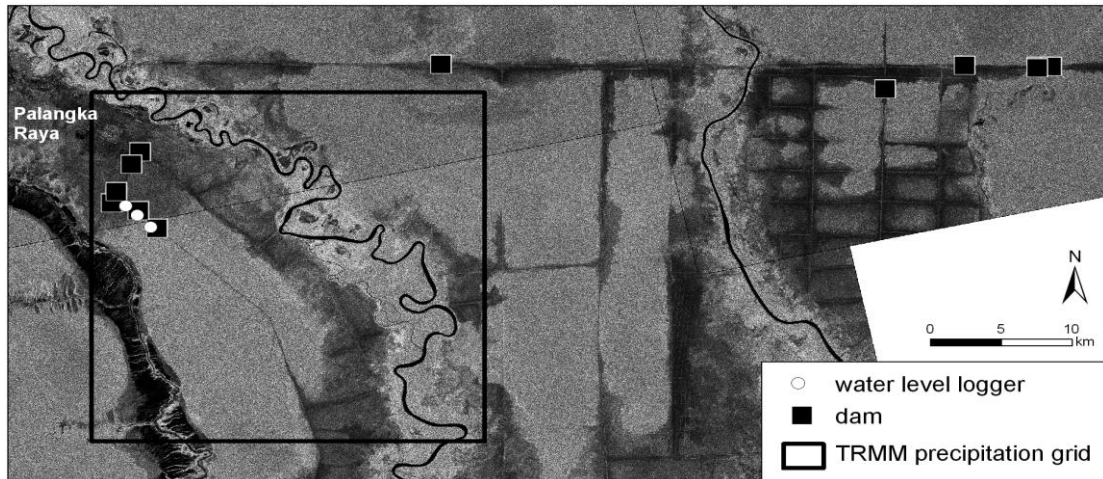


Figure 2 Shown is the location of eleven dams located in the Ex-MRP area, three water level loggers and the TRMM precipitation grid. ALOS-PALSAR dual polarized images from July 2007 clearly show burn scars and vegetation regrowth near the drainage canals (© JAXA).

RESULTS AND DISCUSSION

A direct comparison of daily precipitation data with the ASAR backscatter coefficient σ^0 (VV polarization) shows a good correlation (Fig. 3), and demonstrates the relationship between the intensity of the SAR backscatter signal and the presence of moisture in tropical peat soil. As an example, figure 3 shows a SAR test area near the water level loggers and located on degraded peat. Within the ASAR time series of two years an increase of 0.8 dB occurs after completion of the dam construction, while there is only a very slight increase in precipitation data. On average backscatter values are higher after canal blocking than before. The annual precipitation in 2004 was with 1141 mm equal to the rainfall in 2007 (Jan.-Oct., 1143 mm), while 2005 was slightly drier (1036 mm). In 2006 El Niño caused significantly drier conditions with only 851 mm. This observation suggests that the increase in radar backscatter results from an increase in peat moisture after canal blocking. A similar trend and relationship exists with in situ water level data. The water level during the dry season of 2007 is clearly higher than in 2004 even though rainfall data of several months is directly comparable. Similar observations were made for other test areas and dams.

These preliminary results show the potential of multitemporal SAR imagery for monitoring the success of restoration measures in tropical peatlands. Further research will be conducted in order to confirm these first results. Especially a change detection

analysis of ALOS-PALSAR imagery is of high interest. This sensor acquires data in L-band wavelength, which is longer than ASAR C-band, and thus generally better suited for monitoring soil moisture and surface wetness conditions (Schmullius and Furrer, 1992; Lillesand and Kiefer, 1994). Up to now too few PALSAR images are available for change detection. Unfortunately, there are no images available for the situation before dam construction, because ALOS imagery is available only since July 2006. However, in the near future the effectiveness of latest dam constructions built by the Central Kalimantan Peatland Project (CKPP) in 2007 can be investigated. In addition, PALSAR data have proved to be very useful for monitoring deforestation of peat swamp forest as well as regrowth. Figure 2, a dual polarized PALSAR image, clearly shows various conditions of vegetation regrowth after fire (mid to dark grey shades), which are mainly located near drainage canals. Monitoring of fire occurrence and impact as well as successful fire prevention are important components for peatland restoration. Rewetting of peat soil is an essential measure in order to stop peat oxidation and subsidence, support vegetation regrowth and to prevent fire ignition. On a regional scale peatland restoration will improve the quality of life for local people and is of global importance in order to stop the release of huge amounts of carbon to the atmosphere. With a functional hydrology tropical peatlands even have the potential to sequester significant amounts of CO₂.

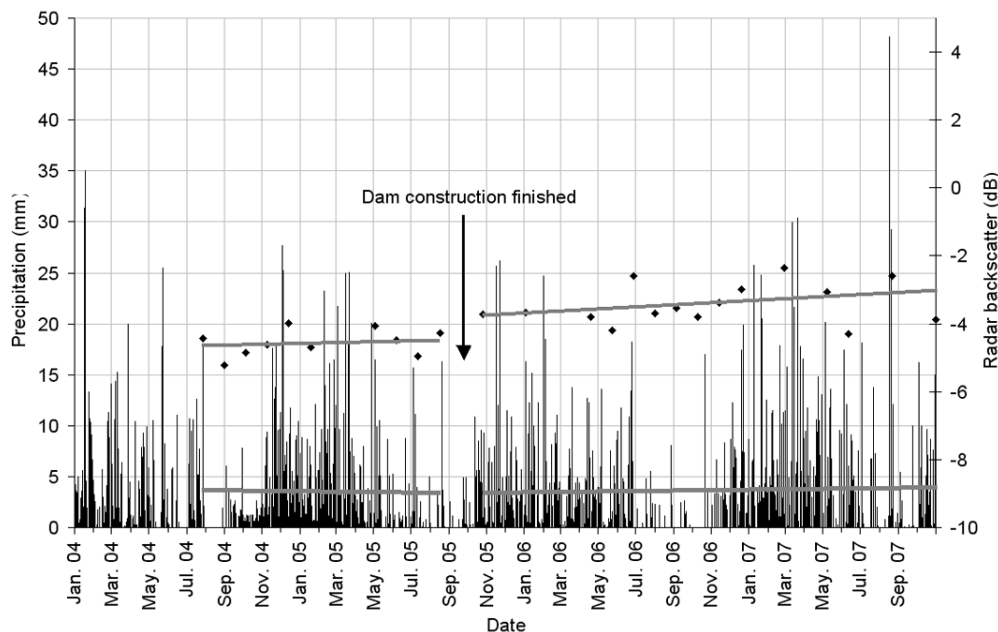


Figure 3 A direct correlation between TRMM precipitation (bar) and ASAR backscatter data (scatter) exists. There is an increase in radar backscatter after completion of dam construction. The backscatter values are means over a 200 m x 400 m large area southeast of Palangka Raya.

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REFERENCES

- Hashim, H., Busu, I., Sim, S.H., Jong, T.K., Wan Kadir, W.H. and Salam, N.D. (2002): Soil moisture, depth of water table and peat decomposition in Sadong Simunjan river basin, Sarawak using AIRSAR/TOPSAR data. *3rd Malaysian Remote Sensing and GIS Conference and Exhibition, 8-9 April 2002, Kuala Lumpur*, 17 pp.
- Lillesand, T.M. and Kiefer, R.W. (1994). *Remote Sensing and Image Interpretation*. Third edition, 750 pp. John Wiley and Sons, Inc., New York.
- Page, S.E., Siegert, F., Rieley, J.O., Boehm, H.-D.V., Jaya, A. and Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature* 420, 61-65.
- Paloscia, S., Pampaloni, P., Pettinato, S., Poggi, P. and Santi, E. (2005). The retrieval of soil moisture from ENVISAT/ASAR data. *EARSeL eProceedings* 4(1), 44-51.
- PS KONSULTANT (Kuching, Sarawak) in Association with LAWOO (The Wageningen Land and Water Research Group) (2001). *Water Management Guidelines for Agricultural Development in Lowland Peat Swamps of Sarawak*. Executive Summary, 9 pp.
- Rieley, J.O. and Page, S.E. (eds.) (2005). *Wise Use of Tropical Peatlands: Focus on Southeast Asia*. Alterra, Netherlands. www.restorpeat.alterra.wur.nl.
- Schmullius, C. and Furrer, R. (1992). Frequency dependence of radar backscattering under different moisture conditions of vegetation covered soil. *International Journal of Remote Sensing* 13(12), 2233-2245.
- Suryadiputra, N.N., Dohong, A., Waspodo, R.S.B., Muslihat, L., Lubis, I.R., Hasudungan, F. and Wibisono, I.T.C. (2005). *A Guide to the Blocking of Canals and Ditches*. 170 pp. Wetlands International – Indonesia Programme, Bogor.
- Ulaby, F.T., Aslam, A. and Dobson, M.C. (1982). Effects of Vegetation Cover on the Radar Sensitivity to Soil Moisture. *IEEE Transactions on Geoscience and Remote Sensing* GE-20(4), 476-481.

DEVELOPMENT OF POST-FIRE VEGETATION IN THE TROPICAL ECOSYSTEM OF CENTRAL KALIMANTAN, INDONESIA

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SUMMARY

This research illustrates the capacity of post-fire secondary vegetation for carbon storage and restoration of the tropical peatland ecosystem. It is evident that the extent and rate of vegetation regeneration greatly depends on fire frequency and burn severity, as well as the pre-fire vegetation condition and proximity to remaining forest. Our investigations show that secondary succession towards forest is possible following a single fire. However, the re-growth potential decreases for areas affected by multiple disturbances over a short period of time. For example, locations subject to two intensive fires are dominated by homogenous, lower growing plant communities dominated by ferns and sedges with very few trees. These locations have a much lower potential, if any, for regeneration of forest vegetation, even over a long time period. Restoration action is, therefore, urgently required in locations where the natural regeneration is halted. Moreover, it is clear that both regeneration and restoration are only possible if further fires are prevented and the remaining patches of natural forest are protected as a potential biodiversity source for recolonisation.

Keywords: post-fire vegetation regeneration, secondary succession, tropical peatland ecosystem, Borneo.

INTRODUCTION

Reducing deforestation and degradation of tropical forest has become a fundamental issue for sustainable land management and climate care. Extensive and intensive fires together with land conversion practices are the main causes of forest loss and degradation in the Southeast Asia region (Rieley and Page, 2005), with heavily degraded forests and abandoned land susceptible to regular, repeated fires. Current research focuses on monitoring these phenomena in order to suggest effective actions for fire prevention and post-fire mitigation. In order to offset the negative consequences of forest degradation there is a growing need to investigate the extent of disturbance caused by repeated fires as well as to assess the natural potential for vegetation regrowth and rehabilitation. Ecological knowledge of post-fire vegetation response is necessary in order to undertake and implement appropriate restoration planning or to convert degraded land to a more efficient land use. It is also important to have knowledge of the condition, volume and biomass of regrowth as this will influence the potential fire risk (through effects on fuel load and fuel quality). Finally, tropical secondary vegetation can play a role as a potential regulator of climate change as a result of its capacity to act as a carbon sink, both now and into the future (Castro *et al.*, 2003; Lucas *et al.*, 2005). The benefits of vegetation restoration listed above

emphasise the importance of this study, although it must be stressed that the regeneration processes in disturbed tropical forest are extremely complex and difficult to examine since they depend upon many factors, including land use history, frequency and severity of disturbance, pre- and post-fire condition of soil, hydrology, etc. (Hughes *et al.*, 1999; Lu, 2005).

This study focused on examination of post-fire vegetation regeneration under different fire disturbance regimes taking into account fire frequency and burn severity. These two factors have been shown to be a major driver of secondary vegetation succession in the heavily degraded tropical peatland of the Ex-Mega Rice Project area (Ex-MRP) in Central Kalimantan, Indonesia. The study was located in the western part of the Ex-MRP in a section called Block C, covering about 4,500 km². Our previous research had revealed that approximately 80% of the study area (mainly comprising of tropical peat swamp forest) had been heavily degraded over the preceding three decades, with the most serious degradation occurring during the last decade as a result of implementation of the Mega Rice Project (Hoscilo *et al.*, 2007). The over-drained peatland became fire-prone, with regular, repeat fires. Some locations have been subjected to two, three or even more fires.

This new phenomenon of regular, widespread peatland fires, which causes a range of environmental, social and economic impacts, has brought together scientists and decision makers in a desire to understand and investigate post-fire succession processes in order to take steps towards sustainable management of the degraded landscape. The research described in this paper focuses on the vegetation response to single and multiple fires over a five year time frame.

MATERIALS AND METHODS

Investigation of post-fire vegetation succession was based on integration of data on biophysical variables collected in the field and spectral data derived from satellite images. This study was conducted in the northern part of Block C, where 20 plots were established to characterise different stages of secondary succession, driven by fire occurrence and burn severity. The main field data collection was carried out during the dry season of 2006. Fire occurrence and burned area maps derived from archive satellite images provided essential information on pre-fire land cover status and the spatial pattern of burned areas over the last three decades. The northern part of Block C was initially (before the fire of 1997) occupied by mixed peat swamp forest with some evidence of logging activities. The fire of 1997 destroyed a large portion of the original forest; new post-fire vegetation (secondary forest) managed to establish over the next five years, only to be re-burnt once again in the fire of 2002. Moreover, the 2002 fires spread over a larger area, entering fragments of remnant forest. The magnitude of fire damage, called burn severity, depends on many factors such as pre-fire land status, vegetation condition, fire regime and intensity as well as duration of the fire (van Wagtenonk *et al.*, 2004). The term burn severity refers to short-term ecological changes occurring as a result of a fire, on a daily or weekly scale, and biophysical effects of fire operating over several years during the post fire period (Roy *et al.*, 2006). Secondary vegetation succession was examined for locations that were burnt by a single fire (SF) and those burnt by multiple fires (MF) with different magnitudes. Three classes of burn severity (low, medium and high) were delineated based on integration of biophysical variables with widely-used multi-temporal spatial indices derived from remote sensing.

Field data collection

The characteristics of different stages of vegetation re-growth were obtained by studying four biophysical indicators: total above ground biomass, canopy cover, ground cover and species composition, in 20 plots, each 20 x 20 m. The diameter at breast height (DBH), height, canopy cover and species composition were recorded for all trees, saplings and seedlings within each plot. Trees were defined as having a DBH equal to or greater than 5cm, saplings with DBH ranging from 1cm to 5cm and seedlings with DBH less than 1cm. Woody above ground biomass (AGB) was obtained by applying the allometric equation proposed by Chave et. al (2005), which is based on DBH and height of canopy. In addition, individual and multiple stemmed canopies were recorded separately in each plot. Non-woody AGB was largely dominated by two fern species: *Stenochlaena spp.* and *Blechnum spp.* Non-woody biomass was measured using an oven-dried laboratory method.

RESULTS

Plots experiencing multiple fires (MF) between 1997 and 2002 were separated into three classes: low (MFLSev), moderate (MFMSev) and high (MFHSev) burn severity and represented by four, six and six plots, respectively. Secondary succession following a single fire (SF), in 1997, was represented by four plots. Table 1 presents a summary of the major biophysical features characterising each of these categories.

	MFHSev	MFMSev	MFLSev	SF
Number of tree species (no/site)	2.67	5.00	8.50	16.25
Tree density (individual/ha)	4.17	62.50	481.00	1881.00
Tree density (multiple stem/ha)	25.00	246.00	425.00	562.50
Tree density (individual + multiple stem)	29.20	308.00	906.00	2444.00
Saplings density (individual/ha)	617.00	1021.00	618.80	5900.00
Saplings density (multiple stem/ha)	20.80	200.00	231.30	0
Seedlings density (individual/ha)	313	779	87	8000
Ratio saplings/tree	29.40	14.20	0.99	2.46
% of <i>Combretocarpus spp.</i> for tree	86.70	98.73	84.47	60.70
% of <i>Combretocarpus spp.</i> for saplings	90.14	68.73	66.26	0
DBH of trees (cm)	6.07	6.58	7.43	7.69
DBH of saplings (cm)	2.58	2.58	3.18	2.20
% of tree DBH <10cm	100	98.33	86.75	84.75
% of tree DBH from 10cm to 15cm	0	1.67	12.5	13.75
% of tree DBH >15cm	0	0	0.75	1.50
Basal area of tree (m ² /ha)	0.19	1.95	6.32	14.37
Fern cover (%/site)	96.50	68.40	38.00	0
Biomass of tree (t ha ⁻¹)	0.23	2.56	11.57	27.23
Biomass of saplings (t ha ⁻¹)	0.26	1.20	1.38	2.49
Total woody biomass (t ha ⁻¹)	0.52	3.89	14.30	29.77
Fern biomass (t ha ⁻¹)	8.52	7.01	3.20	0

Table 1 Average value of biophysical features for four succession classes in Block C of the Ex –MRP in Central Kalimantan, Indonesia; MFHSev, MFMSev, and MFLSev represent locations experiencing multiple fires with high, moderate and low burn severity; SF represents locations that have experienced a

single fire; *Combretocarpus rotundatus* is the dominant recolonising tree species

DISCUSSION AND CONCLUSION

Our study provides the most comprehensive examination of post-fire vegetation succession presently available for tropical peatlands. A key conclusion is that if only burnt once, tropical peat swamp forest has a high potential to recover naturally, assuming that fire does not have a short return period. Secondary re-growth following a moderately severe fire in 1997 was at a relatively advanced stage of succession with 2444 ± 238 (\pm SD) trees greater than 5cm DBH per hectare, although on average 85% of the total number of trees was represented by individuals with small stems of less than 10cm DBH, whilst only 15% was made up of trees with a DBH greater than 10cm. The total woody above ground biomass (AGB) was on average 30 t ha^{-1} (ranging from 20 to 51 t ha^{-1}). The highest value for woody AGB was recorded for a plot located in close proximity to the remaining intact forest, indicating the role that remnant forest fragments play in stimulating successional processes. There was also a significant variation in tree species composition within the SF class. The vegetation in the plot located closest to the edge of the remaining forest contained a mixture of primary forest species, with *Cratoxylon spp.*, *Shorea spp.* and *Litsea spp.* representing 19%, 12% and 7% of the total number of all trees, respectively. In plots further away from the forest edge, primary forest species were replaced by pioneer species such as *Combretocarpus spp.* (comprising up to 75% of all trees recorded). Furthermore, species richness increased considerably from 16 to 29 species per plot on moving closer to the remaining forest. Hence, intact patches of natural forest play a crucial role as a source of biodiversity and also contribute to increased AGB accumulation.

The woody AGB of secondary vegetation in the multiple fire (MF) plots which were dominated by one pioneer species (*Combretocarpus spp.*) was much lower than that of the SF plots, although the woody AGB of MFLSev reached a value of 14 t ha^{-1} over four year post-fire period, which is equal to half the average AGB of SF. The AGB of MFLSev was dominated by a large number of saplings and trees, with 13% of trees greater than 10cm in DBH; these larger individuals probably resisted the last fire. Of interest is the fact that a half of all trees were multiple-stemmed; this could be related to a lack of competition in the exposed areas and could be used as one of the indicators of post-fire regeneration.

The woody AGB decreased rapidly to 4 tonnes per hectare in the MFMSev plots; this was three times less than the AGB of the MFLSev plots. The MFMSev plots also revealed some regeneration potential as they contained a higher number of seedlings and saplings (up to 14 saplings to at least one tree) dominated by *Combretocarpus spp.* and *Cratoxylon spp.* The tree canopy was dominated (80%) by multiple stemmed trees with a DBH of less than 10cm. The principal species was the pioneer *Combretocarpus spp.* (98% of total number of trees).

The lowest woody AGB was recorded in the MFHSev class (0.5 t ha^{-1}). The MFHSev plots represented locations exposed to two high severity burns where repeated fire had irreversibly changed the whole ecosystem. The woody biomass was replaced by non-woody AGB dominated by two species of fern: *Stenochlaena spp.* and *Blechnum spp.* The value of non-woody AGB ranged from 6 up to 12 t ha^{-1} , i.e. much higher than the value for woody AGB; fern biomass has a high flammability and can, therefore, greatly increase the fire risk. Moreover the MFHSev plots revealed an almost complete absence of trees, with only 29 ha^{-1} , and around $638 \text{ saplings ha}^{-1}$ compared

to the canopy inventory in MFMSev where tree density was ten times greater (308 trees ha⁻¹) and the density of saplings was twice as high. In these severely burnt areas, the exposed peat surface was subjected to on-going degradation through wind and water erosion: on the one hand, the MFHSev plots were more susceptible to fire during the dry season, but on the other hand, during the wet season, these sites were flooded regularly owing to subsidence of the peat surface, through a combination of loss of the original tree cover, and peat combustion and oxidation. In order to mitigate the risk of both fire and flooding additional restoration measures may be required.

This brief account of the different stages of post-fire vegetation re-growth following single and multiple fires on tropical peatlands illustrates the potential of secondary vegetation succession for carbon storage and regeneration. The SF and MFLSev plots revealed a considerable capacity for natural regeneration. Although the vegetation structure will take some considerable time to achieve that of primary forest, the accumulating AGB protects the peat soil from excessive degradation and mitigates the fire risk. This study emphasises, however, that it is very important to reduce recurrent fires in secondary vegetation, since this drives the system towards low diversity communities dominated by ferns which are at high risk of fire, and also threatens the remaining patches of natural forest which represent potential sources of biodiversity and act as an engine of AGB accumulation.

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REFERENCES

- Castro, K.L., Sanchez-Azofeifa, G.A., and Rivard, B. (2003) Monitoring secondary tropical forests using space-borne data: implications for Central America. *International Journal of Remote Sensing*, 24, 1853-1894.
- Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B., and Yamakura, T. (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145, 87-99.
- Hoscilo, A., Page, S.E., and Tansey, K. (2007) The role of fire in the degradation of tropical peatlands: a case study from central Kalimantan. *Proceedings of International Symposium and Workshop on tropical Peatlands, Yogyakarta*, 1-5.
- Hughes, R.F., Kauffman, J.B., and Jaramillo, V.J. (1999) Biomass, carbon, and nutrient dynamics of secondary forests in a humid tropical region of Mexico. *Ecology*, 80, 1892-1907.
- Lu, D. (2005) Integration of vegetation inventory data and Landsat TM image for vegetation classification in the western Brazilian Amazon. *Forest Ecology and Management*, 213, 369-383.
- Lucas, R.M., Bunting, P., Cronin, N., Armston, J., Moghaddam, M., Lee, A., and Witte, C. (2005) Integration of radar and Landsat-derived foliage projected cover for woody regrowth mapping, Queensland, Australia. *Remote Sensing of Environment*, 100, 388-406.

- Rieley, J.O. and Page, S.E. (2005) Wise Use of Tropical Peatlands: Focus on Southeast Asia. *Synthesis of results and conclusions of the UK Darwin Initiative and the EU INCO EUTROP, STRAPEAT AND RESTORPEAT.*
- Roy, D., Boschetti, L., and Trigg, S. (2006) Remote Sensing of Fire Severity: Assessing the Performance of the Normalized Burn Ratio. *IEEE Geoscience and Remote Sensing Letters*, 3, 112-116.
- van Wagendonk, J.W., Rootb, R.R., and Key, C.H. (2004) Comparison of AVIRIS and Landsat ETM+ detection capabilities for burn severity. *Remote Sensing of Environment*, 92, 397-408.

EFFECT OF ECTOMYCORRHIZAL FUNGI INOCULATED ON *Shorea balangeran* UNDER FIELD CONDITIONS IN PEAT-SWAMP FORESTS

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SUMMARY

An experiment was conducted to determine the effect of four ectomycorrhizal (ECM) fungi, *Strobilomyces* sp., *Calvatia* sp., *Boletus* sp., and *Scleroderma* sp. on the early growth of *Shorea balangeran* in peat soils under nursery and field conditions. Four ECM fungi were collected from peat soil at Nyaru Menteng, Palangka Raya, Central Kalimantan. Seedlings of *S. balangeran* were inoculated with spores of four ECM fungi and were grown in pots containing sterilized peat soil for 6 months. Six-months-old inoculated seedlings were transplanted into degraded peat-swamp forest. Colonization of *Boletus* sp. and *Scleroderma* sp. increased shoot height and stem diameter of *S. balangeran* 40 months after transplanting in the field. Inoculation of indigenous ECM fungi into native tree species is useful for rehabilitating degraded peat-swamp forests.

Keywords: peat-swamp forest, *Shorea balangeran*, ectomycorrhizae, inoculation, field.

INTRODUCTION

Tropical peat-swamp forests have been decreasing owing to fire, illegal logging, and conversion into industrial and agricultural lands, rubber tree and palm oil plantation and forest plantation estates for pulp trees. Degraded peat-swamp forests are recognized as low value forest resources without successful natural regeneration and become dominated by low growing vegetation dominated by ferns, sedges and scrub (Page *et al.*, 1999; Kobayashi, 2000). The Indonesian Government has a national programme to accelerate rehabilitation of degraded peat-swamp forests. However, it is not easy to rehabilitate this ecosystem immediately, because it is necessary to select and produce high-quality tree seedling species for rehabilitation.

Shorea balangeran (Korth.) Burck (Dipterocarpaceae) is an important timber tree in tropical peat-swamp forests in Indonesia and this species also contributes important timber for domestic needs (Soerianegara and Lemmens, 1994). *S. balangeran* is distributed over scattered locations of Bangka, Belitung and Kalimantan islands and attains a height of 30 m and diameter up to 60 cm. However, *S. balangeran* has been

greatly reduced in number as a result of overexploitation. This species is common and often gregarious in tropical peat-swamp forest. *S. balangeran* is economically important, because it is a major source of red meranti (heavyweight hardwood) and valuable resin is obtained from the wood.

All Dipterocarpaceae surveyed to date were associated with ECM fungi (Smits, 1994), and fungal families with greatest abundance in Southeast Asian dipterocarps forests include Sclerodermataceae, Russulaceae, Boletaceae and Amanitaceae (Sims *et al.*, 1997). However, little is known about the effect of ECM inoculation on the growth of dipterocarp species or *Shorea* species originating from a peat-swamp forest. The objectives of this study were to investigate the effect of inoculating four native ECM species using spore suspension on growth of *Shorea balangeran* under nursery and field conditions.

MATERIALS AND METHODS

Seeds of *S. balangeran* were obtained from Nyaru Menteng arboretum in Central Kalimantan, Indonesia. Peat soil used for the pot experiment was collected from a peat swamp forest in Kalamangan, Palangka Raya, Central Kalimantan. Peat soil was sterilized in a drum by heating over a wood fire for 1 hour. The pH (H₂O) of the peat soil was 3.3; available P (Bray-1) was 5.91 mg kg⁻¹. These seeds were sown in polyethylene pots (size 15 × 10 cm) containing 500 g sterilized peat soil. Pots containing seeds were transferred to a nursery at the University of Palangka Raya, Central Kalimantan. One seedling was grown per pot under a 75% shading intensity net to control solar radiation. Basidiomes of *Calvatia* sp., *Boletus* sp., *Scleroderma* sp. and *Strobilomyces* sp. were obtained in the field under native trees of *S. balangeran* at Nyaru Menteng arboretum in Central Kalimantan. Fruit bodies of ECM species were blended in distilled water (1:10, v/v) for 60 seconds using a blender at low speed. Inoculation of seedlings was carried out 10 days after germination. The spore suspension was added in a 2-3 cm deep hole near the seedling using a 5 ml pipette. The seedlings were irrigated with tap water every day and weeds were removed. The following treatments were used: (1) control, (2) *Calvatia* sp., (3) *Boletus* sp., (4) *Scleroderma* sp. and (5) *Strobilomyces* sp.

The experiment site was located in Kalamangan, Central Kalimantan. The peat soil at the study site has very low pH (<4), that is assumed to result from organic acid compound produce through decomposition of organic matter under waterlogged conditions. One hundred seedlings per treatment were planted individually in holes (15x15x15 cm) at a line spacing of 1 x 1 m. Shoots and roots were harvested six months after being inoculated with ECM fungi. Shoot height, stem diameter, leaf number, and fresh and dry weight were measured. After measuring the fresh weight of shoots, dry weights were determined after drying at 70°C for 72 hours. To calculate the percentage of ECM colonization under dissecting microscopes, roots were cleaned using running water to separate them from the soil and then the root systems were spread on trays (Brundrett *et al.*, 1996). Plant height, leaf number, stem diameter, and survival rates were measured after transplanting in field conditions. Survival rates were calculated as follows; Survival rates (%) = number of viable seedlings / number of initial seedlings 100 x 100. Data were statistically analyzed using analyses of variance (ANOVA) with the statistical software StatView 5.0 (Abacus Concepts).

RESULTS

In the nursery conditions, *Calvatia* sp., *Boletus* sp., *Scleroderma* sp. and *Strobilomyces* sp. formed ECM in *S. balangeran* seedlings (Table 1.). ECM colonization was higher than 50% in all inoculated seedlings. There was no difference in percentage colonization between four ECM species. Control seedlings were colonized by indigenous ECM fungi. ECM colonization of *S. balangeran* using spores of *Calvatia* sp., *Scleroderma* sp. and *Strobilomyces* sp. increased plant height, fresh and dry weight. ECM colonization of *Boletus* sp. increased only plant height. There was no difference in stem diameter and leaf number between four ECM and control seedlings.

Treatment	Plant growth					ECM Colonization (%)
	Shoot height (cm)	Stem diameter (mm)	Leaf number (/plant)	Fresh weight (g/plant)	Dry weight (g/plant)	
Control	23.8a*	2.3a	9.0a	2.0a	0.68a	12a
<i>Calvatia</i> sp.	31.2b	2.4a	9.7a	3.4b	1.12c	67b
<i>Boletus</i> sp.	28.7b	2.4a	10.0a	2.2a	0.74a	67b
<i>Scleroderma</i> sp.	28.7b	2.4a	9.0a	2.7b	0.88b	60b
<i>Strobilomyces</i> sp.	27.5b	2.4a	9.3a	2.5b	0.91b	59b

*Values with the same letter are not significantly different (p<0.05)

Table 1 Shoot height, stem diameter, leaf number and ECM colonization of *Shorea balangeran* inoculated with four ectomycorrhizal fungi 6 months after Transplanting under nursery conditions in Palangka Raya, Central Kalimantan

Under field conditions, ECM colonization of *Boletus* sp. and *Scleroderma* sp. increased plant height and leaf number 8, 14, 16, 19, 22, and 25 months after transplanting (Figure 1). ECM colonization did not increase plant height and leaf number two, four and six months after transplanting. There was no significant difference between four ECM species and control seedlings. There was no difference in height and leaf number between *Calvatia* sp., *Strobilomyces* sp. inoculated and control seedlings. ECM colonization of *Boletus* sp., *Scleroderma* sp. and *Strobilomyces* sp. increased plant height and stem diameter 40 months after transplanting in the field (Figure 2). ECM colonization of *Calvatia* sp. increased only plant height. There was not difference in stem diameter between *Calvatia* sp. inoculated and control seedlings. Survival rates of *S. balangeran* seedlings were increased with ECM colonization of *Calvatia* sp. and *Strobilomyces* sp. 40 months after transplanting in the field (Figure 2). Survival rates of *S. balangeran* seedlings were higher than 90%, except for *Boletus* sp. and *Scleroderma* sp.

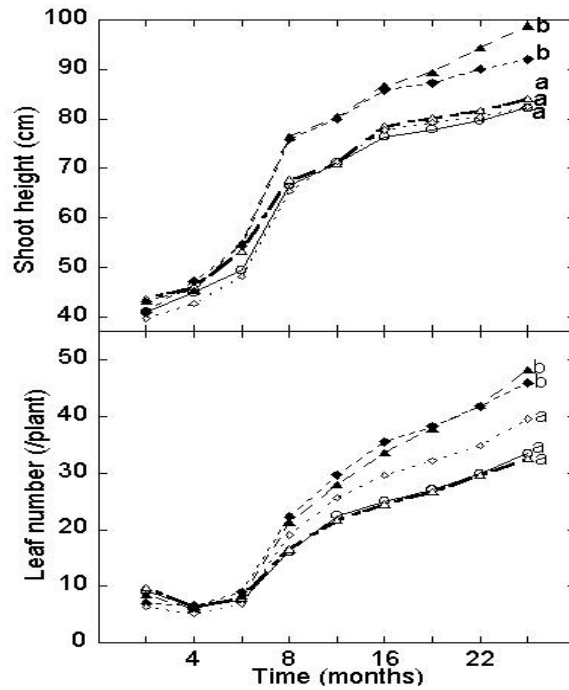


Figure 1 Shoot height and leaf number of *S. balangeran* inoculated with four ECM fungi two -25 months after transplanting under field conditions in Kalamangan zone, Central Kalimantan. *Calvatia* sp. (▲); *Scleroderma* sp. (◆); *Boletus* sp. (◇); *Strobilomyces* sp. (○) and control (△).

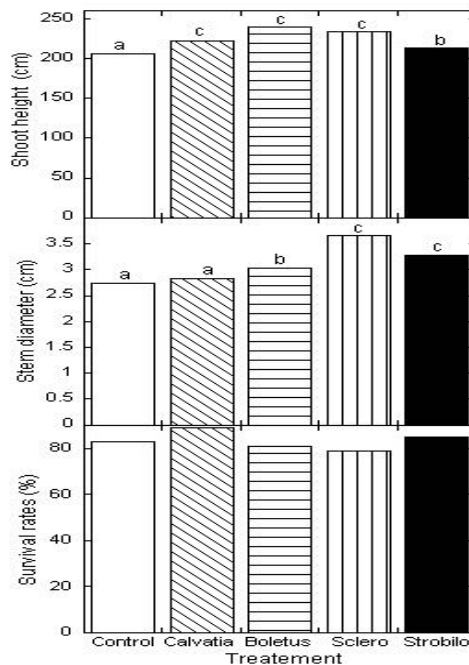


Figure 2 Shoot height, stem diameter, and survival rates of *S. balangeran* inoculated with four ECM fungi 40 months after transplanting under field conditions in Kalamangan zone, Central Kalimantan.

DISCUSSION

Even though the ECM of Dipterocarpaceae in tropical rain forests of Southeast Asia has been reported (Alexander *et al.*, 1992; Smits, 1994; Lee and Alexander, 1996), the role of ECM in dipterocarps species originating from peat-swamp forest needs to be clarified. Our results demonstrate for the first time that ECM fungi have positive effects on *S. balangeran* after six months under nursery conditions and 40 months after transplanting in the field. Colonization by four ECM species was identified as the most appropriate fungi for improving early growth of *S. balangeran* after six months under nursery conditions. Furthermore, *Boletus* sp. and *Scleroderma* sp. proved to be competitive and effective to increase plant growth of *S. balangeran* 40 months after transplanting into the field. Therefore, *Boletus* sp. and *Scleroderma* sp. are to be ECM fungi candidate for production of *S. balangeran* under nursery and field conditions. Ecological categories of ECM fungi may be more useful for summarizing fungal performance in the field than in the growing conditions of nurseries (Brundrett *et al.*, 2005).

ECM plants inoculated with *Calvatia* sp., *Boletus* sp., *Scleroderma* sp. and *Strobilomyces* sp. were not different in height, and leaf number compared to control seedlings during the two – six months in field conditions. At the time, November 2002-May 2003 was the rainy season. It was possible that owing to waterlogged conditions all roots of *S. balangeran* were very saturated with water. The water table in the experimental site was close to or above the peat surface throughout the six months and fluctuated with intensity and frequency of rainfall. Water has become a factor creating other problems i.e. waterlogged stress. The rhizosphere is the part of plant under stress conditions when the oxygen supply for root consumption is being reduced mainly by microorganism respiration. Anaerobic respiration may lead to the synthesis and translocation of some toxic components that affect various processing activities within plants (Naiola and Osaki, 2000). The transplanting shock and waterlogged conditions could be critical to the success of the ECM plants six months after transplanting. After 8 months transplanting in the field (July 2003), *Boletus* sp. and *Scleroderma* sp. increased plant growth of *S. balangeran* in drought periods.

Survival rates of seedlings are important for the first establishment of plant growth of *S. balangeran* after transplanting in the field. The role of ECM in the survival rates of *S. balangeran* requires more careful analyses because survival rates were not different between ECM seedlings and control seedling. It was possible also that waterlogged conditions can affect the survival rates of ECM plants. In a dry tropical area, survival rates of *A. holosericea* inoculated by *Pisolithus albus* or *Scleroderma dictyosporum* were higher (98-100%) than control plants (81%) 12 months after transplanting in the field in Senegal (Duponnoius *et al.*, 2005). It may be possible that in disturbed habitats, there is a succession of ECM fungi where a few pioneering fungi are gradually replaced by an increasing diversity of ECM fungi characteristic of undisturbed habitats (Gardner and Malajczuk, 1988; Lu *et al.*, 1999).

In conclusion, colonization by *Boletus* sp. and *Scleroderma* sp. can consistency increase plant growth of *S. balangeran* 40 months after transplanting in the field. *Boletus* sp. and *Scleroderma* sp. can be used to inoculate *S. balangeran* in nurseries because these fungi are well adapted to the environmental conditions encountered in this area which could explain this better effect on plant growth. It is suggested that inoculation of indigenous ECM fungi to native peat-swamp tree species under nursery conditions is useful for reforestation of degraded peat-swamp forests.

REFERENCES

- Alexander, I., Ahmad, N. and Lee, S.S. (1992) The role of mycorrhizae in the regeneration of some Malaysian forest trees. *Philosophical Transactions of the Royal Society London Series B, Biological Sciences*, 335, 379–388.
- Brundrett, M., Bougher, N., Dell, B., Grove, T. and Malajczuk, N. (1996) *Working with mycorrhizae in Forestry and Agriculture*. ACIAR Monograph 32, Canberra.
- Brundrett, M., Malajczuk, N., Mingqin, G., Daping, X., Snelling, S. and Dell, B. (2005) Nursery inoculation of *Eucalyptus* seedlings in Western Australia and Southern China using spores and mycelial inoculum of diverse ectomycorrhizal fungi from different climatic regions. *Forest Ecology and Management*, 209, 193–205.
- Duponnois, R., Founoune, H., Masse, D. and Pontanier, R. (2005) Inoculation of *Acacia holosericea* with ectomycorrhizal fungi in a semiarid site in Senegal: growth response and influences on the mycorrhizal soil infectivity after 2 years plantation. *Forest Ecology and Management*, 207, 351–362.
- Gardner, J.H. and Malajczuk, N. (1988) Recolonisation of rehabilitated bauxite mine sites in Western Australia by mycorrhizal fungi. *Forest Ecology and Management*, 24, 27–42.
- Kobayashi, S. (2000) Initial phase of secondary succession in the exploited peat swamp forest (*Shorea albida*) at Sungai Damit, Belait in Brunei Darussalam. *Proceedings of the International Symposium on Tropical Peatlands*, Hokkaido University and Indonesian Institute of Sciences, Bogor, pp. 205–214.
- Lee, S.S. and Alexander, I.J. (1996) The dynamics of ectomycorrhizal fungi of *Shorea leprosula* seedlings in Malaysian rain forests. *New Phytologist*, 132, 297–305.
- Lu, X., Malajczuk, N., Brundrett and M. Dell, B. (1999) Fruiting of putative ectomycorrhizal fungi under blue gum (*Eucalyptus globulus*) plantations of different ages in Western Australia. *Mycorrhiza*, 8, 255–261.
- Naiola, B.P. and Osaki, M. (2000) Preliminary study on the water relation of tropical peat lands. *Proceedings of the International Symposium on Tropical Peatlands*. Hokkaido University and Indonesian Institute of Sciences. Bogor, pp. 173–178.
- Page, S.E., Rieley, J.O., Shotyk, W. and Weiss, D. (1999) Interdependence of peat and vegetation in a tropical peat swamp. *Philosophical Transactions of The Royal Society London Series B, Biological Sciences*, 354, 1885–1897.
- Sims, K.P., Watling, R., de la Cruz, R. and Jeffries, P. (1997) Ectomycorrhizal fungi of the Philippine: a preliminary survey and notes on the geographic biodiversity of the Sclerodermatales. *Biodiversity Conservation*, 6, 45–48.
- Smits, W.T.M. (1994) *Dipterocarpaceae: Mycorrhizae and regeneration*. Backhuys Publishers, AH Leiden, The Netherlands.
- Soerianegara, I. and Lemmens, R.H.M.J. (Eds.). (1994) *Timber trees: Major commercial timbers*. *Plant Resources of South-East Asia No. 5 (1)*. Prosea, Bogor, Indonesia.

SPATIO-TEMPORAL DEVELOPMENT OF SELECTED ARTHROPOD FAMILIES ON DEVELOPING PEATLAND ECOSYSTEM: THEIR VALUE AS AN AGRI-ENVIRONMENT INDICATOR.

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SUMMARY

In this study the abundance and distribution of ground beetles, tiger beetles, ants and spiders were monitored with pitfall traps in a peatland ecosystem during its development. The main objective is to identify agri-environment indicators in order to monitor progress towards sustainable development of the peatland ecosystem. Preliminary results indicate that tiger beetles and ants show responsive changes to development activities. Ground beetles and spiders on the other hand do not show responsive change. Between tiger beetles and ants, tiger beetles may be better agri-environment indicators in developing peatland as they show responsive change to spatial configuration of the area, especially in the early stage of development.

Keywords: peatland, indicators, spatio-temporal, arthropod

INTRODUCTION

Sustaining ecosystem functions in tropical peatland during development is a major challenge for sustainable peatland development. Loss of peatland ecosystem functions may lead to loss of many critical ecological services such as pest regulation, pollination, water filtration, etc. (Welch and Graham, 1999). Thus, proper planning of peatland development activities can increase its productivity and thus improve rural livelihoods. It is necessary to identify agri-environment indicators that can be used to assess the impacts of human activities on the ecological integrity of the ecosystem. An agri-environment indicator is a scientific measure used to assess the ecological status and trends in the health of ecosystems and their component parts (Rigby *et al.*, 2001). Indicators should respond quickly to environmental stress, have a short generation time, require only easy sampling and identification and have integrative effects over time (Noss, 1990). The aim of this study is to select agri-environment indicators for monitoring the health of a peatland ecosystem during its development. The study was initiated in December 2005 at MARDI Research Station Sessang, Sarawak.

MATERIALS AND METHODS

In this study the spatio-temporal patterns of ground beetles (Insecta: Carabidae), tiger beetles (Insecta: Cicindelidae), ants (Insecta: Formicidae) and spiders (Arachnida: Araneae) were determined. These arthropods were monitored in 200 m x 650 m area of developing peatland (Figure 1). The area was surrounded by various types of vegetation. The upper edge was bordered with fallow land. The lower edge was

bordered with a main field road. On the left, it was bordered by bushes at the lower part, while at the upper part it was bordered by remnant forest. On the right, it was bordered by bushes and newly planted fruit trees and herbal plants. Inside the area, there was an internal drain at the lower part and the inner field road at the top of the area. The area was divided into four segments. The first segment was planted with pineapple. The second segment was planted with sweet potato for the first three months and later was replaced with pineapple. The third segment was planted with papaya. The fourth segment was fallow land for the first three months and later was planted with pineapple. The monitoring of arthropods was carried out by sampling their population with 104 pitfall traps installed in the area. Traps were arranged in thirteen rows with eight traps in each row. The spacing of the pitfall traps was 50 m between rows and 26 m within rows (Figure 1). The first sampling was started in December 2005 and continued thereafter on alternate months. Trapped arthropods were sorted and counted but owing to lack of manpower, identification was completed to the ‘family’ level only.

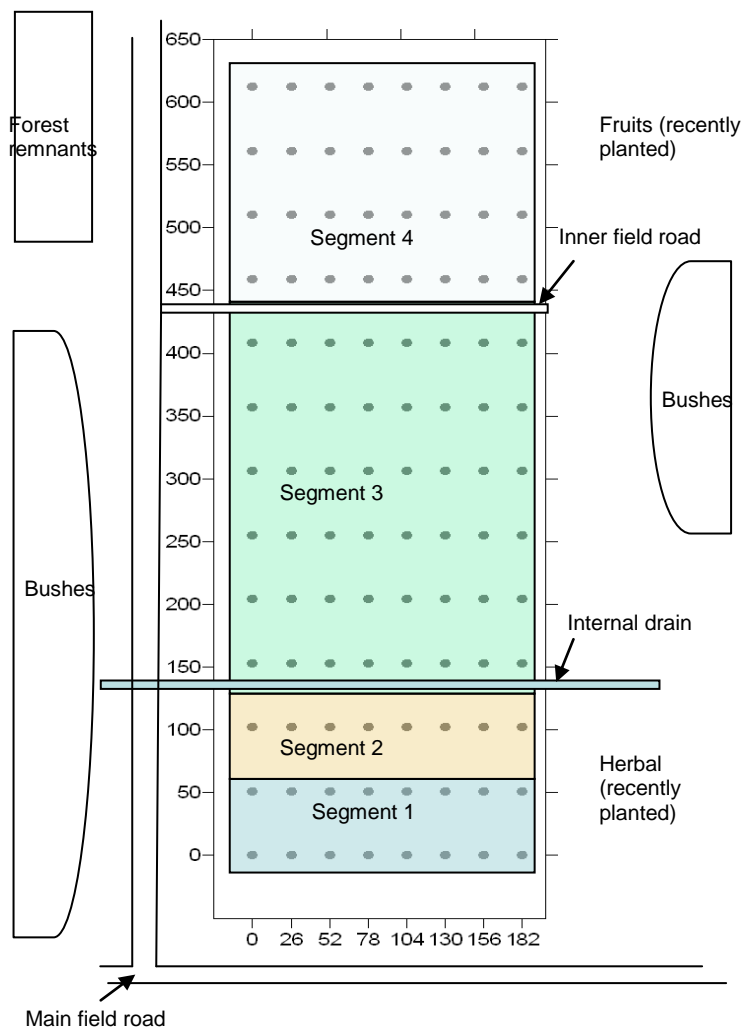


Figure 1 The landscape of the arthropod monitoring area. (The size of area is about 200 metres wide and 650 metres long. One hundred and four sampling points were used for the pitfall traps. Traps were arranged, equally spaced in thirteen rows of eight traps in each row at distances of 50 m between rows and 26 m within rows).

The spatio-temporal patterns were determined by analysing the temporal and spatial patterns of arthropod counts in the area. The temporal pattern of arthropod counts was determined based on its trend in the area. The spatial pattern was determined with the SADIE system (Perry, 1999; Perry et al., 1996) that was introduced to describe the spatial features of such counts, independent of their numeric properties. Spatial relationship between first sampling date and the subsequently sampling dates were carried out for significant $I_a > 1$ to test the stability of its spatial patterns.

RESULTS

Temporal pattern of arthropod counts

Tiger beetles (TB) and ants were the most abundant. TB abundance increases as season progress, except for the final count. Ant abundance also increased with time of development. Spider population was almost uniform throughout this study. Ground beetles (GB) were the least captured and there was no pattern on their temporal development.

Spatial distribution of arthropod counts

Table 1 summarizes the result of SADIE analysis. For GB and spiders no trend of spatial pattern was observed. The spider population was almost uniform and their I_a values were low, and exceeded 1 on only one occasion, suggesting spider counts were dispersed around the area. In contrast, TB and ants counts seemed to indicate a spatial pattern. For TB, two-thirds of its I_a values was significantly above unity. For ants, only three of its I_a values were significantly greater than 1 although it was the most abundant in counts. This indicated that TB counts were strongly aggregated ($I_a > 1.0$). The majority of tiger beetle patches (red area) were situated in the left and toward the middle of experimental area while the majority of its gaps (blue area) were situated at the upper and lower edges of the area (Figure 2). There was no spatial trend on the occurrences of ant's patches and gaps. The occurrence of TB patches were a very stable, positive spatial association between the first sampling dates with several subsequently sampling dates, indicating a possible similar set of populations. In contrast, there was no significantly spatial association recorded for ant counts, indicating the clusters of different sampling dates might come from different sets of populations.

Month	Ground beetles		Tiger beetles		Ants		Spiders	
	I_a	$P_{(a)}$	I_a	$P_{(a)}$	I_a	$P_{(a)}$	I_a	$P_{(a)}$
Dec'05	0.887	0.6561	1.618	0.0327	1.709	0.0191	0.809	0.786
Feb'06	0.83	0.6883	2.189	0.0017	1.044	0.3394	0.917	0.5406
Apr'06	-	-	1.866	0.0107	1.092	0.28	0.97	0.4704
Jun'06	-	-	1.861	0.0109	1.342	0.1079	0.891	0.5951
Aug'06	1.07	0.3094	1.074	0.3312	0.905	0.5656	1.184	0.1798
Sep'06	1.18	0.2288	1.298	0.1262	1.485	0.0498	1.66	0.0228
Dec'06	-	-	1.558	0.0431	1.083	0.2779	0.896	0.578
Feb'07	-	-	1.392	0.0791	1.141	0.2184	0.883	0.5998
Apr'07	-	-	0.907	0.5504	2.118	0.0023	0.827	0.7424

Table 1 Summary of results from spatial pattern analysis with SADIE system for selected arthropod families

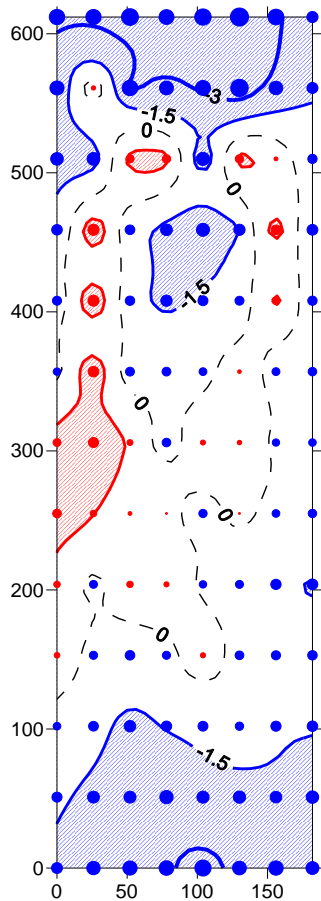


Figure 2 A typical spatial pattern of tiger beetle counts. Patches (red) and gaps (blue) for tiger beetles. Patches (red) were situated on the left side of the segment 3, while gaps (blue) were situated at the segment 1 and the segment 4.

DISCUSSION

Differences within field activities of arthropod families were observed in this study. The difference could have resulted from difference in their responses with respect to abiotic and biotic factors of the area (Riedel, 1995). TB and ants show response change while GB and spiders do not although GB are abundant in the peat ecosystem (Mohd Norowi, 2007).

TB was the most responsive to land use practices and agricultural landscape imposed in this study. They are abundant in segment three where papaya is planted. The openness of the area, contributed to by the nature of papaya growth and the presence of the inner field road, may favour the GB population. It seems that the openness of the area may encourage TB foraging. The results of this study indicate that the ecology of TB may be used as potential agri-environment indicators in developing peatland especially in the early stage of development activities. Overall, the agricultural practices imposed in this study seem to play a minor role in spatio-temporal development of the arthropod families selected in this study. This might be a result of the cultural practices employed in the area that are carefully chosen to minimize their impact on the environment. It is also possible that the area is relatively new and needs longer observations for arthropods to develop a consistent pattern of distribution in response to specific activities (Booij et al., 1995).

REFERENCES

- Booij, C.J.H., den Nijs, L.J.M.F. and Noorlander, J. (1995). Spatio-temporal patterns of activity density of some carabid species in large scale arable fields. *Acta Jutlandica*, 70: 175-84.
- Mohd Norowi, H. (2007). Impact of peatland development on arthropod diversity. In Impact of land clearing on Peat Ecosystems: A Case Study at MARDI Peat Research Station, Sessang, Sarawak, Malaysia (eds A.A. Ismail, H.K. Ong, M.J. Mohamamad Hanif and M.S. Umi Kalsom), pp. 89-98. MARDI, Serdang.
- Noss, R.F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, 4: 355-64.
- Perry, J.N. (1999). red-blue plots for detecting clusters in count data. *Ecology Letters*, 2: 106-13.
- Perry, J.N., Bell, E.D., Smith, R.H. and Woiwood, I.P. (1996). SADIE: Software to measure and model spatial pattern. *Aspects of Applied Biology*, 46: 95-102.
- Riedel, W. (1995). Spatial distribution of hibernating polyphagous predators within field boundaries. *Acta Jutlandica*, 70: 221-6.
- Rigby, D., Woodhouse, P., Young, T. and Burton, M. (2001). Constructing a farm level indicator of sustainable agricultural practice. *Ecological Economics*, 39: 463-78.
- Welch, R.M. and Graham, R.D. (1999). A new paradigm for world agriculture: meeting human needs Productive, sustainable, nutritious. *Field Crops Research*, 60: 1-10.

SELECTION OF LAND CLEARING TECHNIQUE AND CROP TYPE AS PRELIMINARY STEPS IN RESTORING CARBON RESERVE IN TROPICAL PEATLAND UNDER AGRICULTURE

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SUMMARY

Replacement of natural forest by agricultural crops is generally expected to change the role of tropical peatland from that of carbon sink to carbon loss ecosystem. Preliminary studies in Malaysia, however, indicate that CO₂ emission from agriculture on peatland can be minimized through farm management. Land clearing by burying the forest debris added more than 100 t C ha⁻¹ into the peatland; otherwise it would have been immediately lost by burning. Newly cleared plots were colonized by fast growing *Macaranga triloba* that absorbed 25 t C ha⁻¹yr⁻¹ from the air. It was estimated that the agriculture systems experienced minor net-carbon-loss with major emission from decomposition of peat and large amount of biomass waste.

Key words: Peatland, forest clearing, agriculture, carbon emission

INTRODUCTION

Tropical peatland plays an important role in the global carbon (C) cycle. Diemont et al. (1997) estimated that 5 m thickness of tropical peatland stores up to 2,500 tons C per ha. It was estimated that more than 70 billion tonnes, or up to 20% of soil C is stored in tropical peatland. In addition, about 34 million tonnes of C is sequestered annually by tropical peatland. The replacement of natural forest by agricultural crops, however, is expected to reduce its C sink capacity. Immirzi and Maltby (1992) estimated C loss of 5-42 t ha⁻¹yr⁻¹ from peatland under agriculture and Wosten et al. (1997) estimated the release of 7.2 t C ha⁻¹yr⁻¹ from 2 cm yr⁻¹ surface subsidence of peatland under agriculture. This paper presents results of initial efforts undertaken by the Malaysian Agricultural Research and Development Institute (MARDI) to quantify C balance from agricultural development on peatland and its implications for farm management.

CARBON LOSS DURING CLEARING OF TROPICAL PEATLAND

Three months after forest felling in the MARDI Peat Research Station at Sessang, Sarawak, the volume and weight of forest debris, with diameters larger than 15 cm, were recorded as 169 m³ ha⁻¹ and 123 t ha⁻¹, respectively (Mohammad and Ismail, 2007). More than half of the debris was less than 15 cm in size and decomposed naturally within three years. Assuming that the debris contained 10% moisture and 50% C of its dry weight, total C content of the debris can be estimated at about 60 t ha⁻¹. The same amount of C was expected in the smaller sized debris and leaves. The

burning technique of land clearing immediately released all C in the debris into the atmosphere. Meanwhile, zero burning techniques released similar amounts of C within three years. The most environmental friendly method was the one that involved burying of the debris, which added more than 100 t C ha⁻¹ reserves into the peatland. The technique, however, costs three times more than the commonly practiced burning or twice the currently recommended zero burning (Ismail and Jamaludin, 2007). It was reported that the land clearing operations contributing to surface subsidence were drainage (6 cm), human activities (6 cm), machine activities (12-22 cm), removal of underground biomass of 50 cm depth (8 cm) and burning (11 cm) (Ismail and Jamaludin, 2007). Assuming that the bulk density of the peatland surface was 0.1 g cm⁻³ and dry peat material contained 50% C, the burning of 11 cm could result in an immediate release of 50 t C ha⁻¹ into the atmosphere. Immediately after land clearing, peat soil CO₂ fluxes exhibited diurnal variations, peaked during mid afternoon and increased with the extent of disturbance caused by the forest clearing (Zulkefli et al., 2007). Highest soil CO₂ flux recorded at noon was from the plot cleared by the burning method (700 mg CO₂ m⁻² hr⁻¹) and followed by zero burning (450 mg CO₂ m⁻² hr⁻¹). In all cases, the fluxes remained at these levels for more than three years. This may explain the constantly high CO₂ level detected over Sumatra and Kalimantan after extensive peat fires in 1997/8 and 2001. Ten months after land clearing, 92 plant species belonging to 72 genera and 47 families regenerated (Salma et al., 2007). The most dominant tree species regenerated was *Macaranga triloba*. Six years later, this species had grown to a height of about 20 m, with average stand density of about 2,000 ha⁻¹ and 20-60 cm girth size. With estimated fresh weight of 0.3 t per tree, 40% moisture content and 40% C of the dry biomass, the total C sink in the regenerated trees was estimated to be 150 t C ha⁻¹, equivalent to about 25 t C ha⁻¹ yr⁻¹. Considering soil CO₂ flux of 10 t C ha⁻¹yr⁻¹, the species regeneration had resulted in net C-sink of about 15 t C ha⁻¹yr⁻¹.

CARBON BALANCE FROM AGRICULTURAL ACTIVITY ON TROPICAL PEATLAND

Water table depth under various agro-systems, measured weekly in 2006, are shown in Table 1. Generally, it fluctuated within the intended depths. There was occasional under-drainage and but no occurrence of over-drainage. Table 2 showed that the highest soil CO₂ flux was recorded under oil palm (150-200 mg C m⁻² hr⁻¹), followed by pineapple (120-150 mg C m⁻² hr⁻¹), jackfruit (100-120 mg C m⁻² hr⁻¹) and sweet potato (80-110 mg C m⁻² hr⁻¹). There was no clear indication on the effect of water table depth as commonly perceived. Other than the crop type and its agronomic practices, the high soil CO₂ flux under oil palm could also be influenced by a higher degree of peat decomposition, as the plot was planted almost 10 years earlier. It is important to note that the figures represent highest possible fluxes as these were measured at noon.

Crop type	Year started	Water table depth (cm)	
		Intended	Measured (weekly in 2006)
Pineapple	2004	30-50	10-50
Jackfruit	2004	50-80	30-70
Oil palm	1995	50-80	35-80

Table 1 Intended and measured water table under various agro-systems on tropical peatland

Crop Types	CO ₂ flux (mg C m ⁻² hr ⁻¹)					
	February 2006	March 2006	June 2006	August 2006	December 2006	March 2007
Pineapple	120	148	130	119	115	125
Jackfruit	100	105	110	99	120	97
Sweet potato	80	100	90	110	81	96
Oil palm	146	178	160	150	150	192

Table 2 Soil CO₂ flux in various agro-systems measured at noon on tropical peatland

The number of weed species recorded under various agro-systems is presented in Table 3 and their occurrence in Table 4. Weeds infestation is a major problem for agriculture on tropical peatland and is generally controlled by chemicals on a regular basis. Rough estimations of the quantity and C content of agricultural biomass indicated net-C-loss in oil palm and pineapple agro-systems (Table 5). Other than soil CO₂ flux, a significant portion of C emission is expected from degradation of large quantities of biomass waste. Only a small portion of the biomass is currently utilized, e.g. for making compost, animal feed, 'bio-mat', etc. It is expected that the C balance in these agro-systems can be improved significantly by increased utilization of the biomass waste.

Sampling time	No. of weed species			
	Papaya	Sweet-Potato	Jackfruit	Oil Palm
October 2005	25	31	30	38
April 2006	29	41	34	39
September 2006	31	48	45	45

Table 3 Weed species regenerated under various agro-systems on tropical peatland

Weed species	Sweet potato	Papaya	Jackfruit	Oil palm
<i>Fimbristylis pauciflora</i>	X	X	-	-
<i>Cyperus rotundus</i>	X	X	X	
<i>Melastoma malabathricum</i>	X	-	X	X
<i>Pityrogramma calomelanos</i>	X	-	-	-
<i>Hedyotis corymbosa</i>	-	X	-	-
<i>Lindernia crustacean</i>	-	X	-	-
<i>Asystasia intrusa</i>	-	-	X	X
<i>Ageratum conyzoides</i>	-	-	X	-
<i>Nephrolepis biserrata</i>	-	-	-	X
<i>Dianella ensifolisa</i>	-	-	-	X

Table 4 Dominant weed species in various agro-systems on tropical peatland

	Estimated biomass (t ha ⁻¹ yr ⁻¹)	Estimated moisture content (%)	Estimated C sink (50% of dry biomass (t ha ⁻¹ yr ⁻¹))	Estimated C emission (70% of discard C) (t ha ⁻¹ yr ⁻¹)
Oil palm (150 palm/ha, 25-year cycle)				
Peat soil	-	-	-	10
Fresh fruit bunch (80% discard - fresh)	20	70	6	3
Discard frond (dry)	10	0	5	3
At replanting (frond, trunk, root - dry)	(5)	0	3	(2)
Weed (fresh)	4	80	1	1
Total		-	15	18
C balance (sink–emission)			- 3	
Pineapple (40,000 plant/ha, 2-year cycle)				
Peat soil	-	-		8
Fresh fruit (50% discard - fresh)	30	80	6	1
Planting material (300 g/sucker - fresh)	6	50	1	-
At replanting (1.5 kg/plant – fresh)	(30)	50	7	(6)
Weed	4	80	1	1
Total	68	-	15	16
C balance (sink–emission)			-1	

Note: In parenthesis – the actual effect is on total value at replanting

Table 5 Estimated carbon balance from oil palm and pineapple agro-systems on tropical peatland

CONCLUSION

The changing role of developed peatland from that of C sink to C loss, to some extent, can be minimized. Our initial studies indicate that land clearing by burying the forest debris should be encouraged as a large quantity of additional C reserve will be stored in peatland. Newly cleared peatland, if not immediately used for crop cultivation, should not be disturbed but allowed to be colonized by the fast growing *Macaranga triloba* that can utilize large amounts of C from the air, resulting in a net C-sink environment. Current peatland agro-systems are estimated to be minor net C-emitters, which can be improved by proper utilization and management of biomass waste. A more damaging effect is probably the continuous depletion of C reserves from peat decomposition under aerobic conditions.

REFERENCES

Diemont, W.H., Nabuurs, G.J., Rieley, J.O. and Rijkssen, H.D. (1997). Climate change and management of tropical peatlands as a carbon reservoir. In J.O. Rieley and S.E. Page, (eds), *Biodiversity and sustainability of tropical peatlands; Proc. Int. Symp. On Biodiversity, Environmental Importance and Sustainability of Tropical Peat and Peatlands; Palangka Raya, 4-8 September 1995*; pp. 363-368. Samara Publishing Ltd., UK.

- Immirzi, C.P. and Maltby, E. (1992). *The global status of peatland and their role in carbon cycle*. A report for Friend of the Earth by the Wetland Ecosystems Research Group, Department of Geography, University of Exeter; Friend of the Earth, London, UK.
- Ismail, A.B. and Jamaludin, J. (2007). Land clearing techniques employed at MARDI Peat Research Station, Sessang, Sarawak, and their immediate impacts. In A.B. Ismail, S.K. Ong, M.J. Mohd Hanif and M.S. Umi Kalsom (eds), *Impact of land clearing on peat ecosystems: A case study of MARDI Peat Research Station, Sessang, Sarawak, Malaysia*, pp. 1-8. MARDI, Serdang.
- Mohammad, A. and Ismail, A.B. (2007). Status and decomposition of woody biomass after clearing of peatland. In A.B. Ismail, S.K. Ong, M.J. Mohd Hanif and M.S. Umi Kalsom (eds), *Impact of land clearing on peat ecosystems: A case study of MARDI Peat Research Station, Sessang, Sarawak, Malaysia*, pp. 9-18. MARDI, Serdang.
- Salma, I., Masrom, H., Hatari, S. and Norowi, A.H. (2007). Species composition in peat swamp forest and impact of land clearing on their regeneration and population. In A.B. Ismail, S.K. Ong, M.J. Mohd Hanif and M.S. Umi Kalsom (eds), *Impact of land clearing on peat ecosystems: A case study of MARDI Peat Research Station, Sessang, Sarawak, Malaysia*, pp. 63-80. MARDI, Serdang.
- Wösten, J.H.M., A.B. Ismail and A. L.M. van Wijk (1997). Peat subsidence and its practical implications: A case study in Malaysia. *Geoderma* 78 (1997); Elsevier; Amsterdam: 25-36.
- Zulkefli, M., Ismail, A.B. and Jamaludin, J. (2007). Soil CO₂ flux from tropical peatland under different land clearing techniques. In A.B. Ismail, S.K. Ong, M.J. Mohd Hanif and M.S. Umi Kalsom (eds), *Impact of land clearing on peat ecosystems: A case study of MARDI Peat Research Station, Sessang, Sarawak, Malaysia*, pp. 99-104. MARDI, Serdang.

PEATLAND CHARACTERIZATION AND RESTORATION IN VO DOI NATIONAL PARK, THE MEKONG DELTA, VIETNAM

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SUMMARY

Tropical peat wetlands cover an area of about 3,900 ha in the U Minh Ha region of Ca Mau, the southernmost province of Vietnam. Although small in size, this area is widely regarded as important for its biodiversity, and it represents one of the key semi-natural wetland habitats remaining in the southern Mekong Delta of Vietnam. Over the past decade or so, management interventions, fire and surrounding landuse practises have changed the hydrology the of the core peatland area appreciably, which in turn appears to have led to a reduction in plant biodiversity. This paper describes the physico-chemical properties of the peat soils in Voi Doi National Park, assesses the likely impact of changes in hydrology on biodiversity, and explores some options for management that could help to manage the fire risk and maintain or enhance biodiversity of the peat land in the park.

Keywords: Tropical peat, biodiversity, management, physico-chemical properties of peat, Vietnam

INTRODUCTION

Tropical peatlands cover an area of about 40-50 million ha globally, of which about 25-30 million ha (60-70%) are found in Southeast Asia (Rieley, 2004; Rieley and Page, 2005). The range in these figures reflects the current uncertainties in estimates of tropical peatlands, some explanations for which are given by Rieley and Page (2005). Nevertheless, tropical peatlands represent a very large global terrestrial carbon reservoir, and their conservation and stability are of great importance for managing future global climate change. Estimates of carbon accumulation by tropical peatlands range from about 0.6 to about 1.5 t C ha⁻¹ y⁻¹ (Rieley and Page, 2005). Taking the lower value in this range and a conservative estimate of 30 million ha of tropical peatland, it is likely that tropical peatlands could remove more than 18 million metric tons of carbon per year (66×10^6 t CO₂ y⁻¹) from the atmosphere, about 0.5-1% of current total emissions from burning fossil fuel. Though small, this is nevertheless significant.

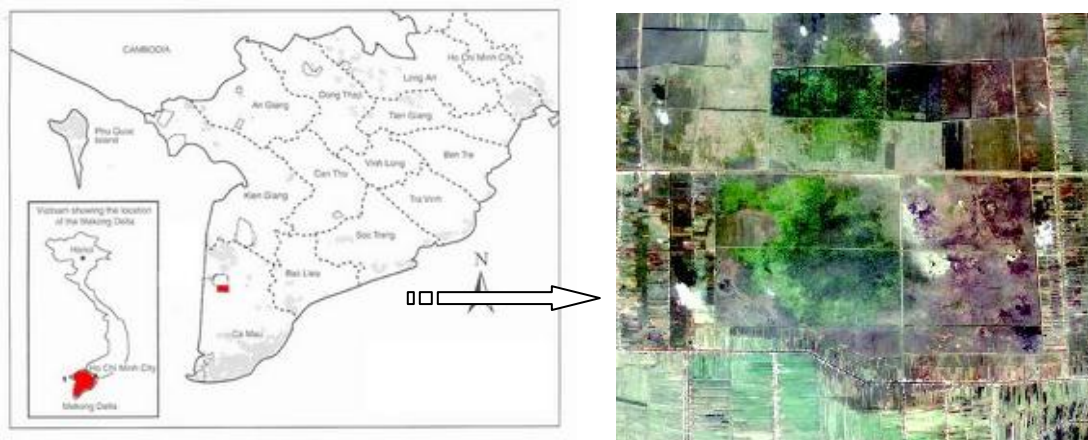
The present extent of tropical peatland in Vietnam is not known precisely. However, it is probable that Vietnam's remaining peatland is restricted to just two areas in the southern Mekong Delta, U Minh Thuong in Kien Giang Province, and U Minh Ha in neighbouring Ca Mau Province. Safford et al. (1998) estimated the area of peatland to be about 21,000 ha in U Minh Thuong, of which about 8,100 ha lay within a core

protected zone. In U Minh Ha, the area of peatland was estimated to be 3,900 ha, of which 2,530 ha was in a core protected zone. However, there have been both fires and changes in land use since that survey and it is very likely that there has been a consequent reduction in the extent of peatland in both areas, particularly outside core protected zones. Although the area of peatland in Vietnam is small by comparison with that in some other countries in SE Asia, it is nevertheless very important for its contribution to biodiversity and its role as habitat for a number of rare or endangered bird species (Safford et al., 1998; Buckton and Safford, 2004).

SITE DESCRIPTION

Vo Doi National Park lies between 9 12' and 9 14' N, and 104 55' E and 105 00' E in the U Minh Ha region of Ca Mau Province, approximately 10 km inland from the Gulf of Thailand (Figure 1). What is now Vo Doi National Park was first established as U Minh Nature Reserve in 1986. However, a management plan for the nature reserve was not implemented until 1992, when its name was changed to Vo Doi Nature Reserve. Vo Doi Nature Reserve is now under the management of Ca Mau Provincial Forest Protection Department, and its status has been changed recently from a nature reserve to a national park. Vo Doi has a maximum elevation of 2.5 m above mean sea level and is seasonally flooded to a depth of 0.5 to 1 m during the monsoon period from May to November. The water is fresh, with a pH of less than 5.0 owing to the widespread presence of acid sulphate soils in the area around the park and to the exposure of the underlying acid sulphate soils in areas within the park where peat has been burnt away by fire.

The history of the vegetation in the area since human settlement is not well known. Much of the original vegetation was probably destroyed prior to 1975 by the widespread spraying of defoliants during wartime. For this reason most of the present peat forest vegetation in Vo Doi National Park is a secondary growth forest resulting from replanting or natural regrowth after the cessation of hostilities in 1975.



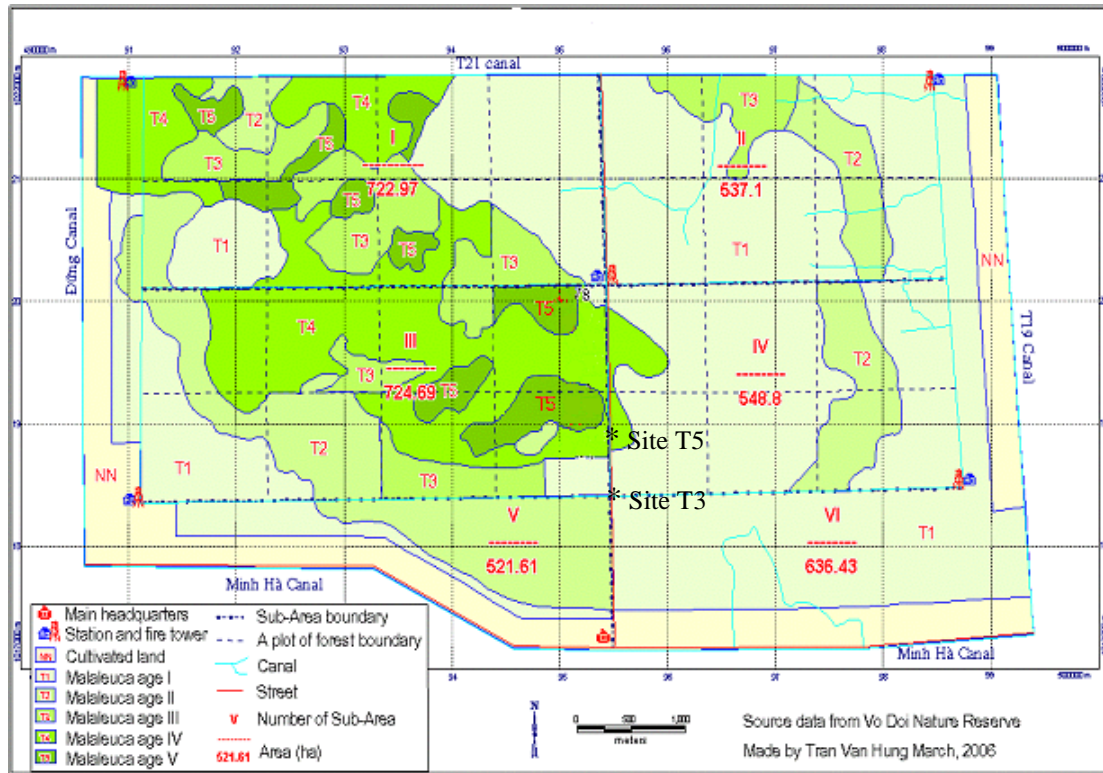
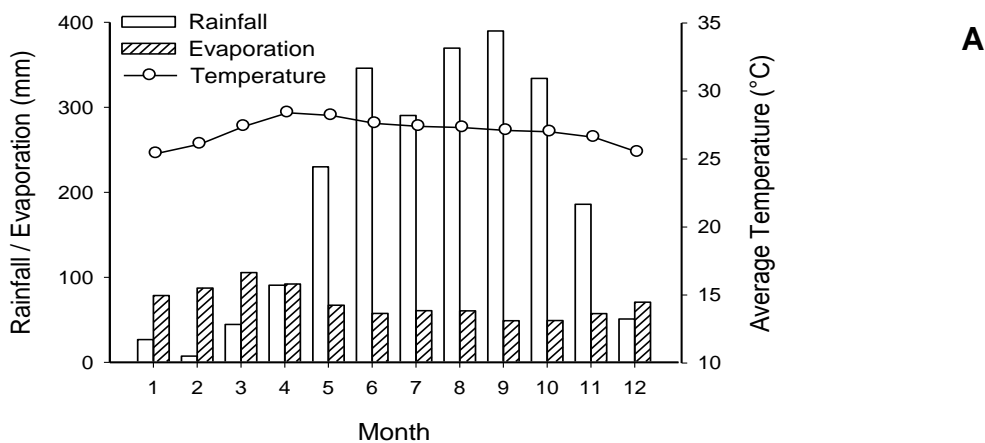


Figure 1 Map and satellite image showing the location and main forest types in Vo Doi National Park.

The climate of the area is typical of monsoon climates in many parts of SE Asia, with a relatively uniform temperature throughout the year. There is a distinct wet season from December to March and a dry season from May to November (Figure 2). The total rainfall and rate of evaporation average about 2300 mm and 830 mm per year, respectively (Ca Mau Weather Station records for the period 1971 – 1988), with the highest monthly rainfall usually occurring from August to October, although this can vary greatly from year to year (Figure 2). Precipitation exceeds evaporation during the wet season, but evaporative losses can be considerable, up to 150 mm per month, during the dry season (Figure 2). Evaporative losses are likely to increase further as global temperatures rise.



B

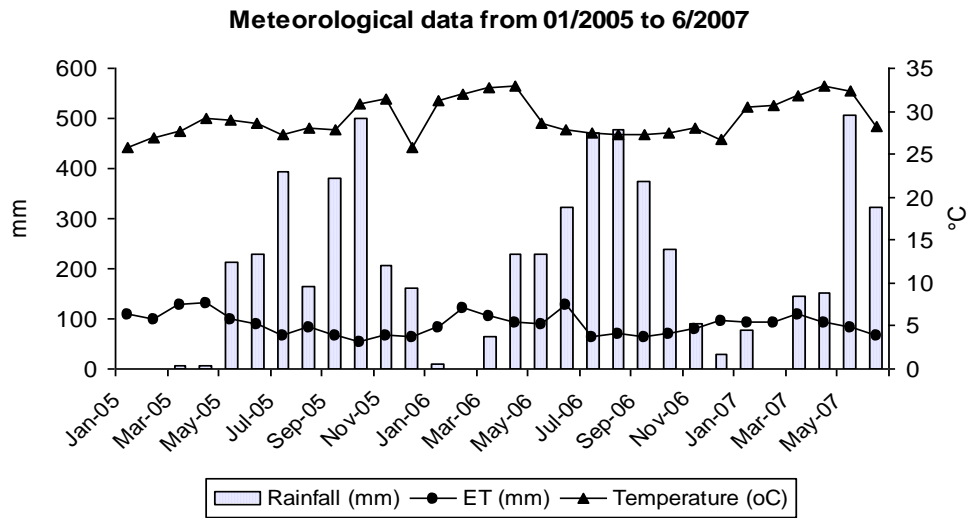


Figure 2 (A) Mean monthly rainfall, evaporation and temperature for Ca Mau (1971-1986, Ca Mau Meteorological Station); (B) Monthly rainfall, evaporation and mean temperature at Vo Doi National Park between January 2005 and May 2007.

HYDROLOGY

The protected core zone enclosed within dikes is flooded during the wet season. The depth of flooding depends on rainfall and the water level in the canals outside the protected area, the average depth usually being about 30-50 cm towards the end of the wet season (Figure 3). The water gates are closed for most of the dry season to maintain a high water level in the core protected zone, thereby reducing the risk of fire. Water levels throughout the dry season are therefore much higher than they were prior to the construction of the dike around the core protected zone.

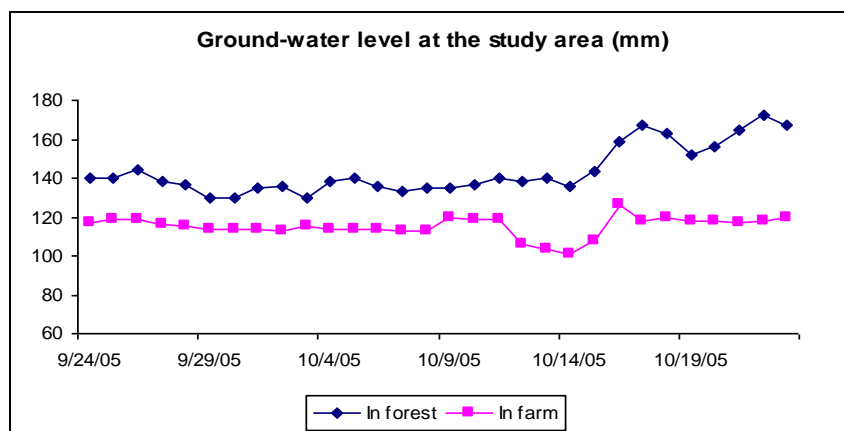


Figure 3 Water levels in the peat forest of the central core zone of Vo Doi National Park (enclosed by a dike) compared with those in adjacent farming areas outside the dike in the latter part of the wet season.

PHYSICOCHEMICAL PROPERTIES OF PEAT AND ACID SULPHATE SOILS

The physicochemical properties of peat were determined at two sites in Vo Doi National Park, T3 and T5 (Figure 1). The top 5-10 cm of both profiles was composed largely of semi-decomposed leaf litter and other debris. The main difference between the two profiles was the thinner peat layer in profile T3 (Table 2). At the time of sampling, the water table was only 5 cm below the peat surface at Site T3 but 25 cm below the surface at site T5.

Table 2 Peat soil profiles for two sites in Voi Doi National Park

Profile T3			Profile T5		
Horizon	Depth (cm)	Description	Horizon	Depth (cm)	Description
H1	0-10	Peat layer (mainly loosely-packed leaf litter)	H1	0-10	Peat layer
H2	10-30	Peat layer	H2	10-70	Peat layer
H3	30-40	Peat layer	B1	70-80	Mineral layer
B1	40-50	Mineral layer	Bj	90-110	Sulphuric horizon
Bj2	50-85	Sulphuric horizon	Cp	>110	Pyritic material
Cp	>85	Pyritic horizon			

Bulk densities ranged from 0.18 to 0.27 g cm⁻³, with only relatively small and somewhat inconsistent variations vertically down through the peat profile (Table 3). The porosity ranged from 81% to 87%, again with relatively small changes vertically down through both profiles (Table 3). There is a close relationship between bulk density, particle density and porosity, and all three parameters appear to be fairly typical of peat that is intermediate between fibric and sapric (Rieley and Page, 2005). The changes in these parameters reflect the variation in the degree of decomposition of peat material in the profile. Peat in both profiles had almost identical water retention characteristics, water retention being about 79% at pF=0, 37% at pF=2 and 16% at pF=4.2, which again are fairly typical of peat intermediate between fibric and sapric (Rieley and Page, 2005). A pF of 0 corresponds roughly to a soil saturated with water, a pF of 2 corresponds roughly to a soil at field capacity, and a pF of 4 corresponds roughly to the water potential at which mesophytic plants wilt.

Table 3 Some physical characteristics of peat at two sites in Voi Doi National Park.

Depth (cm)	Bulk density (g cm ⁻³)	Particle density (g cm ⁻³)	Porosity (%)	Hydraulic conductivity, K _{sat} (cm h ⁻¹)	Available water content (%)	Shrinkage (% Volume)
Profile T3						
0-10	0.26	1.50	83.0	108	21	25
10-20	0.21	1.55	86.5	119	20	32
30-40	0.21	1.42	85.3	22	23	41

Profile T5

0-10	0.19	1.41	87.0	125	19	28
20-30	0.18	1.40	87.2	134	16	46
60-70	0.27	1.45	81.4	12	28	50

On the other hand, both profiles had hydraulic conductivities of 108 to 134 cm h⁻¹ in the upper 30-40 cm, dropping to 12 to 24 cm h⁻¹ at the bottom of the peat layer (Table 3), which appear to be more typical of relatively undecomposed fibric peats (Rieley and Page, 2005). Available water contents ranged from 16 to 28%, with only minor variations at different peat depths (Table 3). The volume change on drying ranged from about 25% in the upper 10 cm to 50% at lower depths. About 69 ml of water was required to saturate 100 cm³ of dry peat material. These results are generally similar to those for other peats (Rieley and Page, 2005). The pH of peat in a 1:5 suspension with water was around 3.8, with a somewhat lower pH of 2.3-2.5 in the underlying sulphuric layers (Table 4). The total acidity in the top 40 cm of peat was similar in profiles T3 and T5. Exchangeable Al was low in T3 and T5 peat material, however it was very high in sulphuric and pyritic material, especially when Al was determined in air-dried samples (Table 4). Soluble SO₄²⁻ and oxalate extractable Fe in peat material in T3 and T5 were low compared to the sulphuric and pyritic layer (Table 4). Peat pH in Vo Doi falls well within the range of 3-4 reported for tropical peat in Central and South Kalimantan (Rieley and Page, 2005). The electrical conductivity (EC) of Vo Doi peat was low, ranging from 0.53 mS cm⁻¹ to 0.61 mS cm⁻¹ (Table 4), although it was 2 to 10 times greater than reported for peats in Kalimantan (Rieley and Page, 2005).

Table 4 Some physico-chemical properties of peat at two sites in Vo Doi National Park. pH values are for oven dried samples re-suspended in distilled water in the ratio of 1 part sample to 5 parts water by weight, except for the pH of the pyritic layer in Profile T5 which was measured on fresh samples. Total acidity, Al³⁺ and all values in % are expressed on a dry weight basis.

Horizon	Depth cm	pH H ₂ O (1:5)	EC mS cm ⁻¹	Total Acidity meq kg ⁻¹	Al meq kg ⁻¹	OM (%)	Soluble SO ₄ ²⁻ (%)	Oxalate extractable Fe %Fe ₂ O ₃
Profile T3								
Peat layer	0-40	3.75	0.61	49.5	5.9	93.91	0.21	0.37
Mineral layer	40-50	3.78	0.81	87.4	9.7	24.17	0.23	0.32
Sulphuric layer	50-85	2.26	4.46	392.0	242.0	9.55	1.62	0.73
Profile T5								
Peat layer	0-50	3.79	0.53	51.4	10.6	95.12	0.17	0.13
Mineral layer	70-80	5.61	3.09	5.6	4.13	2.78	1.45	0.49
Sulphuric layer	90-110	2.5	3.50	285.8	182.6	10.36	1.71	0.71
Pyritic layer	>110	2.36	5.32	480.0	305.6	5.25	3.40	1.31

Total nitrogen contents on a dry weight basis ranged from about 2.1% in the top 10 cm of peat, down to 1.4-1.5% below 10 cm, with easily decomposable - organic nitrogen contents ranging from 53 to 98 mg N kg⁻¹ dry weight (Table 5). No figures for available N appear to have been reported for other tropical peats, but the total

nitrogen content of Vo Doi peat (1.4-2.1%) appears to be towards the middle to higher end of the range of 1.0-2.2 % reported for tropical peats in Kalimantan (Rieley and Page, 2005).

Table 5 Nitrogen and phosphorus concentrations of peat at two sites in Vo Doi National Park.

Profile	Depth (cm)	Total N (%)	^{1/} Available N (%)	Total P (%)	^{2/} Available P (mg kg ⁻¹)
T3	0-10	2.12	98.1	0.12	28.4
	10-40	1.52	69.8	0.09	12.5
T5	0-10	2.09	69.0	0.10	24.2
	10-30	1.38	52.9	0.06	11.2

^{1/} Available N determined by the difference between N extracted by 1N KCl at boiling point and 1N KCl at room temperature.

^{2/} Available P determined by Bray 2 extraction.

Total phosphorus contents on a dry weight basis ranged from 0.10-0.12 % in the top 10 cm of peat, falling to as low as 0.06% below 10 cm in depth (Table 5). This appears to be well below the range of 0.3-0.9% reported for tropical peats in Kalimantan (Rieley and Page, 2005). The C/P ratio of about 470 – 500 is also well below the range of 760-1330 reported for tropical peats in Kalimantan (Rieley and Page, 2005). Available phosphorus was about 26 mg P kg⁻¹ dry weight in the top 10 cm, falling to about 12 mg P kg⁻¹ dry weight at depths below 10 cm (Table 5). As with available nitrogen, no figures for available phosphorus seem to have been reported for sites elsewhere in Vietnam.

Based on this evidence, the nitrogen status of peat in Vo Doi seems to be comparable with that of other tropical peats, whereas its phosphorus status seems to be lower than that of other tropical peats for which data are available. However, given its low bulk density, peat at Vo Doi has very low absolute nitrogen and phosphorus contents per unit volume, and it therefore has low fertility in terms of nitrogen and phosphorus.

Peat at Vo Doi appears to have moderate levels of major cations such as Ca, Mg and K on a dry weight basis (Table 6), but on a volume basis their concentrations are well below those generally considered necessary for optimal plant growth. The concentration of micronutrients such as Zn and Cu were also low, whereas the concentrations of Fe and Mn were very high (Table 6). Taken at face value, the levels of both Fe and Mn could be high enough to be toxic to plants and aquatic organisms. However, the EDTA extraction technique also extracts Fe and Mn from organic Fe and Mn complexes. These may be less harmful to plants and aquatic organisms because the Fe and Mn are bound and not readily water-soluble. The concentration of water soluble Fe and Mn would be a better indicator of potential toxicities.

Table 6 Concentrations, on a dry weight basis, of some major cations and EDTA-extractable micronutrients in peat at two sites in Vo Doi National Park

Soil profile	Depth cm	Ca meqkg ⁻¹	Mg meqkg ⁻¹	K meqkg ⁻¹	Na meqkg ⁻¹	Fe mg kg ⁻¹	Mn mg kg ⁻¹	Zn mg kg ⁻¹	Cu mg kg ⁻¹
T1	0-10	163.3	223.8	3.5	1.9	4264	55.48	3.54	2.53
	10-30	223.8	275.5	3.7	4.4	6636	103.78	10.44	3.09

T2	0-10	209.3	212.0	3.5	2.5	2818	45.08	5.88	2.38
	10-30	275.5	264.0	2.9	2.4	3755	63.35	8.41	2.27

BIODIVERSITY

Plant Biodiversity

The three major vegetation types at Vo Doi Nature Reserve are ‘semi-natural’ (originally planted but no longer tended) *Melaleuca* forest, *Melaleuca* plantations and seasonally inundated grassland. Semi-natural *Melaleuca* forest covers a large area in the west of the site. The tree flora is dominated by *Melaleuca cajuputi*, although other tree species are also present. *Melaleuca* plantations of varying ages are distributed in the east of the nature reserve. In the centre of the nature reserve, there are areas of grassland with scattered, young, naturally regenerating *Melaleuca* trees. The most widespread grassland community is one dominated by *Eleocharis* and *Cyperus*. *Phragmites* is also common (Buckton *et al.* 1999). Surveys of plant biodiversity were carried out along two transects in intact peatland, and two transects in areas where a fire in 2002 had burned the peat and exposed the underlying acid sulphate soils. The main objective of the surveys was to compare the species diversity of vascular plants in the central intact peat zone with that in areas which had been burned by fire. A secondary objective was to try, if possible, to determine whether or not there has been a change in species composition in recent years due to changes in hydrology resulting from the construction of a dike around the core peat zone.

A total of 33 species of vascular plants were found in Vo Doi National Park. Species diversity was much greater on intact peatland (28 species) compared with that of burned areas having exposed acid sulphate soils (14 species). The most striking difference between the two areas was in the number of tree species and climbers. A total of eight tree species was common on intact peatland, whereas only one, *M. cajuputi*, was found on exposed acid sulphate soils (Figure 4). Similarly, of the six climbers common on intact peatland, only one, *C. trifolia*, was found rarely on exposed acid sulphate soils (Figure 4). The ground flora of more elevated peat sites consisted mainly of ferns, the sedge *Cyperus compuctus* and a few small shrubs. Shrub and terrestrial herb species were poorly represented in the ground flora of areas with exposed acid sulphate soils. The reed grass, *Phragmites karka*, was almost entirely absent at more elevated peat sites, but a conspicuous component of the ground flora on exposed acid sulphate soils. The parasite *Dendrophthoe pentandra* was comparatively rare on peat soils, but much more common in areas with exposed acid sulphate soils.

There are discrepancies between the species recorded by Buckton *et al.* (1999) and those recorded in the present study. This could be due to (i) mis-identification by either study, (ii) the restricted area sampled in the present study, and/or (iii) actual changes in species composition over the period between the two studies.

It is clear that acid sulphate soils exposed after the peat has been burned have a much lower vascular plant biodiversity than intact peat areas. This loss in biodiversity is associated with two factors: Firstly, the much lower elevation of burned areas means that they are often permanently, flooded, giving rise to a ground flora of predominantly aquatic grasses, sedges and floating aquatics. Secondly, the species

composition is limited to those species that can tolerate the very low soil and water pH associated with acid sulphate soils. For example, canal water pH was significantly lower in the area with exposed acid sulphate soils (pH 2.5 – 6.3; mean = 4.1) than in the area with intact peatland (pH 4.9 – 6.5; mean = 5.5), with no significant difference between wet season and dry season values. Of the tree species in the area, only *M. cajuputi* and perhaps some mangroves can tolerate such conditions.

The distribution of these community types depends mainly on elevation and the height of the water table. As pointed out earlier in this chapter, water levels have changed considerably since the construction of a dike around the core zone of the national park in 2004. This has raised the water table, particularly in the dry season, thereby leading to more or less permanent ponding of some parts of the core zone that formerly drained during the dry season. This appears to have increased the area of aquatic swamp vegetation within the core peat zone. Whether or not peat forest has also been lost is not clear because of the lack of reliable quantitative baseline data on the aerial extent and species composition of peat forest prior to the construction of the dike in 2004. Water levels above the peat surface were observed at a number of peat forest sites at the end of the dry season in 2007, which appears to have led to the encroachment of aquatic plant communities into the peat forest. Many of the tree species and climbers that were found only in intact peat forest in the core zone are not particularly tolerant of permanently flooded, waterlogged soils, and field observations indicate that many individuals of *M. cajuputi*, some climbers and the grass *Stenochlena palustris* are either growing poorly or have died in those areas that are flooded all year round.

Although the variation in elevation within Vo Doi National Park is less than 2m, three quite distinct plant communities were evident: peat forest on intact peat at higher elevations; aquatic swamp communities on both intact peat and exposed acid sulphate soils at lower elevations. If current management practices persist, the peat forest community in these more or less permanently flooded areas may gradually disappear and be replaced by aquatic swamp communities. These changes are subtle but important, and are likely, in the longer term, to change the floristic composition of peatland in Vo Doi National Park significantly.

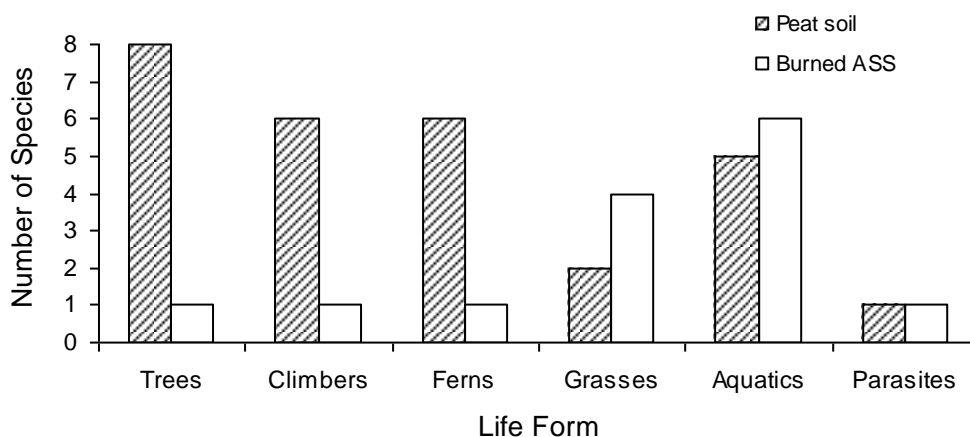


Figure 4 Comparison of the number of species of different life forms found on peat and burned acid sulphate soils in Vo Doi National Park.

Unfortunately, there appear to be few prior quantitative studies of the species composition of plant communities specifically for Vo Doi National Park. Safford et al. (1998) identified 40 species of vascular plants in the peat forests of the U Minh wetlands, but their survey did not distinguish species that were only found in U Minh Ha, where Vo Doi National Park is situated. By contrast, the present survey found only 28 species of vascular plants in the peat forest of Vo Doi National Park. In the absence of good baseline data it is difficult to say with confidence whether or not this represents a reduction in species diversity over the past few years. However, given considerable loss of peatland as a result of forest fires, and significant changes in hydrology, it seems likely that there has been some reduction in species diversity over the past decade, particularly of tree species and terrestrial ground flora.

Fish

In this study, six commercial fish species were found in Vo Doi: *Ophiocephalus striatus*, *Anabas testudineus*, *Clarias macrocephalus*, *Notopterus notopterus*, *Trichogaster trichopterus* and *T. pectoralis*. Of these, *N. notopterus* and *T. pectoralis* were apparently absent from the area with exposed acid sulphate soils. Truong and Tran (1993) recorded 173 freshwater fish species in the Mekong Delta, but only a few of these are found commonly in areas with low water pH. In a recent assessment of the fisheries resources in neighbouring U Minh Thuong Nature Reserve, where the water pH is similar to that of Vo Doi, Tran et al. (2003) found nine species of commercially important fish. As in the present study, they did not sample for smaller non-commercial species, but it is likely that there might be another ten or so small non-commercial species (Tran Dac Dinh, pers. comm., 2008). Thus, it appears that the fish biodiversity in Vo Doi is a little lower than in U Minh Thuong, and that there might be fewer species in areas with acid sulphate soils than in areas with peat soils, but a much more extensive and quantitative survey would be needed to confirm this.

Birds

Birds were not included in the present survey, but there have been regular surveys of birdlife in the area over the past decade or two, the most recent being that by Buckton and Safford (2004). Vo Doi National Park and the surrounding area is reported to be rich in bird species. In particular, the area supports a high abundance and species richness of waterbirds, including small bitterns (*Ixobrychus* sp. and *Dupetor* sp.), Bronze-winged Jacana, *Metopidius indicus*, and Purple Swamphen, *Porphyrio porphyrio*. There are recent records of adjutants, probably the Lesser Adjutant, *Leptoptilos javanicus*, from Vo Doi. This species was believed to breed at the nature reserve in the past but appears to no longer do so. However, the species may still occur outside of the nature reserve to the north. In addition, Woolly-necked Stork, *Ciconia episcopus* has been reported to occur in the area to the north of the nature reserve, where it might breed. The reasons for the apparent absence of the larger waterbirds from the nature reserve itself are not clear but may include disturbance and habitat deterioration in the past, partly due to forest fires (Buckton et al. 1999).

Fire Management

Forest fires represent a serious threat to the integrity of the remaining peatland in Vo Doi National Park. In 1995, for instance, a fire destroyed some 200 ha of *Melaleuca* forest, and again in 2002, fire destroyed a significant area of peat forest. Park rangers also report patches of *Melaleuca* die-off, although the reasons for this are not clear (Buckton et al. 1999).

The most common causes of fire are unextinguished cigarettes and the use of fire to generate smoke during the collection of honey. Once started, forest fires are very difficult to control owing to poor accessibility, limited fire-fighting resources, and the large amount of fuel in the form of peat and volatile oils in *Melaleuca cajuputi*, the dominant tree species in the peat forest. Current management strategies are therefore focused chiefly on reducing the risk of fire.

The fire risk depends on several factors, most notably the weather conditions, the amount of fuel, and the flammability of the fuel. The latter, particularly in the case of peat, depends mainly on its moisture content, which, in turn, is strongly influenced by the level of the water table. As pointed out earlier, the peat in Vo Doi has very high hydraulic conductivity and a low water holding capacity, so it can dry rapidly when the level of the water table falls, thereby increasing its flammability.

In order to manage the fire risk more effectively, a fire hazard early warning system is being developed, based on weather conditions, the amount of fuel available and its flammability. For this, weather data is collected from local weather stations located at five manned fire lookout towers in Vo Doi National Park. Rainfall is measured twice daily, at 7am and 5pm, and the two readings are added together to give the total daily rainfall. Wet and dry-bulb temperatures are measured daily at 1300 hours. Two wood fuel samples are collected for each tree age category from a 1m² quadrat. Sampling is conducted once per month. The moisture content of the fuel samples is determined by oven drying in the laboratory.

In the initial stages of development completed thus far, only the prevailing weather conditions have been used to give a fire ignition index. This is based on a modified Nesterov Index (Pham Ngoc Hung 1998);

$$P_i = K \sum_{i+1}^n T_{13}^0 D_{n13}$$

Where P_i is the ignition index, n is the number of consecutive days without rain, T_{13}^0 is the temperature at 13 00 hours, D_{n13} is the differential saturated between dry graph and wet graph, and the coefficient K has a value of 0 when rainfall ≥ 5 mm or 1 when rainfall < 5 mm. The Fire Risk Level is then determined from the modified Nesterov Index using the following classifications (Pham Ngoc Hung, 1998).

Fire Risk levels (FRL)	Modified Nesterov Index	Forest Fire Risk
I	100 - 1000	Very Low
II	1001 - 2500	Low
III	2501 - 5000	Moderate
IV	5001 – 10 000	High
V	> 10 000	Extreme

CONCLUSIONS

Overall, the physical and chemical characteristics of peat in Vo Doi National Park are similar to those reported for other tropical peatlands in Malaysia and Indonesia for which comparable data exist. Plant biodiversity in Vo Doi, however, appears to

significantly lower than that of other pristine tropical peatlands. There are a number of explanations for the low plant biodiversity in Vo Doi. One is the fact that the vegetation in Vo Doi is only semi-natural, since most of the area is a secondary growth of mainly planted *Melaleuca cajuputi* (post 1975), with limited natural regeneration of other tree species, climbers and ground flora. Furthermore, high planting densities of *Melaleuca* and its aggressive canopy dominance of other species may limit opportunities for other species to become established. A second explanation is that the construction of dikes and canals, together with land use practices in the surrounding area, have changed the natural hydrology of the peatland area. In particular, the higher water levels that now exist in the core peatland area limit the establishment, survival and growth of many peat forest tree species, climbers and dicotyledonous ground flora, most of which are tolerant of ephemeral flooding, but relatively intolerant of flooding for extended periods. Plant diversity may also be limited by the unavailability or poor dispersal of seeds, particularly for those species that are relatively uncommon in the peat forest.

Effective management of peatland in Vo Doi National Park presents managers with a dilemma. The strategy of maintaining artificially high water levels throughout the year seems to have been effective in reducing the loss of peatland from fires, but it comes with a cost. The cost is that higher water levels appear to be changing the vegetation patterns in some parts of the core peat zone, with a possible loss of biodiversity in the peat forest flora, and perhaps also the fauna. It is therefore reasonable to ask the question, what is the objective of conserving the Vo Doi peatlands? If the answer is simply to prevent peatland fires and their consequent release of CO₂ into the atmosphere, then the present management strategies seem to be relatively effective. If, on the other hand, the answer is to maintain biodiversity, then present management strategies pose the risk of reducing or destroying the biodiversity that they are supposed to protect.

There appears to be no clear and simple solution to the dilemma faced by park managers. However, there are several interventions that together could help to manage the risk of fire and maintain biodiversity. Firstly, breaching the dike around the core peat forest zone at several locations at the beginning of the wet season to allow water levels to follow the natural water levels in the surrounding canals instead of flooding the peat zone to abnormally high levels in the wet season when the fire risk is relatively low. The dike could then be re-sealed at the end of the wet season to maintain a water level sufficient to reduce the risk of fire in the dry season. Secondly, building a network of elevated walkways through the core peat forest zone to improve accessibility for park rangers and firefighters. These could also be used for guided ecotourist tours.

Finally, a more equitable distribution of benefits from the national park to the local community would promote greater awareness of its value and encourage more effective participation of the local community in its protection. One approach might be to provide guided tours of the park and market it as an ecotourist attraction. The local community could then earn income from services provided to tourists, and from selling honey and local handicrafts. The success of this approach, which combines community-based protection with direct economic benefits to the local community, depends mainly on four factors: (i) The extent to which benefits are shared amongst all stakeholders, which is perhaps the key factor influencing the participation of the local community in protecting the park; (ii) the quality of the park, the tours and the

services provided; (iii) how well the park is marketed as an ecotourist destination; and (iv) the quality and packaging of the goods sold by the local community. There are a number of examples from Thailand and other countries in the region where this community-based approach has been implemented successfully. There may well be other approaches to promoting an awareness of the value of the park and encouraging the participation of the local community in its protection, but none are likely to succeed unless they bring benefits to, and improve the livelihoods of those living near the park.

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REFERENCES

- Buckton, S. T., Nguyen Cu, Ha Quy Quynh and Nguyen Duc Tu. 1999. The conservation of key wetland sites in the Mekong Delta. Hanoi: BirdLife International Vietnam Programme.
- Buckton, S.T. and Safford, R.J. 2004. The avifauna of the Vietnamese Mekong Delta. *Bird Conservation International* 14:279-322.
- Pham Ngoc Hung (1998). Forest fire management in Vietnam (Quan ly chay rung o Viet Nam). Nghe An Publishing House.
- Rieley, J.O. and Page, S.E., Eds. 2005. Wise Use of Tropical Peatlands: Focus on Southeast Asia. ALTERRA - Wageningen University and Research Centre and the EU INCO - STRAPEAT and RESTORPEAT Partnerships, Wageningen. 265 pp.
- Safford, R.J., Tran Triet, Maltby, E. and Duong Van Ni. 1998. Status, biodiversity and management of the U Minh wetlands, Vietnam. *Tropical Biodiversity* 5, 217-244.
- Tran Dac Dinh, Ha Phuoc Hung, Nguyen Thanh Phuong, Truong Quoc Phu, Nguyen Thanh Long, Le Bao Ngoc, Nguyen Trong Ho, Mai Viet Van, Mai Viet Thi, Nguyen Van Kiem, Nguyen Van Thuong and Nguyen Thanh Toan. 2003. Fish Stock Assessment and Development of a Management System for Sustainable Exploitation of Fish Resources in U Minh Thoug Nature Reserve. Care International, Vietnam.
- Truong Thu Khoa and Tran Thi Thu Huong. 1993. Fresh water fish classification in the Mekong delta.

GIVING FULL RESPONSIBILITY FOR LOCAL COMMUNITY AS ONE WAY OF FIRE MANAGEMENT IN CENTRAL KALIMANTAN: THE TSA CONCEPT

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SUMMARY

Prevention and suppression of forest fires are certainly ineffective and inefficient with the fire brigade units available and without the involvement and full responsibility of the local communities who live within and surrounding the fire sensitive areas. This is mainly owing to the unnecessary bureaucratic systems and dubious tasks assigned to the teams. For example, the Head of the Department for Forest Management and Protection is given limited responsibility for fire prevention and suppression only inside National Park Protected Areas, and not within other areas. Based on experience of suppressing fires in 1997 and 2002, a concept has been formulated, which is called the Concept of Fire Fighting Team or the TSA Concept. This explains how to bring together local people to develop high awareness and responsibility for the prevention of forest fire. This should be carried out through the establishment of TSAs in villages with a planned approach to provide a source of income as compensation for their fire fighting activities and responsibilities. This strategy can also be developed directly to implement community environmental education. This strategy has been formulated clearly and accepted by the local Government of Central Kalimantan through a Workshop on Strategies and Integrated Action Plan on Land and Forest Fires Prevention in Central Kalimantan, 14 - 15 April 2003, but it has not been implemented yet.

Keywords: fire management, tropical peatland, environmental education

INTRODUCTION

Land and forest fires occur every year in Central Kalimantan, especially in the dry season as a result of human carelessness and natural disaster. The two big forest fires that occurred in 1997 and 2002 were the most disastrous in recent memory and brought about many disadvantages to human life in Kalimantan. Through these two incidents, it appeared that there was less real action to decrease or to minimize the negative impacts on humans, such as controlling the spread of fire and suppressing fires which had become established. In other words, the agencies that were given the task and responsibility for land and forest fire prevention, were in most cases ineffective and gave up in the face of these massive obstacles. The local communities who were most affected by the negative impacts of these fires and expected greater efforts by the authorities to cope with the forest fires were extremely disappointed and felt let down (Limin et al., 2003).

Addressing the forest fire disasters of 1997 and 2002, which totally paralyzed most of the socio-economic activities of the people of Central Kalimantan, it is generally

concluded that one of the causal factors was that there was no real preventative action in the field when the fires were still small scale. In other words, many people and agencies could only start thinking that suppression was needed when the fires extended and endangered human life. In these emergency conditions, only a small group of people with limited resources was mobilized to suppress the fires. The reasons for this limited action were lack of funding and the high risks involved (Limin, 2003). The principal threat to the team working in the jungle was to their health and safety. The threat to their physical safety arose because they worked close to fire hot spots that released thick smoke and haze. The negative impacts to the health of the fire fighting team, and also to many people throughout the province, would be effective in both short and long terms, regardless of whether they stayed indoors or out because they could not avoid inhaling the thick smoke.

According to Limin et al. (2003), the long-term negative impacts as a result of inhaling highly dangerous polluted air are difficult to determine. If we believe, however, the warnings posted in public places about the hazards to human health caused by cigarette smoke that does not fill the entire atmosphere then, it can be concluded that, there must be severe negative impacts from inhaling the thick smoke produced by forest fires. Therefore, the understanding and opinion from various parties saying that forest fire suppression would be unsuccessful in putting out the burning fires, and waste a great amount of energy and money must be corrected and changed. It indicates the ignorance and low public awareness of the extended disadvantages resulting from the forest destruction, but also that as long as the fires continue burning wildly the danger to human life is prolonged and the suffering caused by inhaling polluted air continues for a long period.

Based on the experience of the TSA fire fighting team since 1997, the Government must allocate full responsibility and proper guarantee to the communities living in or near fire sensitive areas in order to prevent and suppress fires. For the last ten years affected by forest fire, local communities have been mere spectators when Government teams attempted to suppressing fires close to their villages. Government teams have involved some members of the local community for a short time during fire emergencies, but their status has only been as volunteers with very low payment and without compensation for working hard and at high risk.

THE TSA CONCEPT

According to CIMTROP UNPAR (2004), since the Tim Serbu Api (TSA) or Fire Fighting Team was established in 1997, the concept to involve the community with full responsibility was already formulated, as follows:

Institutional Requirements

The organization of the TSA must be legal and established as a foundation (Lembaga or Yayasan). The management of the foundation can be by either the local government or by the local community, but there must be good coordination. If the foundation belongs to the community, the Government must support it fully. The organizational network of the TSA is shown in Figure 1

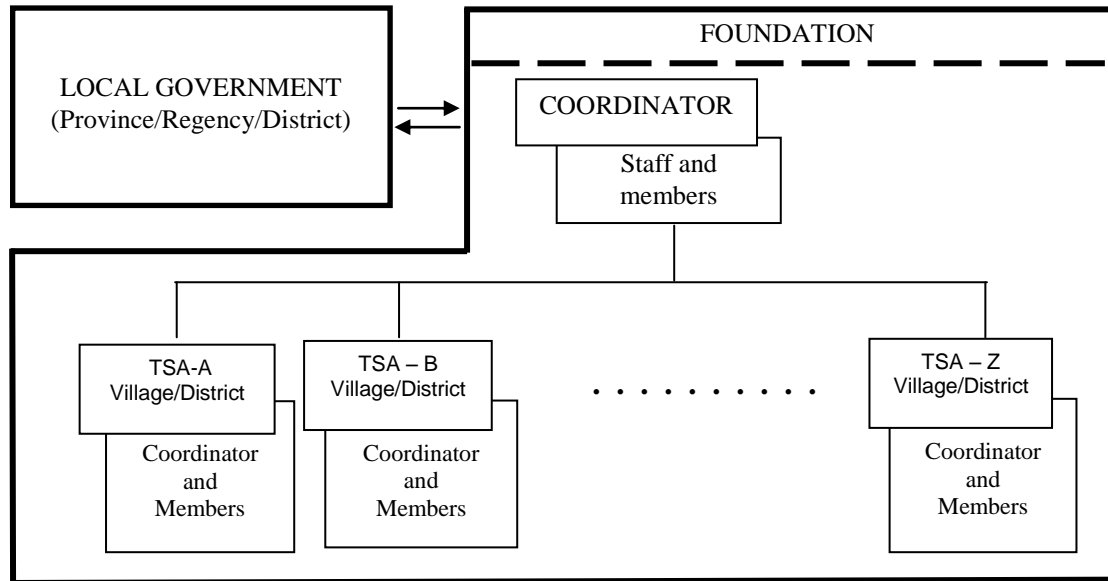


Figure 1 Proposed TSA organization network

Membership and clarity of tasks

a. Establishment of the TSA

In establishing a TSA several aspects should be considered, e.g. sensitivity of the area to fire, determination of the community to protect against fire and dedication to implement the TSA programme.

b. Membership of the TSA should be determined by criteria as follows:

- Age 18 – 50 years
- Healthy, free from the colour blindness, nearsightedness, deafness and mute, and heart disease.
- Capable for working in the open night and day.
- A farming background.

c. Training

All of the TSA members must be trained by senior TSA members. Five modules of a training programme have already been written based on the TSA experience since 1997 and this information will be transferred to new members when the training is conducted (TSA UNPAR, 1998).

Welfare guarantees

a. Insurance

All of the TSA members must be covered by insurance.

b. Fixed Income

The TSA members must establish their source of income relevant to the carrying capacity and their interests. The income source must be managed according to the cooperative system, so they can provide money for action and put this into a joint account (Limin, 2002a; 2002b and TSA UNPAR, 1998).

METHODS AND STRATEGY

According to Limin (2000b) and CIMTROP UNPAR (2004), the best methods of fire suppression are (i) KATIR; this is the acronym of “sekat bakar diairi”, meaning the fire transects were watered till saturated, and (ii) BOMTIK; this is the acronym for the Indonesian words “Bom Air Plastik”, or plastic bag which could be filled with about 1.0-1.2 litres of water, and used like a bomb.

The strategy carried out by the TSA team to conduct the two methods can be explained as follows:

- (a) In order to work efficiently the assigned TSA members have to stay and sleep in temporary tents near to the fire hotspots;
- (b) The TSA team members carry out a prior observation of the fire movement and the hot spot, i.e. by climbing up trees for 12 –20 m above ground;
- (c) Make a transect line for 20 – 100 m or so away from the fire, depending on the vegetation type and fire spreading speed;
- (d) At the same time while one group makes the transect, other members of the TSA are assigned to drill a deep well through the peat to find underground water;
- (e) Take coordinates to determine the exact distance for the next deep wells;
- (f) Along the transect, deep wells are drilled every 300 – 500 m, depending on the site condition;
- (g) The ditch or transect must be kept saturated with water to prevent the fire from spreading to a larger extent through the deeper peat layer;
- (h) Only then can the TSA members start to suppress the fire inside the transect line;
- (i) The TSA members are divided into 2 – 4 groups for working at noon and at night or at other times depending on the fire threat level. Under certain condition, fire suppression has to be carried out nonstop for 24 hours by 4 groups in turn;
- (j) Each group of 5 – 7 TSA members, equipped with 3 hand radios are assigned to operate one pump machine with 200 – 400 m of hose;
- (k) Dead standing trees (“punggu”) are felled using a chainsaw as they can facilitate the fire to spread over a larger area, through flying embers.

Equipment and finance

The TSA members must be supported by command posts and equipment. The basic equipment needed for suppressing fire are portable pumps operated by petrol engines that can be carried by 1-2 persons only. Another essential item is a borer for drilling deep wells.

Multifunctionality of the TSA teams

Establishment of the TSAs is not only for suppressing fire. Through the TSA, education can be provided to local communities on how to manage their environment better to obtain sustainable livelihoods. TSA members can explain their experience about the importance of the environment and explain the negative impact of forest fire on local communities. They also can also carry out reconnaissance on those destroying the environment and report to the local Government.

Experience of Implementing the TSA Concept

Since 1997, when Indonesia was affected by EL-NINO, the TSA concept was used to suppress land and forest fires which produced thick smoke throughout Central Kalimantan. The results of the TSA actions in 1997 and 2002 are as follows:

TSA Action in 1997

Implementation of well planned action started on 27 September and operated until 10 November 1997, during which the TSA successfully suppressed a total of 50.7 hectares of peat fires at 8 hot spots and established 6 deep wells. Working hours for field operation was 300 hours (238.5 hours, including the operation of water pump machine). TSA managed to pump 1.8 – 2.1 million litres of ground water. TSA also coordinated the provision and the application of 16,000 BOMTIK (about 16,000 litres of water).

TSA Action in 2002

Fire Transect

The TSA established 9 fire transects, totalling about 8.75 km that were used for blocking or hampering fire spreading to other areas.

a. Kalampangan zone

a1. Transect 1: 1.40 km	a5. Transect 5	: 0.80 km
a2. Transect 2: 0.30 km	a6. Transect 6	: 1.30 km
a3. Transect 3: 0.25 km	a7. Transect 7	: 1.80 km
a4. Transect 4: 1.60 km	a8. Transect 8	: 0.70 km

b. SMU 5 Plus, Jalan Tingang Palangka Raya: 0.60 km

c. Natural Laboratory for Peat Swamp Forest (NLPSF): no transect.

Deep Wells

The total number of deep wells established during the 3 months of fire fighting activities by the TSA was: 21 units in Kalampangan zone, and 2 units in SMU 5 Plus. The depth of deep wells varied between 12 to 16 metres.

Dead Trees

A total of about 394 dead trees were felled during the TSA activities to prevent fire spreading from their crowns with the help of wind blowing during the fire.

The Area Saved and Protected

The total area burned and successfully saved and protected from fire (including in SMU 5 Plus) was about 50 – 60 ha near the fire transects. As a result, fire was prevented from spreading to a much greater area of surrounding virgin peat swamp forest.

The total area burned outside the TSA activities is estimated to be about 2,600 ha in the Kalampangan Zone (Mega Rice Block C), 1.0 ha in NLPSF Sebangau, and more than 500 ha near SMU 5 Plus.

Based on the field observations, it was concluded that all of the fires in this area were caused by humans, because the fires always started from locations where there was human activities and access.

Fire Behaviour

a. Fire depth

Based on measurements taken by the TSA during the fire, the depth to which the peat was burnt varied between 0 – 42.3 cm.

b. Fire Speed

The speed of fire in the secondary forest was different from primary forest. Based on TSA measurements in secondary forest, the fire speed was about 1.2 m/hour on average depending on vegetation species and the thickness of dried biomass in the surface. The fire speed was slower at 8 - 14 cm in the peat layer where it burned dry biomass such as root and wood the debris.

Water Spraying Volume

The total water volume in accordance with the size of the nozzle used was 2.5 l/second on average. It was found that to suppress 1 m² of forest fire, took 2-3 minutes and used about 300-450 litres of water.

Number of Work Days

Fire suppression commenced in the field on 25 July and continued until 25 October 2002. The numbers of work days of each team member varied according to their availability and ranged from 7.5 days to 88 days. The total number of man days worked by the TSA UNPAR team was 651.5 days, while local people worked for 770.5 days.

DISCUSSION

Loss of community awareness and respect has been caused by several factors, for example:

1. law enforcement is applied only to people who do not have power and money;
2. all of Central Kalimantan has been divided up and allocated to Forest Companies and community rights to the trees surrounding their villages have been transferred to these;
3. local communities that already fulfill their rights to the environment surrounding them suddenly had these rights removed by Government regulation, and
4. the Government gave full support and attention to these logging companies.

Limin (1999; 2000a) observed that when fire occurred along the roads and spread into the forest, the local people just watched because they know that the owners of the forest are the logging companies. Local communities would have put much effort into suppressing fire, if their land supported trees with high economic value. Since their land was now without economic trees, most people just allowed the fires to blaze.

Suppression of fire by people organized by the Government through the agencies BAKORNAS in Jakarta, SATKORLAK in the Provinces and SATLAK in Regencies involving temporary, short-term action has been neither efficient nor effective (Limin, 2003 and CIMTROP UNPAR, 2004). The lack of responsibility given to people involved in these activities, because they don't receive real guarantees relevant to the risks of the job, has led to thousands of people just sleeping and waiting for something to happen but without contributing. Therefore, in order to obtain a good solution and give real benefits to local people for suppressing fire, the TSA concept as formulated above must be implemented.

Based on implementation of the TSA concept since 1997, many local communities are interested in becoming involved in fire suppression because they have real understanding of rights and obligations. They believe the TSA concept is part of an

education process on how to manage their lives, so they can obtain income by managing their business although for the moment in small amount. It is hoped that the effect of implementing this strategy will spread to other communities in the surrounding landscape so all villagers can understand the importance of their environment. One of the important points is that by implementing a part of the TSA concept, they can see real results from their actions, e.g. the rate of fire spread to other area is reduced and stopped totally in some cases. To take action in the field, the TSA members do not depend on the water available on the surface, but they dig deep wells to reach underground water that is available in abundance. During their work in the field, they are also trained to conduct research on the thickness of the peat layer burned, rate of fire spread and other observations. This situation is very different compared to before, when the communities joined with Government groups that worked in the field without strategy, target or real guarantee (Limin et al., 2003).

On April 14 - 15, 2003, the Government of Central Kalimantan organized a workshop and invited all of the heads of regencies (Bupati) to discuss and formulate a strategy on how to prevent and suppress fires. The main output from this workshop was that the TSA concept was adopted totally by all of the participants as a method and strategy relevant to implement in Central Kalimantan. Through this agreement, every fire brigade must be merged into one institution or foundation as a good solution for effective field work, rather than separate actions by each agency. Limin (2003) stated that the TSA concept was formulated based on real situations and problems when fire spreads rapidly and widely in the dry season. All agencies or groups that have budgets and work separately only in certain hotspots are ineffective and inefficient because they only work near to roads, although the fires have spread already hundreds or even thousands of metres inside the forest. These groups have also concentrated their actions on hotspots only if much water is available on the surface e.g. in ditches and drains. Owing to the limited amount of water in these ditches, these groups always move to another hotspot when the water supply is exhausted even though the fire at the first site is still raging on a big scale. Therefore, the activities of these groups are without strategy and target, and they constantly chase the fire movement and water supply.

To realize the TSA concept, through the agreement of the Central Kalimantan Workshop held in April 2003, it is apparently difficult to succeed because the various agencies that have a budget still work alone. Therefore the EU-funded RESTORPEAT project has been invaluable for initiating the source of income for the TSA team as an important activity in the TSA concept. The incorporation of the TSA into one of the tasks in the RESTORPEAT project is very important to achieve restoration of tropical peatland because fire is a major factor that destroys all possibility of sustainable wise use in locations where peatland restoration is being conducted. The site location of RESTORPEAT is fire prone, because every year fire always occurred there, starting from the road, where farmland is located but without real control activity. Therefore, if this area burns, the owner of land is happy, because it is kept clear of bush and scrub and there is no law enforcement against them for starting fires.

According to the Director of Forest Fire Fighting in the Department of Forestry (CIMTROP UNPAR, 2003 and Limin et al., 2003), forest fire in Indonesia is always caused by human activity in the course of land preparation. Forest fires in Central Kalimantan have almost always been caused by human carelessness, such as people

throwing away cigarette ends, lighting fire in the forest, clearing and burning land outside the city along the road sides, as well as land clearance for large scale plantations of oil palm and industrial forest plantation, or by simply setting the bush by the road on fire for fun. In the other words, where there is access to the forest and peat swamp that is where the hotspots started (Limin et al., 2003).

The Government fire brigade is unable to prevent and suppress fires although it has a large amount of money available. Therefore the involvement of local communities is the best strategy to prevent and suppress fire (Limin, 2003; CIMTROP UNPAR 2003). Because of the negative attitude of communities mentioned above, the TSA is very important in the awareness programme. In other words, the giving of trust to the community is very important for raising awareness and providing responsibility to develop this country according to their capabilities. By according full rights, obligations and responsibilities to local people so they can organize and manage their own activities and business, is equivalent to giving them trust on their private personalities, so they feel obliged to contribute to the development of their country. For several decades local communities have only been objects for Government projects without requiring their initiative and creativity. From the other side, they saw the Government staff living in luxury while they established communities of people who would continue to live in poverty.

CONCLUSION

- 1). The strategy for suppressing forest fire as established by Government through the BAKORNAS, SATKORLAK and SATLAK agencies has been inefficient and ineffective because, for the last decade, the awareness and responsibility of communities have never changed as indicated by the fact that fires occurred everywhere in the dry season.
- 2). The lost community rights to the environment must be restored back to the people, because before the regulation for forest exploitation, communities lived in harmony with their environments.
- 3). Recovery of community trust concerning their environments needs a new approach which is relevant to their background, ability and culture. This trust could change all of the negative thinking of communities that is embedded in Government policy.
- 4). The TSA concept has a stated and full objective that provides a unified platform onto which to invite all of the community to be of the same opinion and devote their attention to the importance of the environment to ensure its survival to support future generations. Implementation of the TSA concept could change and increase community awareness and following by the income guarantee.
- 5). It is impossible to stop fire totally once it has spread , but action to stop fire entering other areas is feasible and can be achieved by concentrated action at small hotspots.
- 6). Government policy should consider and incorporate local knowledge, local initiative and local creativity which are relevant to their environment condition and culture. Without the involvement of local communities and the devolution of responsibility to them it is unlikely they will give their full support to fire control initiatives and, as a consequence, forest fire in Central Kalimantan will become a bigger disaster year on year.

REFERENCES

- CIMTROP-UNPAR. (2003) Laporan Penyelenggaraan Workshop. “Strategi dan Rencana Aksi Terpadu Pencegahan dan Penanggulangan Kebakaran Lahan dan Hutan di Kalimantan Tengah “, Palangka Raya, 14 – 15 April 2003. (in Indonesian).
- CIMTROP-UNPAR. (2004) Strategy For Suppressing Fire In Peatland. Fire Attack Force (TSA Brochure). CIMTROP, The University of Palangka Raya, Indonesia.
- Limin, S. H. (1999) Pengalaman dan Persepsi di Daerah Tentang Pengembangan Masyarakat (Suatu Tinjauan di Daerah Kalimantan Tengah). Seminar Nasional “Dampak Sosial dan Pengembangan Masyarakat”. Peresmian Ikatan Profesional Lingkungan Hidup Indonesia (IPLHI) Jakarta, 28 April 1999. (in Indonesian).
- Limin, S. H. (2000a) Kontribusi Nilai Eksploitasi Hutan Bagi Kesejahteraan Masyarakat. Disampaikan pada Seminar Advokasi Kependudukan dan Lingkungan bagi Gubernur, Bupati/Wali Kota, Camat dan DPRD. Palangka Raya, 28 Maret 2000. (in Indonesian).
- Limin, S. H. (2000b) Metode Katir dan Bomtik Salah Satu Prosedur Penanggulangan Kebakaran Lahan dan Hutan. Disampaikan pada Temu Karya Nasional PPKAN ke-40 di Palangka Raya, 24 Oktober 2000. Tim Serbu Api (TSA), Universitas Palangka Raya. (in Indonesian).
- Limin, S. H. (2002a) Combatting Peat Fires Surrounding the Orang Utan Habitats in Sebangau, Central Kalimantan. CIMTROP, Palangka Raya University.
- Limin, S. H. (2002b) Pemadaman Dini Titik Api dan Pendanaan. Masukan Kepada Pemerintah Daerah Kalimantan Tengah. CIMTROP Universitas Palangka Raya. (in Indonesian).
- Limin, S. H. (2003) Implementation of TSA Concept for Environmental Education (Fire Prevention, fire Fighting and Sustainable Livelihood). Presented at the International Workshop: Human Dimension on The Management of Peatland in Southeast Asia. Palangka Raya, 1–2 December 2003.
- Limin, S. H., Saman, T. N. and Alim, S. (2003) Forest Fire Suppression Activities in Kalampangan Zone and the Natural Laboratory of Peat Swamp Forest (NLPSF) in Central Kalimantan. Presented at Hokkaido University, Sapporo, Japan, 20 March 2003.
- TSA UNPAR. (1998) Planning for a Research and Training Centre in Management of Land and Forest Fires at Palangka Raya University Central Kalimantan. TSA UNPAR, Universitas Palangka Raya Kerjasama dengan BAPEDAL Jakarta.

Socio-economic and Governmental Aspects of Restoration

INDONESIAN GOVERNMENT APPROACH TO PEATLAND RESTORATION

B. Setiadi

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Chairman Ad Hoc Team for Mitigation Plan for the ex-MRP Area
Chairman Indonesian Peat Association

SUMMARY

In order to solve the problems caused by the MRP, Presidential Decree 80/1999, specified “Guidelines for a Mitigation Plan for the ex-MRP Area”, based upon management of peat >3 metres thick for conservation and economic development of peat < 3 metres through spatial land use planning. An Ad Hoc team and Core Team for Mitigation of the ex-MRP (The Core and Ad Hoc Team - TCAHT) was established by the Minister of Acceleration and Development of KTI in 2002 to implement the guidelines. The rationale behind the establishment of the TCAHT was: because the Mega Rice Project was started by Central Government the problems must be resolved by Central government. Members of the Ad Hoc team were government officials, scientists, and university and professional associations. The tasks of the Ad Hoc team were evaluation and mitigation of the ex-MRP, formulation of a concept for rehabilitation of the ex-MRP, formulation of a concept for the mechanism of mitigation, and formulation of recommendations with alternatives. A grading system for the ex-MRP area, based on an impact and evaluation matrix, was developed by TCAHT as a tool to guide the planning of the rehabilitation programme. Advantages of the grading and matrix applied to the ex-MRP area are integration of approaches and options, data co-ordination, monitoring and evaluation, and understanding of the entire ex-MRP area as a holistic entity. TCAHT concluded that there can still be prospects for future development of the ex-MRP area by changing the principles of the approach to development of the area following some of the recommendations of the Pontianak Workshop on Tropical Peat that was held in 2004.

Keywords: tropical peatland, peatland restoration, mega rice project, mitigation, land use planning

INTRODUCTION

The one million Peat Area Development or “Proyek Lahan Gambut Satu Juta Hektar” (PLG) in Central Kalimantan Province was executed under Presidential Instruction on June 5th 1995 on Food Resilience, followed by Presidential Decree No. 82/1995 on the Utilization of Peat Area for Food Production purposes in Central Kalimantan Province. The main objective of this project was to convert wetlands in Central Kalimantan to paddies in order to keep the rice self-sufficiency attained by Indonesia in 1984. This programme was in line with the Indonesian Government’s policy which is, in its efforts to meet the food demand, to open new cultivation areas (extensification), and to intensify the cultivation as well as other intensification efforts, with production increase as its main aim.

The Peat Development Area geographically located in between the city of Palangka Raya (River Kahayan) toward the east connected by the 187 kilometres Main Primary Canal (SPI) which cuts the Barito River at Mangkatip. On the west side, the PLG location stretches from the city of Palangka Raya towards the south along the eastern side of the Sebangau River up to the Gulf of Sebangau in the Java Sea. On the east side it is bordered by the Barito River, following the Kapuas Murung River towards the south, passing the Kuala Kapuas up to the Kapuas River estuary at the Java Sea. Soil on the area mainly consists of wetland, dominated by peat with a thickness of more than 3 metres (35%), less than 1.5 metres (18%) and acidic sulphate soil (12%), potential acid sulphate soil (33%), and saline soil (2%). The PLG was developed in stages, starting from the beginning of 1996 and during the period 1996-1997 a 187 km long Main Primary Canal (SPI) was constructed, connecting the Kahayan and Barito Rivers. In addition, 958.18 km Dividing Primary Canals (SPU, Saluran Primer Utama) in Blocks A,B,C and D were also constructed. In Block A, the secondary canal, collector canal, primary and tertiary canals all had been constructed, so that this block could provide 30,000 hectares of paddies. For a variety of reasons the PLG was abandoned in 1999 with Presidential Decree No.80/1998.

REASONS FOR THE PLG PROJECT'S FAILURE

The PLG project's main aim was to produce new agricultural land to replace that converted from agriculture in Java. The plan to develop peatland into highly productive food producing agricultural cultivation did not materialize and this failure left many negative impacts that need to be resolved immediately. Most of the PLG Project's failure may be divided into the 3 stages of the project:

Planning and Design stage

- (a) Contravening basic procedures in planning and design for wetlands;
- (b) Generalising the area's condition in a single unit;
- (c) The limited availability of basic data required for natural resources planning;
- (d) Limited knowledge of local culture during the planning stage.

Execution stage

- (a) The construction of the water system pattern, which cut through the mid-section of the peat domes, caused excessive drainage that degraded the environment;
- (b) Settling transmigrants who had little or no understanding of swampy and peat area conditions;
- (c) Technical guidance given to transmigrants and local farmers had not made them self-sufficient;
- (d) Lack of cultivation preparation;
- (e) Sectoral program's coordination was ineffective

Area Utilization stage

The low cultivation productivity owing to the change from reductive condition to oxidative condition, making the soil acidic;

Low farm productivity;

The little guidance given to the local communities;

Environmental degradation

The closed water system had not met its planned target.

EX-PLG AREA MANAGEMENT BASIS

Based on in depth evaluation and assessment, the Government concluded that the Central Kalimantan PLG Project was not unsuccessful, so the Government promulgated Presidential Decree 80/1999, which mainly gives guidelines for its rehabilitation.

To execute Presidential Decree 80/1999, The Minister for Acceleration of East Indonesia Area Development, as the chief of Daily Council for East Indonesia Development Acceleration, issued decree No.SK/004/KH.DP-KTI/IX/2002 establishing the Ad Hoc Team to solve the problems of the ex-PLG Project in Central Kalimantan. This was headed by the Secretary General of the Council for East Indonesia Development/Expert Staff of Minister for National Development. Planning/Bappenas, East Indonesia Development Acceleration/ Less Developed Area. The Ad-hoc Team was mandated to undertake the following actions in respect of the Ex-PLG Project in Central Kalimantan: (a) evaluate the manner in which it was planned, designed and executed, (b) prepare a rehabilitation concept, (c) draft an implementation strategy to coordinate the teams involved, and (d) prepare alternative management recommendations. The Ad-hoc Team completed its task and produced the “Plan for Rehabilitation of The ex-One Million Hectares Peat Development Area in Central Kalimantan” document which contains guidelines for Central Government, Local Governments (provinces, regencies or cities) and other stakeholders in their efforts to manage and develop further the ex-PLG Area.

The aim of writing the Planning for Rehabilitation of the ex-Peat Development Area document is to produce a guideline for Government institutions at central and local level as well as other stakeholders in their efforts to rehabilitate these landscapes through the followings activities:

- (a) Evaluating the way in which the Project was handled;
- (b) Preparing a rehabilitation concept;
- (c) Drafting a mechanism for coordinating the institutions involved; and
- (d) Preparing alternative recommendations for rehabilitation.

APPROACH AND STRATEGY OF REHABILITATION OF THE EX PLG

Various documents have been examined to develop the plan of rehabilitation of the Ex PLG Project at Central Kalimantan. The documents encompass the report of the Mega Rice Project (MRP), Grand Strategy (Directorate General of Spatial Planning, Department of Public Work), Agricultural Business Development (Department of Agriculture), Rehabilitation Strategy Plan (Department of Forestry), Programs of Technical Services and related sectors at national, provincial and regency levels. Besides that, reviews were also executed on the result of Tim Kaji Ulang (Department of Public Work), Tim 20, WALHI, CIMTROP – Palangka Raya University, STRAPEAT, BPPT, IPB, and UGM. The review also encompasses the output of the seminar held at BPPT in 1998, which was able to push the issuance of Presidential Decree No. 80/1999 that automatically annulled the Presidential Decree No. 74/1998.

REHABILITATION PLAN FOR THE EX PLG

A matrix of guidance activities were established in the form of a rehabilitation plan of the Ex PLG by the various institutions involved. The matrix considers goals (objectives) and locations, institutions in charge, funding sources, and execution time. In its implementation, some factors below should be considered:

1. Prior to implementation of activities/programs, updating data of land quality and correction of area should be conducted.
2. Every working block, which is in fact a united ecosystem, should have integrated plans of activities/programs and executed simultaneously by relevant institutions.
3. The prioritized activities/programs at every working block must be set based on funding availability and executed in a coordinated manner.
4. Personnel involved in the implementation of the rehabilitation activities/programs must be permanent.

CONSERVATION ZONE

Areas with peat thickness over 3 metres within the Ex-PLG zone must be determined and designated as protection or conservation zones under the Ministry of Forestry's Decree according to function and specificity of habitat, so they will not be used for other purposes. The protection or conservation zone within the Ex-PLG serves the functions of both water management and carbon sink. Opening deep peatland leads to fragile conditions, especially it will be burned easily during dry seasons. Deep peat thickness must be protected to control CO₂ emission rate as one factor causing global warming and climate change. In addition, opening peatland for agricultural purpose can cause harmful flood and drought. Considering these facts, deep peatland must be conserved or protected as a reservoir that holds water during the rainy season, and releases it gradually during the dry season.

Damaged peatland with thickness over 3 metres owing to fire, logging and other factors will become colonized by open bush vegetation. Such peatland within the conservation zone must be rehabilitated immediately by planting appropriate, useful plants that can also protect water resources. According to the assessment by the Soil Research Centre, Research and Development Agency of Agricultural Department (1997 – 1998), the area of peatland with thickness over 3 metres is estimated to be 177,373 hectares, located in working zones Block A (91,493 hectares) and Block B (85,880 hectares). This peatland distribution does not include deep peatland in the working zone at Block C, which was estimated by the IPB Team (1997) to be around 202,108 hectares. There is no thick peatland within the working zone Block D. The development of irrigation channels, particularly primary and secondary channels, which crossed peat dome has caused land subsidence of between 1 – 2 metres, but the peat still can be categorized as deep peatland (as the dome peat thickness is still over 5 meters).

Conservation action must be conducted at the very deep peatland since this blackwater ecosystem, which is rare to found in throughout the world, occurs in this zone. By designating the very deep peatland (> 3 metres) as a conservation zone, illegal logging should be able to be prevented.

The conservation activities on very deep peatland (over 3 metres) should be conducted according to reviews from various literatures, which indicate that the deep peatland (over 3 metres) must be allocated as either a protection zone or preservation zone, and various forms of production activities must be avoided. Some activities of the rehabilitation plan of the deep peatland are as follows:

Nature Conservation

The deep peatland (over 3 metres) in Blocks A, B, C, and D are designated to be nature conservation land. The largest area (192,619 hectares) is located in Block D, whereas the smallest area (14,729 hectares) is in Block A. The nature conservation area within all of these blocks totals 284,289 hectares.

Gelam Forest Zone Conservation (Actual Acidic Sulphate)

The rehabilitation of the Ex PLG for gelam forest conservation or actual acidic sulphate should be conducted in Blocks A, B, and D with a total area 70,600 hectares. The gelam forest conservation must be part of the rehabilitation of the deep peatland at the Ex PLG.

Blackwater Ecosystem Conservation

The Black water ecosystem on the very deep peatland must be preserved because of its global rarity (it is believed there are only 2 black water ecosystems in the world). This tropical blackwater ecosystem possesses specific flora and fauna, including the False Gharial (*Tomistoma schlegelii*) a relative of the crocodile. The blackwater ecosystem occurs only around the Sebangau River (Block C) with an area 18,804 hectares and the Mentangai River (6,650 hectares).

Mangrove Forest Conservation

Mangrove forest conservation is a feature of working zone Blocks C and D. There are 36,304 hectares of mangrove forest that must be designated as protection zone, because of the forest functions as a spawning ground for fish and other aquatic animals.

Kerangas/Quartz Forest Conservation

There are 81,264 hectares of kerangas (heath forest) in working zones Blocks E and C which possesses specific vegetation, and is very fragile to opening owing to the thin layer of peat that overlies a thick layer of quartz sand. Consequently, the kerangas forest zone must be conserved.

Flora and Fauna

Peatland is a unique and fragile ecosystem, possessing specific flora and fauna that are not available in other ecosystems. Because of that protecting and conserving its biodiversity should be conducted to prevent losses and erosion of the gene pool of the ecosystem. Trees with economic value found in this ecosystem are ramin (*Gonystylus bancanus*), gaharu (*Aquilaria* sp.), nyatoh (*Palaquium* sp.), bintangur (*Calophyllum* spp.) and jelutung (*Dyera* sp.) Endangered and rare fauna are orang utan, burung rangkong (hornbill), honey bear, tree tiger, and varied fishes. The area for flora and fauna conservation is 126,261 hectares, distributed in Blocks A, C, and E.

Reforestation and Greening

Woody commercial vegetation no longer exists on this large area of thick peatland, but a rehabilitation effort in order to accelerate the restoration of forest must be

conducted. Following the Land Use Guidance Map produced by the Soil Research Centre, Research and Development Agency, Agricultural Department (1998), the Ex PLG zone with very deep peat thickness (over 3 metres) must be conserved and restored to forest as a matter of high priority. One of the rehabilitation programs of the peatland at the Ex PLG zone is land replanting of forest and non-forest zone through reforestation and greening. These activities should be conducted in Blocks A, B, C, and D, with a total area of 201,713 hectares.

Water Management (Canal Blocking)

Impacts generated by canal construction with poor planning are diminished land condition, and various problems related to water management, such as drought in dry seasons and flood in rainy seasons. As a result, rehabilitation should be focussed on canals with problems and which do not provide vital access to local communities. Closing those canals will restore the peatland, particularly by reducing fire hot spots in dry seasons which happens quite frequently. Water management should be conducted on all blocks covering a total area of 340,340 hectares.

River Maintenance and Control

The Kahayan, Kapuas, and Barito Rivers in Central Kalimantan not only function to provide water and irrigation for agriculture, but also serve major functions as infrastructure and means of water transportation. Because of these functions, river surfaces, river condition, and the nature surrounding them must be protected and guarded against damage. The maintenance and protection of rivers and canals should be exercised over all Blocks A, B, C, D and E with a total length of 1,600 kilometres.

CULTIVATION ZONE

Thin peat (50 – 100 centimetres) can be utilized for paddy rice, dryland crops, vegetables and fruits and medium peat (101 – 200 centimetres) can support fruits and plantation crops. Deep peat (201 – 300 centimetres) is suitable for plantations and forestry. Some rehabilitation activities for peatland < 3 metres are as follow:

Food Crops and Horticulture Development

The area recommended for cropland development is 163,600 hectares and horticulture 210,600 hectares, with most of this area located in Blocks A, B, C, and D, with the smallest area of 46,000 hectares in Block C.

Plantation Development

Some estate plantations that can be developed in the Ex PLG are rubber, coconut, palm oil, purun, and abaca banana. The most appropriate estate plantation developments in Blocks A and C are rubber and coconut, with a total area of 22,900 hectares. These activities should be undertaken by the private sector, with the Government acting as facilitator.

Fishery Development

The potential fish to cultivate are local species, such as patin, nila (kissing gouramy), and udang windu (penaeid shrimp). Total land parcels for fishery development in all blocks amount to 1,500 packages, with 550, 250, 300, and 400 packages in Blocks A, B, C, and D, respectively.

Husbandry Development

The development of cow, water buffalo and goats can be conducted at all blocks, whereas duck and local chicken could be promoted in Block A. Total number of cows, water buffalo and goats is 1,500, 8,250, and 9,500 animals, respectively; while duck and local chicken is a total of 16,000 animals.

Harvest Processing and Development

Post harvest handling includes reducing harvest losses, quality improvement, processed product development, utilization of side products and waste. Related to these, a harvest marketing network must be developed to allow the products to be absorbed by the market.

Water Management

Total development area of water management at each block is Block A 12,000 hectares, Block B 25,925 hectares, Block C 137,270 hectares, and Block D 79,700 hectares.

Society's Handil (Access)

The access of local people from and to the Ex PLG zone and its adjacent area is by water transportation. Because of this the existence of handil is vital to the local society since the majority of people still depend on it for social and economic activities. All the handils within the PLG working zone generally were formed naturally as a result of natural topography following the flow of the rivers. To preserve the function of the handils, national and regional governments must protect them and ensure they function accordingly. The maintenance of handils should be conducted in Blocks A, B, and D, with a total area of 45,722 hectares.

Industrial Forest Development

Plantation forestry is exercised through utilization of forest land for industrial trees. Such utilization of forest land should be conducted in every block, including the conservation zone in Block E. This activity is expected to restore many marginal land parcels distributed around the Ex PLG, that otherwise have the potential to degrade the environment. In addition, the existence of Transmigrant Settlement Units in Blocks A and C can be capitalized to support the sustainability of plantation forests.

SOCIO – ECONOMICS

The suffering endured by local people because of the failure of the PLG Project and efforts to place society as the focus of development are important matters in the establishment of the rehabilitation plan strategy of the Ex PLG zone. Society empowerment, especially of local communities, by providing opportunities to actively participate in development, is vitally important, so the concept of bottom up planning or community based development can be exercised into reality. Society empowerment will be conducted through training, provision of health and educational facilities and infrastructure construction, such as laboratories and libraries. One of the problems that should be handled immediately is socio–economics of the former PLG and surrounding areas. Besides the existence of 8,487 families of transmigrants, there is also the local society that lives in a low standard. The low standard of life results from the limited accessibility and poor infrastructure of the region, and these limitations must be resolved immediately.

THE KEY TO SUCCESSFUL MANAGEMENT OF PEATLAND IN CENTRAL KALIMANTAN IS CORRECT GOVERNMENT POLICY

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SUMMARY

The utilization of peatland for agriculture in Central Kalimantan always has been in trial and error. Unsuccessful utilization of peatland has occurred ever since the National Government opened the peatland in coastal areas and undertaking water management, successively, with the Anjir system, Polder system, Sisir and Garpu systems, Kolam system and finally employing giant canals in Mega Rice Project. These programmes were executed without any strategy and they failed largely because: (1) the Government of the Republic of Indonesia did not have guidelines to follow as a result of comprehensive research, and (2) the Government never considered the views of peatland researchers because they believed they already had experts who could plan these programmes by themselves. One example of the Government's neglect of local knowledge and research information was the opening of peatland in coastal and inland areas of Central Kalimantan for the Mega Rice Project (MRP). International peatland experts attending the International Peat Symposium held in Palangka Raya in 1995 already warned the Indonesian Government that it should be careful before using peatland for agriculture. The opening of peatland for the Mega rice Project was indicated a major mistake of Government policy because, although research groups had made their recommendation based upon hard work, this warning was ignored by the Government.

Keywords: tropical peatland, peatland management, Mega Rice Project, Government policy

INTRODUCTION

The successful utilization of peatland in Central Kalimantan could be achieved by the correct Government policy which should be based on the experience of scientists who have carried out research on peat and peatlands in Central Kalimantan and other countries. One of problems with Indonesian scientific research on peat is that it is based on results derived from small scale experiment carried out over short time periods and lacking and integration with other aspects. The many Agencies, Departments and Ministries of the Government of the Republic of Indonesia have great difficulty in working together to implement projects in the field, because each of them is used to working alone to fulfill their own specific role in the national planning process. For example, to establish a transmigration settlement, the Department of Public Works will provide infrastructure (e.g. roads, canals and rice fields), and they will be followed by the Department of Transmigration Department that will construct houses and provide public facilities, while the last step is the planting of crops, the means for which are the province of the Department of Agriculture. By this system

many Government projects whose main purpose was to improve community welfare have ended mainly in failure. The failure of Government projects has also been caused by the lack of experience of Government officials and Government scientists to predict the impact of projects in the long term. In reality, the Government has always neglected local knowledge when establishing a new project. One example of the Government's mistaken interpretation of the success of local people in management of peatland (shallow peat) in Central Kalimantan was that they extended this "Handel" small-scale system to justify construction of the excessively large canals used in the Mega Rice Project. According to Limin (2005) the technologies to utilize peatland in Central Kalimantan have to be determined by trial and error, especially after the Government neglected the local knowledge which had successfully managed peatland in a limited area. The efforts of the Government to extend the area of rice fields based on "Handel system" then the "Anjir system", "Garpu and Sisir systems", "Kolam system", and eventually the giant canal system of the MRP was a mistaken interpretation of the success of the traditional way of growing rice in tidal areas ("Handel system").

GOVERNMENT POLICY AND PROBLEMS

The basis of Government policy in the case of peatland development should be a Presidential Decree which has comprehensive socio-economic and environmental considerations providing high benefits for human society and sustainability of environmental functions. Consequently, Government policy must be based on comprehensive research findings based upon detailed work carried out by professional researchers. In Indonesia, many scientists have carried out research not for science, but for family economic sufficiency. This behaviour of researchers arises because their salary incomes from their normal work are too low. Therefore many Indonesian researchers use research projects in order to obtain extra money and sacrifice research quality as a result. In addition to this unethical behaviour of researchers, the Government has also made severe mistakes in the interpretation of the results of research once they received them owing to a lack of deep understanding of the accuracy of the data obtained and the research procedures carried out. This situation prevails still because the Government and also the companies involved have never considered research results seriously. Sometimes Government Agencies provide funding for scientists, but the research results must be consistent with the requirements of the sponsors. In other words, the Government and sponsors have known the results even before any field research has been carried out by the researcher. Therefore, many research results have been only for collection and then placed in a cupboard where they are stored for posterity and never seen again.

In reality Government policy has always been erroneous on the feasibility of field conditions or carrying capacity of tropical peat but, if action is taken now, there may still be time to maintain the existing undamaged peat swamp forest and restore some of the peatland that has been damaged already. This will be very difficult to achieve because many Government staff have used their positions of authority to enrich themselves. Therefore, in the past and even now, Government policy was operated as a simple procedure, so that development programmes were never based on comprehensive considerations.

A general statement of considerable importance that is enshrined in a President Decree relates to peat thickness for agriculture and conservation. Presidential Decree No 32/1990 states that peatland less with less than 3 m of peat can be converted for agriculture while that with more than 3 m should be conserved. This regulation presents many problems for the environment, because it does not include other criterion related to the unique characteristics of tropical peat and peatland. For example, the Mega Rice Project was opened based on this decree. Planning of the MRP was carried out by an Indonesian Consultant who stated that all of the peat within the proposed area of the MRP was less than 3 m and was all shown by the same colour on the planning maps. Unfortunately, that report appears to have disappeared, perhaps destroyed, because this planning proposal contained manipulated data and misinformation.

Another source of error in Government policy has been caused by misinterpreting results of experiments carried out in the field over short periods of time and extrapolating these to determine impacts on very large areas over a long time. One example of this type of mistaken assessment of the carrying capacity of peatland converted to agriculture occurred when President Suharto visited Lamunti in the Mega Rice Project in 1998 to inaugurate the first rice harvest. Four months before the harvesting schedule, officials of the Provincial Government visited Lamunti area in order to supervise planning arrangements to ensure that some rice would grow, so that the President could harvest rice and be satisfied the project was a success.

Based on field observation, I have made two versions of field preparations for growing rice. Firstly, an experimental unit under natural condition and water supply using existing canal construction. Secondly, water supply provided by pump, so the water needed for rice can be supplied according to the phase of growth. After President Suharto visited Lamunti for his inaugural harvest it was reported in the press that the productivity of rice in the MRP is almost same as the national standard for non-peatland areas.

Following this apparent success of harvesting a large amount of rice in Lamunti it was reported that the President had not harvested rice that had been planted and grown there but the rice plants were brought from another area and replanted one or two days before the President arrived. The same was true for other crops that had been 'grown' at Lamunti, for example mature banana plants were standing alone without the presence of either young plants or new buds. This was not the first time that project implementers deceived high officials and politicians because the results of small-scale experiments have not provided a true insight into the consequences of large scale land development.

INDICATORS OF THE GOVERNMENT MISTAKES

Several indicators of Government mistakes in the utilization of peatland can be explained by the history of peatland development, local income and rice imports by the Indonesia Government.

History of peatland utilization

Traditional way

For centuries Dayak people in Central Kalimantan have employed two types of rice field (“ladang”) in peatland which were managed in traditional ways.

1. “Petak Luwau”, identical with “sawah tadah hujan” that was located in upstream areas with the following characteristics:
 - Peat thickness less than 50 cm with clay in the bottom
 - Located behind the river bank or between two hills
 - Cultivation without canal
 - Rice field blocked by a soil bank
 - Land preparation by slash and burn
 - Always saturated and generally flooded by river water.
 - Productivity 1.75 – 3.00 t/ha
 - Seedling transplanting after ~ 2 months in nursery
2. “Sawah Pasang Surut” in coastal areas with characteristics as follows:
 - Peat thickness less than 50 cm and clay in the bottom
 - Cultivation using small canal (“handel”)
 - Rice field blocked by bank with water gate
 - Land preparation slash and burn
 - Located behind river bank at a distance from the river of less than 1 km
 - Productivity 1.90 – 4.00 t/ha
 - Seedling transplanting after 2 months in nursery. (In the beginning, seedling need 3 times before transplanting, i.e.; teradak (30 – 45 days), lambak/ampak (25 – 35 days) and lacak (70 – 85 days)).
 - Always influenced by tidal movement of sea water (flooding) 1-2 times a day.

Canal technology for irrigation

The Government of Indonesia started to develop peatland for agriculture in upstream and coastal areas using a system of canals for water management.

1. Upstream area in “Petak Luwau”
 - Government constructed a canal in petak luwau. (e.g. In Goha and Tabak Kanilan villages)
 - Government opened inland peat e.g. Kalamangan (1980s), Transbangdep (1991s) and Bukit Rawi (2002).
2. Coastal area “Sawah Pasang Surut”
 - Handel system (traditional way)
 - Anjir (1920 by Dutch Government)
 - Polder system (1950 by Schophuys/Dutch expert)
 - “Garpu” (UGM)/ “Sisir” system (IPB and ITB) (1980s)
 - “Kolam” system (1980s)
 - Giant canal system (1996, Mega Rice Project)

The main purpose for establishing the MRP was to maintain Indonesia’s self-sufficiency in rice production that was achieved in the 1980s and which was lost in the 1990s when approximately one million hectares of rice fields in Java were converted to commercial, industrial and urban land uses. It was realized early in the

planning of the MRP that the initial concept of establishing rice estates in areas where it is possible for rice to grow successfully and without opening new areas of land was impossible.

In order to understand the problems confronting the MRP it is essential to realize the area of landscape involved and the dimensions of the canals constructed.

Total area: 1,457,100 ha.

- Block A: 227,100 ha (15, 59 %)
- Block B: 161,480 ha (11, 06 %)
- Block C: 568,635 ha (39, 03 %)
- Block D: 162,278 ha (11,14 %)
- Block E: 337,607 ha (23,17 %)

Total length of canals:

- First Primary Canal 183.1 km
- Secondary Primary Canal 620.5 km
- Support Primary Canal 241.1 km
- Tertiary Canal 964.0 km

Transmigration people

- In 1999/2000 about 15,600 families (60,000 persons) of transmigrated people were settled in 45 units
- 30,000 ha of rice planted by these people resulted in total failure because of a plague of rats.

The real condition of peatland cultivation in Central Kalimantan.

Upstream areas

“Petak Luwau “

- After canals were established, the status of the land changed from wet to dry land
- Rice production decreased. In Tabak Kanilan less than 50% of farmers are still growing rice owing to low production and in Goha village it has totally stopped

Inland peat or deep peat

- About 80% of land has become un-productive land (“lahan tidur”).
- Not economic, because high inputs are required (ash, lime, fertilizer, etc).
- The farmers disappeared e.g. Transbangdep, Bukit Rawi, etc.

Coastal areas “sawah pasang surut“

- Rice production decreased after excessively large canals were constructed.
- The status of land changed from wet to the dry, because the water cannot flood the surface any longer
- Rice fields have been replaced by other crops including, rubber, banana, coffee, jack fruit, zallaca palm, nephelium, pineapple and the weed grass alang-alang (*Imperata cylindrica*).

Farmers' welfare and income

Based on research results in a village near Palangka Raya city (~ 24 km distance), average family income is about Rp. 661,348 per month. This income is very low, however, because it has to cater for the living costs of 3-6 persons (Socio-economic activities of local communities at Mega Rice Project (MRP) area in Palangka Raya District, Central Kalimantan, (CIMTROP, 2003).

Regional Income per Capita Kalimantan Tengah Province

- The cost of living (prices) increased constantly from 1995 to 2000. During this period, the highest increase of 44,79% occurred in 1998. In 2000 the increase in regional income per capita was 13.81%.
- Regional income per capita based on constant price of 1993 in the period of 1996 to 2000 increased significantly. The highest increased was in 1996 of 11.85%. But in 1998 it decreased by 6.92% while in 2000 it increased again but by only 2.17%. (source: BPS-Statistics of Kalimantan Tengah Province, 2000)

Regional incomes per capita, based on prevailing prices and constant prices in Central Kalimantan from 1999 to 2004 are shown in Table 1. Although the income per capita in 2004 was around 7,176,364 (US \$ 717.64) this value differs from the real condition at the grass roots level. Based on the poverty limit in the same year of about Rp 128,382 in villages and Rp 148,964 in cities the total of poor people was about 12.20% in the villages and 6.13% in cities showing that poverty in Central Kalimantan is still high. Related to the income above, the population of poor people in Central Kalimantan and Indonesia is presented in Table 2.

Year	Regional income per capita based on prevailing price		Regional income per capita based on constant price 1993	
	Value (Rp)	Growth (%)	Value (Rp)	Growth (%)
1999	4,258,398	-	1,779,576	-
2000	4,650,803	9.21	1,725,533	-3.04
2001	5,146,481	10.66	1,739,919	0.83
2002	5,687,035	10.50	1,771,295	1.80
2003	6,386,932	12.31	1,819,485	2.72
2004	7,176,364	12.36	1,862,281	2.35

Source: Kalimantan Tengah in Figures (2004)

Table 1 Regional income per capita based on the prevailing price and constant price

Place	Poverty Limit (Rp/capita/month)		Total of poor people (thousand)		Percentage of poor people (%)	
	2003	2004	2003	2004	2003	2004
Central Kalimantan						
Villages	114,357	128,382	166.40	161.10	12.64	12.20
City	134,788	148,964	41.30	33.00	8.10	6.13
			207.70	194.10	11.37	10.44
Indonesia						
Villages	105,888	108,725	25,075.70	24,777.90	20.23	20.11
City	138,803	143,455	12,263.70	11,369.00	13.57	12.13
			37,339.40	36,146.90	17.42	16.66

Source; Statistik Indonesia, 2004. BPS Jakarta-Indonesia

Table 2 Population of poor people in Central Kalimantan and Indonesia.

Rice Imports

The high total rice imports by the Indonesian Government over the 11 years from 1994 to 2004 are proof of the country's unsuccessful management of its rice fields (Table 3). This situation is very contradictory when compared to the amount of land available and the number of farmers.

Year										
1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
* (million ton)						** (million ton)				
0.6330	1.8079	2.1498	2.5000	7.1000	5.000	1.3557	0.6447	1.8054	1.4285	0.2369

Source: * Noor, 2001 ** Statistik Indonesia, 2004. BPS Jakarta-Indonesia

Table 3. Total of rice imports by Indonesian Government

DISCUSSION

Based on the history of peatland utilization as explained above, the Indonesian Government has shown its weakness on the importance of research findings. The failure of transmigration project was used peatland have never considerable to open new area which have same characteristics or more less. In the other words, the opening of peatland for agriculture and placement of transmigration people has involved movement of poverty from one area to another. The contradiction between the livelihoods of transmigration people compared to that of the Government officials who manage these projects is very significant. On the one hand, the farmer are living in poverty while, on the other hand, the Government people are living in luxury. Limin (1999) stated that failure of peatland utilization in Central Kalimantan was caused by the Government because it never considered local knowledge, carrying capacity, culture and marketability. Consequently, peat utilization in Central Kalimantan has always been by trial and error.

Real evidence that the Government neglected local knowledge, carrying capacity and culture was shown by the opening of a new area of peatland for transmigrate after UPT Bereng Bengkel (Kalampangan) in Tahai (called Transbangdep), Bukit Rawi and other areas in coastal part of Central Kalimantan. If the Government's policy was good they would never open new areas of inland peat for agriculture. For example, if the Government was aware that extending the "handel system" on a large scale would lead to decreasing rice production they should not have implemented this policy. Decreasing in the rice production in coastal peat areas was evident from the return to their traditional homes of large numbers of Dayak people who had been persuaded to join transmigration programmes to develop rice fields in coastal areas. According to these farmers, decreasing rice production occurred after the Government constructed the over-size canals that led to drought and pollution of both land and water.

The main purpose of establishing these enormous canals was for water management on the rice fields where transmigrant people from outside of Kalimantan were to be settled. Relocation of people from Java, Bali and other Indonesian islands to Central Kalimantan through the transmigration project was carried out in order to increase their welfare through managing land for agriculture. But, in reality the management of land in transmigration settlement was not successful, so many of the transmigrants moved to other areas. They were unable to cultivate their land so they chose to seek

alternative jobs as labourers in towns and cities. The largest area of converted that has not been cultivated by the transmigrants is located in the interior, especially is very far from the major rivers. This area is unaffected by tidal sea water movement and therefore because the volume of water available is always draining away along the large canals it is impossible to irrigate the farmers rice fields. Therefore most of the land located far from the rivers has becoming unproductive (called “lahan tidur”). Limin et al. (2003) and Limin (2005) stated that because of Government policy in these large scale areas, many centres of rice production have lost their status as ‘rice barns’. Based on real facts obtained in the field, the traditional way before developed by over dimension canal system, Basarang, Palingkau, Tamban, Mintin, Pembuang and Tabak Kanilan. Changes to the status of these areas have never been considered by the government before extending development to open new areas, so that the mistakes always accumulated year by year.

Almost all of the transmigration projects on peatland have been unsuccessful and are now becoming a heavy responsibility for the local government, a potential threat to the environment and a cause of friction between native and transmigrant people.

Levels of community welfare are indicated by food materials. In block A sub block A2 ex. MRP, transmigration people must be satisfied to eat cassava, because they cannot grow rice and do not have money to buy rice. Based on CIMTROP research (2003) the level of average income in the community at the Kameloh Baru village and Bereng Bengkel village which are located near to Palangka Raya city is Rp 661,348/month/family (Rp 7,936,176/year/family) (about US\$ 73,48/month/family) and indicates the difficulties of community economics. This income has decreased compared to the year before because the natural ecosystem changed after the MRP was established. The income rate of communities as listed in table, showed that the increase of income year by year was not significant, and many of these communities have an income lower than Kameloh Baru and Bereng Bengkel.

The number of people living in poverty has not decreased significantly almost 30% of people living below the poverty level reside in cities. Factual data on the lack of success of rice cultivation in Indonesia is indicated by the amount of rice imported from other countries. The total of rice imports is in contradiction with the Indonesian population of which about 80% are farmers or live in villages. This situation occurred because farmland which was fertile and productive became unfertile and unproductive because the ecosystem surrounding the farmland was changed. In other words, the extension of rice fields through the transmigration projects has caused existing of farmland to become un-productive or to have lower yields making them uneconomic. The opening of large areas for rice fields without considering the ecosystem surrounding them results in unsatisfactory yields and even crop failures.

Unsuccessful utilization of peatland for agriculture has been showed through the ill-fated MRP. The main purpose to provide a major centre for rice production has, in fact, become as a major centre for fire and the production of thick smoke and dense haze every year. The MRP area is now sensitive to fire because the surface peat becomes very dry during the dry season because the water table falls to very low levels. Limin et al. (2003) explained that changing the hydrological status of peatland in the MRP was caused by the over dimension of the canals constructed there and since these were connected to the big rivers, so the water will flow from the land system to the river.

According to Limin (2000), fire will occur in peatland wherever there is human access e.g. road, canal, river, lake, plantation, settlement, and illegal activity in the forest. This is confirmed by satellite imagery that shows the majority of fire hotspots occur around or near to routes of human access.

Finally, because of the mistaken planning of the MRP it is now extremely difficult to restore, repair and/or redesign this vast peatland area because all of the environmental components that need to be made functional again require a new approach based upon new information obtained in the field.

CONCLUSIONS AND SUGGESTIONS

The utilization of peatland for agriculture, although still may provide economic value, always has negative impacts on the environment which are related to socio-economic problems in the long-term that are always bigger than the economic value in the short-term.

The peatland areas (including ex MRP) which were designed for agriculture and/or transmigration, should be re-designed before implementing other projects, through comprehensive and extensive research.

The Government must stop sending new transmigrants to Central Kalimantan because it is better to use the money to improve the livelihood of existing transmigrants, including re-locating them from un-feasible to feasible areas.

The peat swamp forest area should be maintained for producing timber on a sustainable basis, so that the ecosystem will be capable of supporting the community activities in its surroundings. It is better if the peat swamp forest should be the lung of Indonesia.

The opening of peat swamp forest for food crops and plantation have a need high cost and will initiate new problems for the future.

The government should consider how to improve the salaries of Government employees in order to stop corruption, but this must be accompanied by increased professionalism of the staff.

REFERENCES

- BPS. (2004) Kalimantan Tengah in Figures. Statistics of Kalimantan Tengah Province.
- BPS. (2004) Statistik Indonesia. Jakarta. Indonesia.
- Limin, S. H. (1998) Residual Effect of Lime, Phosphate and Manure on Crops Commodities in Inland Peat. The University of Palangka Raya.
- Limin, S. H. (1999) Pengalaman dan Persepsi di Daerah Tentang Pengembangan Masyarakat (Suatu Tinjauan di Kalimantan Tengah). Makalah Seminar Nasional Dampak Sosial dan Pengembangan Masyarakat Dalam Rangka Peresmian Ikatan Profesional Lingkungan Hidup Indonesia. (IPLHI) Jakarta, 28 April 1999.
- Limin, S. H., Tampung N. Saman., Patricia, E. Putier, Gunung Daun, and Layuniyati. (2000) Konsep Pemanfaatan Hutan Rawa Gambut di Kalimantan Tengah. Disampaikan pada "Seminar Nasional Pengelolaan Hutan Rawa Gambut dan ekspose hasil Penelitian di Lahan Basah", diselenggarakan oleh Balai Teknologi Reboisasi Banjarbaru, Istana Barito Banjarmasin-Kalimantan Selatan, 9 Maret 2000.

- Limin, S. H. (2000) Sistem Pengelolaan Lahan Gambut Berkelanjutan untuk Kesejahteraan Masyarakat. Disampaikan Pada Temu Karya Nasional PPKAN ke-40, Palangka Raya, 24 Oktober 2000.
- Limin, S. H, Layuniyati and Yahya M. Jamal. (2000) Utilization of Inland Peat for Food Crop Commodity Development Requires High Input and Is Detrimental to Peat Swamp Forest Ecosystem. Proceedings of The International Symposium on Tropical Peatland Management. Ciloto-Bogor, 22nd-23rd November 1999.
- Limin, S. H., A. Jaya, S. Dohong and Y. Jagau. (2003) Some Important Considerations on The Restoration of The Ex-Mega Rice Project in Central Kalimantan. Presented in the Meeting on the Integrated Plan on the Restoration of the Ex-Mega Rice Project, BAPPENAS, Jakarta, 8th-10th September 2003.
- Limin, S. H. (2005) History of Peatland Management In Central Kalimantan. Presented in Eco-Human Interaction in Tropical Forests Symposium. Kyoto, JAPAN 13rd – 14th June 2005.
- Noor, M. (2001) Pertanian Lahan Gambut. Potensi dan Kendala. Kanisius, Yogyakarta.

RESTORATION, REHABILITATION AND SUSTAINABLE LIVELIHOODS: THE IMPORTANCE OF ALTERNATIVE INCOMES FOR TROPICAL PEATLAND-DEPENDENT COMMUNITIES.

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SUMMARY

The restoration of tropical peatlands is unlikely to succeed without strong support from and engagement with local communities. In the absence of alternative income earning opportunities, populations whose livelihoods currently depend on the exploitation of peatlands may destroy restoration efforts that they perceive not to be in their interest. Focusing on agriculture and community-based forest management in Indonesia, this paper will examine a range of strategies for promoting alternative livelihoods that have potential for meeting local needs as well as wider tropical peatland restoration and ‘wise use’ goals.

Key words: tropical peatland, restoration, communities, forests.

INTRODUCTION

This paper argues that for restoration measures to succeed on tropical peatlands, they must be conducted in collaboration with local communities. This is because communities who currently depend upon peatlands for meeting their livelihood needs may destroy restoration efforts that they perceive not to be in their interests. Examples of how they may do this include illegal forest felling, the use of fire to promote agriculture in degraded forests, or the destruction of dams designed to slow peatland drainage. Significant and appropriate incentives are therefore needed to persuade local communities to substitute peat degradation-based income earning strategies with alternative livelihood opportunities that have limited impacts on tropical peat ecology and hydrology.

SUSTAINABLE AGRICULTURE ON TROPICAL PEAT?

Agriculture is difficult on tropical peat owing to the nutrient deficient and highly acidic nature of the soils. But as many people already live (or have been settled) on peatlands, it makes sense to use ‘wise use’ principles to minimize the impacts of peatland agriculture and raise its economic value to help prevent ‘the misuse of these areas by burning caused by careless use of fire’ (Silpola: 2007: 4). In this regard, district-based land zoning approaches would be valuable for identifying areas where cultivation is most likely to succeed and least likely to cause further environmental damage (Rieley and Page, 2005). Using existing data on landuse, vegetation, drainage status, peat thickness, substrate type, water table depth, available infrastructure, flooding regimes and so on appropriate cropping systems could be identified for discussion and participatory experimentation with farmers who have difficulty

cultivating peatland soil. Depending on subsistence needs and the proximity of local markets for cash crops, examples could include rice on peat less than 1 m thick; maize, soybean, groundnut, cassava, rambutan, oil palm or coffee on 1-1.5 m thick peat and perennial crops such as coconut or pineapple on 1-2 m thick peat (Rieley and Page, 2005).

COMMUNITY-BASED FOREST MANAGEMENT (CBFM).

Given the Indonesian government's current emphases on both social forestry and the need to rehabilitate state forests (Nawir *et al*, 2007), it is a good time to investigate the potential of CBFM to address the twin goals of tropical peatland restoration and alternative income generation for peatland-dependent communities.

Opportunities for CBFM in Indonesia

According to an international study by Angelsen and Wunder (2003) three main types of CBFM have significant potential for poverty alleviation. The first involves increased local control over and formalized benefits from natural (often state) forests and can have important benefits to local communities so long as tenure is secure and benefit-sharing arrangements are clearly understood (Kerr *et al*, 2006: Nawir *et al*, 2007). Formal rights to collect specified types of non-timber forest products (NTFPs), fuel wood and timber from local forests can be an important incentive to participate in CBFM while incomes from tending tree nurseries, clearing land and planting trees are also popular with many local communities. In areas with a high level of dependence on fuel wood for cooking, CBFM schemes could investigate opportunities for providing alternative household energy sources such as small biogas plants fed by kitchen waste and/or animal manure.

As around 2.5 million ha of Indonesia's peat swamp forest is situated within National Parks, Game Resource Areas and Nature Reserves, the development of ecotourism could be a possible income-earning strategy for local communities. A community-based forest rehabilitation scheme in Meru Betiri National Park, for example, was very successful in reforesting degraded areas, improving forest ecological functions and raising local incomes (Nawir *et al*, 2007). Similar participatory initiatives involving replanting and rehabilitation activities (such as blocking drainage canals), the construction of ecotourism facilities (such as tree walks or wildlife viewing stations) and the processing and sale of NTFPs could be pursued if funding could be secured.

The second initiative involves smallholder tree growing projects on private or community land and may be appropriate on the degraded peat of the ex-Mega Rice Project where there is an urgent need to increase land productivity and reduce the risk of fire. Possible avenues to explore with local communities include the socio-economic and ecological suitability of perennial crops such as rambutan, coffee, coconut, aloe vera and pineapple that tolerate peat soils and high water tables thus promoting restoration. Peat-friendly agribusiness involving peat tolerant crops that can easily be processed and marketed by local people also offer opportunities for income diversification. Promising examples include *nilam* (*Pogostemon sp.*) for perfume oil production, *kumis kucing* (*Orthosiphon sp.*) for medicinal use, tomatoes for ketchup and *bungamasalan* flowers; some of which have markets well beyond the production area. Oil palm may also be a suitable option for revegetating degraded peat and helping to protect it from fire and carbon loss (Limin *et al*, 2003).

The third initiative involves income generation from small-scale, wood-based enterprises and could be important for communities living on degraded peat or undertaking CBFM in peat swamp forests. Tree species that grow well on peat and can easily be processed by local communities include rubber (*Hevea brasiliensis*) and *Acacia mangium*, although a mixture of indigenous and exotic species with different growth rates are good for meeting future demand for ‘hard wood chips, sawn timber, veneers, medium-density board and oriented-strand boards’ (Rieley and Page, 2005: 86). Assistance from the state in the form of soft loans to provide start-up capital plus training and extension to deliver business skills and knowledge of market networks is very important in helping local communities to set such enterprises up.

Limitations of CBFM in Indonesia

Although CBFM coupled with agribusiness and small-scale forest-based enterprises would appear to offer some promising restoration opportunities, certain limitations must be considered. Firstly, there are limits to the degree of poverty alleviation that can be provided from CBFM without some degree of commercial forestry, so ecological/livelihood trade-offs may have to be made. Secondly, it is important not to over-romanticize the desire or ability of local communities to be involved in CBFM (Jewitt, 2002) as they may be far more interested in logging forests or converting them for agricultural purposes than in rehabilitating them. The following sections will offer some practical suggestions to overcome these limitations and make the most of CBFM as a means of promoting tropical peatland restoration.

Important criteria for successful CBFM in Indonesia.

As for sustainable agriculture on peatland, one of the foremost suggestions for successful CBFM would be to use district based land zoning approaches to target the most suitable areas. Initiatives are already afoot to coordinate Indonesia’s Master Plan for Forest and Land Rehabilitation with a view to synergizing forest and land-use management planning (Nawir *et al*, 2007). Master plan data could be combined with data on causes of deforestation, peat thickness, substrate type, water table depth, existing drainage canals, population density and socio-economic data on neighbouring communities to identify the most suitable areas and communities for CBFM and reforestation of degraded private/community land. When identifying peatland restoration strategies, it is also important to consider factors such as the socio-cultural and subsistence-related importance of forests to local people and their history of (or interest in) community-forest management (Jewitt, 2002). In isolated areas where population density is low, CBFM plus natural regeneration could be a suitable option while in more densely populated areas with accessible markets, a more integrated strategy focusing on the development of agribusiness or forest produce-based enterprises might be more appropriate (Nawir *et al*, 2007).

Once promising communities are identified, it is important to conduct an intensive period of participatory appraisal to investigate local people’s livelihood portfolios, chart existing peatland uses and determine existing land/forest ownership and access rights. It is also important to explore the underlying causes of peatland deforestation/degradation as these are likely to act as continuing disturbances if unaddressed. Wealth ranking can be carried out to establish intra-community wealth variations and identify marginal and/or vulnerable groups whose preoccupation with daily subsistence and lack of time and money might prevent them from being involved in restoration projects. Discussions can then focus on how to tailor projects to minimize harm and maximize benefits to such groups, thus reducing the danger of

exacerbating their marginal status. As a common feature of CBFM is for men to dominate decision-making while women are either excluded from, or feel socially restricted from attending CBFM meetings (Jewitt, 2002), gender analysis techniques are useful for identifying gender divisions of labour and variations in natural resource access, use and management.

Participatory mapping techniques are helpful for identifying different land uses, highlighting the role of different peat ecosystems in supplying local subsistence and cash requirements and pinpointing problem areas (waterlogged, drought prone, high fire risk, pyretic substrate, etc). Similar methods can also be used to produce rehabilitation and/or landuse planning maps based on community consensus regarding areas to be reforested, suitable species to be planted and so on while matrix ranking can be a useful tool to establish tree species and agricultural crop preferences for different stakeholder and gender groups. A local organization or NGO can be extremely valuable for helping to empower the community's institutional and technical capacities to support the rehabilitation programme and facilitate multi-stakeholder analyses at various stages of the program.

A detailed analysis of intra-community livelihood priorities can be very important for identifying appropriate income-generating strategies and restoration activities as program incentives must be closely linked to local requirements. Clear economic incentives are needed to stimulate a high level of community participation (Nawir *et al*, 2007), so participatory financial analyses conducted prior to the start of the project with different socio-economic groups are helpful for designing suitable incentives for long term participation. The most common economic incentive associated with CBFM is income from employment associated with tree planting and land preparation which can be expanded by making longer-term payments for tree maintenance (based on survival rates). Where benefit sharing mechanisms are to be used, a range of different possibilities should be discussed with all stakeholders to ensure appropriateness, transparency, equity and fairness. The most widespread mechanism is for communities to receive a pre-agreed share of the value of any timber trees that they plant and protect but, as this forces participating communities to calculate and act over extended temporal horizons, projects should also offer a range of income and asset generating activities that produce a quick return. Examples could include training and support for small-scale food processing activities, the marketing of herbal medicines, goat and poultry breeding or the provision of small-scale biogas plants.

FUNDING MECHANISMS FOR PEATLAND RESTORATION

To achieve the twin goals of tropical peatland restoration and alternative income generation, additional funding sources are needed to supplement what is available from existing government forest rehabilitation budgets. Payment for ecological services (PES) and carbon credit schemes have a lot of potential in this regard but are largely still untested.

Payment for Ecological Services (PES)

PES initiatives offer important opportunities to compensate local communities for providing environmental services such as carbon sequestration/storage, biodiversity conservation and watershed protection (Wunder, 2005) and are particularly relevant for tropical peatlands which act as important global carbon stores as well as having

important drainage and water control functions. PES is based on direct, conditional payments to local land users for ‘adopting practices that secure ecosystem conservation and restoration’ (Nawir *et al*, 2007: 193) and can reduce rural poverty by offering additional incomes to communities willing to be involved in forest/watershed protection. Community-based peatland restoration lends itself well to PES payments if suitable ‘buyers’ can be found. Where this proves difficult, initiatives that reward people for environmental services (RES) may be an alternative means of linking benefits such as enhanced tenure security to resource protection and landuse agreements (Kerr *et al*, 2006).

Carbon credit funding for peatland restoration

‘Avoided deforestation’ (AD) schemes in the voluntary carbon markets sector and new ‘Reducing Emissions from Deforestation and Forest Degradation’ (REDD) initiatives offer significant incentives for protecting carbon stocks in natural forests and may have important pro-poor benefits if suitably targeted. Tropical peat is a good candidate for REDD in terms of preventing further emissions from drainage and fire.

Biorights

Another source of funding that could be tailored more specifically to the restoration of tropical peatlands and the provision of alternative livelihoods for their residents is the ‘biorights’ approach established by Wetlands International (WI). This involves the ‘establishment of business contracts, providing micro-credit for sustainable development, in exchange for the conservation or rehabilitation of globally important biodiversity or environmental values’ (Silvius and Diemont, 2007: 35). Biorights schemes implemented by WI are currently operating in the buffer zones of the Berbak National Park in Sumatra. The scheme also has potential to pay local communities to build dams and block logging canals (to preserve peatland hydrology and biodiversity) and be involved in community-based fire prevention (Limin, *et al* 2003).

CONCLUSION

For global concerns regarding carbon emissions to result in sustained action on the ground by resource poor communities whose priorities reflect daily subsistence needs, significant economic incentives are needed. Mechanisms such as PES, REDD and biorights offer important opportunities but for these to make headway in terms of either tropical peatland restoration or the provision of alternative local livelihoods, they have to be highly flexible and responsive to local needs. At present, there is much uncertainty about the willingness of buyers to invest in community-based peatland restoration and the degree to which poor people can take advantage of these emerging markets. Unless these issues can be resolved, the future is likely to be very problematic for tropical peatlands.

REFERENCES

- Angelsen, A. and Wunder, S. (2003). Exploring the forest - poverty link: Key concepts, issues and research implications. CIFOR Occasional Paper No. 40. Bogor, Indonesia.
- Jewitt, S. (2002). *Environment, Knowledge and Gender: Local Development in India's Jharkhand*. Aldershot: Ashgate.

- Kerr J., Pender, J. and Suyanto. (2006). Property Rights and Environmental Services in Lampung Province, Indonesia. Paper presented at the 11th Conference of the International Association for the Study of Common Property, Bali, Indonesia, June 19-23, 2006
- Limin, S., Nasir, D., Jaya, A., Setiadi, B., Rieley, J., Page, S., Husson, S., Radjagukguk, B., Diemont, H., Verhagen, J., Ritzema, H., Takahashi, H., Silvius, M. (2003). Financial Mechanisms for Poverty-Environment Issues - The Case of Central Kalimantan (II). Wageningen: Alterra/Wetlands International.
- Nawir, A. Murniati, and Rumboko, L. (2007). Forest rehabilitation in Indonesia: where to after three decades? Bogor, Indonesia: Center for International Forestry Research (CIFOR).
- Rieley, J.O. and Page, S.E. (eds). (2005) *Wise Use of Tropical Peatlands: Focus on Southeast Asia*. Wageningen: ALTERRA...
- Silpola, J. (2007). Tropical Peatlands Need Rapid Actions. *Peatlands International* 2/2007, 4.
- Silvius, M. and Diemont, H. (2007). Deforestation and Degradation of Peatlands. *Peatlands International*, 2/2007 32-34.
- Wunder, S. (2005) Payments for environmental services: Some nuts and bolts. CIFOR Infobrief, 9 May 2005. Bogor: CIFOR www.cifor.cgiar.org

SOCIO-ECONOMIC LINKAGES OF RURAL POVERTY AND FOREST FIRE PHENOMENA IN A DEVELOPMENT SCENARIO OF PEATLAND REHABILITATION AND AGRIBUSINESS REVITALITATION IN CENTRAL KALIMANTAN

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SUMMARY

In an isolated peatland forest agro-ecosystem characterized by a relatively closed socio-economic set-up, rural poverty and forest fire incidents tend to be closely interrelated and mutually influencing factors. From the standpoint of poverty, unfavourable economic conditions associated with insufficient family income encourage more people to get involved in extensive illegal logging, which could eventually destroy various ecological functions and make the peatland ecosystem more vulnerable and prone to fire. It can be shown that the marginal productivity value of labour (MPV) dedicated to intensive farming in such peatland agro-ecosystems is certainly smaller than the comparable MPV of labour for illegal logging. On the other hand, extensive peatland and forest fires, once they spread over the ecosystem, bring negative impacts to people and their farming plots including increased incidence of drought and flooding on agricultural land. In a traditional and labour intensive farming activity, two changes can be measured, namely: (1) agricultural labour productivity ($t\ ha^{-1}\ yr^{-1}$) appears to decreased over time, even taking into account women's and children's labour contributions; (2) additional family labour (e.g. from grandparents, wives and children) measured in terms of man-working-days (MWD) has to be devoted to deal with forest fire-related activities at particular times (notably during and after fire/flooding events), which takes effort away from dealing with more important poverty-related problems. Consequently there is an urgent need to investigate socio-economic responses to agricultural or non-agricultural based programmes on poverty eradication. In addition, forest fire management must be designed carefully to match the household labour availability. The action plan (for restoration and rehabilitation of the former Mega Rice Project) should therefore take into consideration: (1) periodic distribution of family labour availability during 'normal' and 'below-normal' scenarios; (2) the extent of increased income and gendered labour productivity expected to result from a particular remedial programme.

Keywords: social forestry, peatland ecosystem, family labour, rural poverty.

INTRODUCTION

Agro-forestry agribusiness frameworks have received a lot of attention lately, not least at the UNFCCC meeting in Bali, December 7-15th 2008. The crucial issue is how to get smallholders involved in environmental protection under the CDM (clean development mechanism) and REDD (Reducing Emissions from Deforestation in Developing-countries) carbon trading mechanisms (Cacho, 2007; Murdiyarto, 2007)

to minimize sources of global warming. This paper discusses possible frameworks to enable smallholders to become active in forest resource management schemes, for example under the SFMU (social forestry management unit) concept of social forestry, as a means of addressing rural poverty and reducing social conflict (Sjarkowi, 2007).

The technical and social targets of forestry-based carbon trading are certainly not easy to accomplish, and for a less-developed country (LDC, such as Indonesia) there are five main constraints to smallholder engagement in such mechanisms, namely: (1) Lack of medium-term credit; (2) Lack of silvicultural skill; (3) Lack of tenurial security; (4) Lack of commercial economies of scale, and; (5) Lack of institutional capacity (Taylor, 2007). In terms of applying carbon-credit schemes to peatland agroecosystems, additional difficulties include: (6) Lack of knowledge of peatland agroecosystem instability; and (7) Lack of rural infrastructure (Sjarkowi, 2006; 2007).

RURAL POVERTY and FOREST FIRE: SOCIO-ECOLOGICAL CONTEXT

It has been widely argued that forestry based-CDM, and REDD in particular, is a golden opportunity for Indonesia to kill two birds with one stone regarding issues of rural poverty and forest fire. However, some western countries and also Walhi (a leading environmental NGO in Indonesia) are still unconvinced about whether or not carbon trading could be an effective means for LDCs to contribute to the global war on greenhouse gas emissions. Therefore, in order to have a realistic and saleable transaction scheme, REDD-oriented agroforestry must be subjected to sound scientific analysis prior to its implementation. The main constraints associated with carbon trading from an LDC perspective relate mainly to issues of forest and social engineering. The first 5 constraints mentioned relate mainly to the social engineering domain while the last two constraints belong to the peatland forest engineering domain. Both social engineering and forest engineering must be undertaken thoughtfully to allow the anticipation of possible problems including: (1) The risk of commitment betrayed when the income stream from carbon trading is not technologically predictable or poorly estimated. This could result in the conversion of the planted forest into rubber or palm oil; (2) As tree crop life cycles are very different from those of agricultural crops, non-tree (food) crops must be treated as supporting crops to a tree crop farming system. This could complicate associated institutional arrangements followed eventually by institutional failure.

PRODUCTIVITY and EFICIENCY: PEATLAND AGRO-FORESTRY

On a hemic and sapric peat-soil, various agricultural crops could grow productively as long as suitable and appropriate water management is practiced (ALTERRA, 2005). Empirical data show, however, that income earning from cropland is rarely sufficient to support constantly increasing family needs and spending (Marwan and Sjarkowi, 2007). There are three reasons behind this (Sjarkowi, 2006): (1) Low agricultural productivity that tends to be irresponsive to the current state of the art of peatland agronomy; (2) Unstable agricultural commodity prices that are irresponsive to markets with limited demand from small regional populations and agro-industries; (3) Poor transportation infrastructure for generating smallholders incomes but irresponsive to transactional price changes. This agro-economic condition may make REDD-oriented agro-forestry very attractive for many people. It will eventually

become apparent that: (1) Seasonal mixed farming could minimize risk and increase sources of income; (2) Seasonal and annual cropping including tree crop farming could isolate any boomerang effects from land expansion associated with more forest conversion.

As a marginal ecosystem Jauhiainen (2004) argued that in their natural state, peatland ecosystems are characterized by interconnections between 4 main factors, namely: (1) Hydrological factors; (2) Flora and fauna; (3) Peat characteristics, and; (4) C-peat deposit. Peat hydrology becomes damaged by the opening-up of peat dome vegetation, which in turn increases peat decomposition and C loss on the peat dome as well as peat subsidence. All of these factors, coupled with the micro-climatic changes that they bring, cause an increase in peat fire incidence. Therefore, as Dana Veltman (2006) concluded in her thesis (based on her research in Sarawak) peatland reclamation for agricultural purposes is technically possible, but must be carried out with extreme care. She implied that any kind of agricultural activity on peatland should not be for agricultural production *per se*; but rather, for the multiple purposes of producing food and non food products in order to support tree planting. This is because the increased forest cover associated with such activities is likely to promote ecosystem recovery. With regard to forest engineering on degraded peatland ecosystems in Central Kalimantan, there are three operational assumptions that need to be taken into consideration:

- (1) Agricultural activities for food production and forest replanting should concentrate on shallow peat found at the rim of peatland landscapes. A combination of silvicultural and agronomic treatments must seek to both maximize benefits from the chosen crop mixtures and consider the need to improve soil structure, ecosystem and function.
- (2) In a landscape with peat dome damage, the SFMU model requires the revegetation of the peat dome simply by focusing on plants that grow naturally in such environments. In addition to *Shorea balangiran*, an endemic species called *Tumeh (Combretocarpus rotundatus)* grows well in Central Kalimantan's peatland ecosystems.
- (3) The use of tree crops to revegetate peat domes must be carried out in stages, starting at the margins and gradually working in toward the centre of the dome. As a means of alleviating poverty, tree crop farming can be partially substituted by rubber crop (*Hevea brasiliensis*) planting. In this case a financial scheme called Bio-credit can be applied.

GENDERED LOCAL LIVELIHOODS AND REDD-ORIENTED AGROFORESTRY

Today the lives of local people living within and around peatland ecosystems is constantly being threatened by regional development demands that seek to utilize these ecosystems more profitably. To unorganized smallholders living in rural areas with limited market accessibility and a lack of innovative agribusiness, the remaining (peatland) forest is often considered as a source of land for the next generation to farm. If that occurs, however, then there is a strong likelihood of conflict amongst stakeholders over access to forests (natural or planted) for conversion to agriculture. In such a situation people are likely to work on the principle of 'first come, first served' with the result illegal logging and slash and burn agriculture (including "paddy sonor" farming) would be considered as justifiable livelihood opportunities. It is precisely this scenario that REDD-oriented agroforestry has the potential to prevent.

An agroforestry concept called SFMU (social forestry management unit) was introduced (Sjarkowi, 2006, 2007) following detailed socio-economic research in Central Kalimantan and South Sumatra. This research (annex Table 1) highlighted the fact that the role of female labour in cash-crop farming (that may potentially support catch crop and tree crop farming) is very important. Likewise, from a simple econometric analysis using cross-sectional data, the tendency of male family labour to favour illegal logging over agriculture, was also apparent.

CONCLUSION

This paper makes three concluding points:

(1) The vicious cycle of rural poverty and forest fire which is commonly found in degraded peatland ecosystems could potentially be overcome using REDD-oriented agro-forestry. Food crop and catch crop farming is needed to provide socio-economic support to tree crop farming designed for both income generation and peatland restoration purposes;

(2) Socio-economic approaches are crucial as a means of encouraging local institutions to revitalize peatland ecosystems for the purposes of sustaining various traditional but sustainable livelihoods whilst at the same time improving agro-ecological conditions for the benefit of non-tree crop farming;

(3) As a peatland based agribusiness designed for both socio-economic and socio-ecological purposes, smallholder agro-forestry systems could only be developed effectively when small-scale market-based agro-industry can provide added value that will simultaneously help to guarantee fairer and more stable product prices.

REFERENCES

- Cacho, 2007; Economic Potential of Land-use Change and Forestry for Carbon Sequestration and Poverty Reduction. As quoted by Taylor, Robin "Farm Forests Seen as Commercial Carbon Sinks"; in Partners (www.aciar.gov.au) Nov.2007; a special coverage on climate change.
- ALTERRA, 2005. Wise Use of Tropical Peatlands: Focus on Southeast Asia. Editors: J.O. Rieley and S.E. Page. ISBN: 90327 0347 1.
- Jauhiainen, 2004. Scientific approach to canal blocking and monitoring at Kalamangan. Paper presentation at International Symposium on Peatland Development. Pontianak West Kalimantan, 14-16 April 2004.
- Marwan and Sjarkowi, 2007. Tingkat Harga Pokok Pertanaman Sela dan Pengambilan Keputusan Hedonistik pada Agribisnis Tanaman Kayu; Kasus lahan gambut Kalimantan Tengah dan lahan kering Sumatra Selatan.). Jurnal SUPK (Satuan Usaha Perhutanan Kerakyatan). Edisi Khusus Agustus, 2007. Jaringan Komunikasi PASAKBUMI. Palembang, Indonesia.
- Murdiyarso, 2007 Three concrete steps borne out of the Kyoto Protocol. As quoted by Trihusono, Putut "The Nusa Dua Mandate", in GATRA December 2007; a special edition on Bali Mandate 'Save the earth'. Jakarta
- Sjarkowi, 2006 Is Poverty Eradication Possible in Peatland Areas of Central Kalimantan? Paper presentation at International Symposium on Peatland Development. Palangkaraya. Central Kalimantan, 22-23 September 2005. Proceedings, 2006.

- Sjarkowi, 2007; conceptual framework towards social forestry management unit (SFMU). *Jurnal SUPK (Satuan Usaha Perhutanan Kerakyatan)*. Edisi Khusus Agustus, 2007. Jaringan Komunikasi PASAKBUMI. Palembang, Indonesia.
- Veltman, 2006; Visualisation of Land-use Scenarios on Tropical Peatland in Central Sarawak, Malaysia: Towards a Decision Support System on Strategies of Sustainable Water Management. Thesis submitted to Larenstein University of Professional Education. Velp. The Netherlands.

ATTACHMENT

Source of livelihood	Marginal Productivity Value		Main Period of Activity
	2000	2008	
Illegal Logging	Rp1.2 million mo ⁻¹	Rp400.000 mo ⁻¹	Wet season
Agriculture	Rp350.000 mo ⁻¹	Rp350.000 mo ⁻¹	Dry season

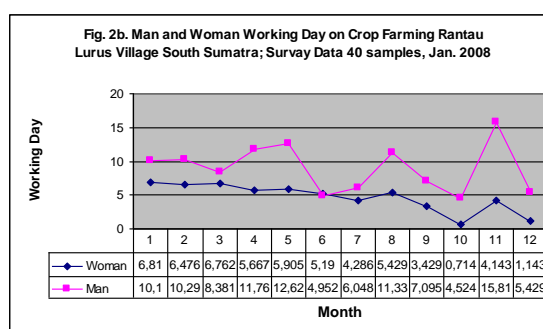
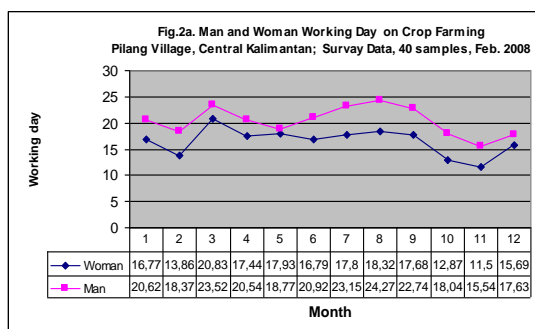
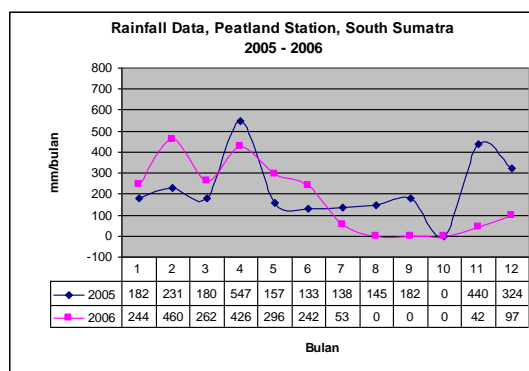
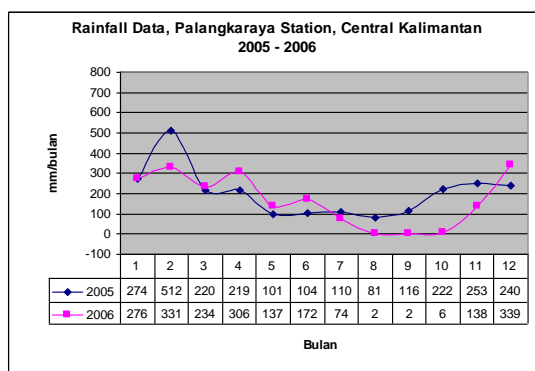


Figure 1 Rainfall Data, Palangka Raya Central-Kalimantan (left), and Peatland Region South Sumatra (right).

No.	Crops	Man Working Days (MWD) equivalent					
		Including harvest and marketing			Excluding harvest and marketing		
		Man	Woman	Total	Man	Woman	Total
1.	Mustard (0,70 Ha in total main plot)	14,9	11,65	26,25	11,3	9	20,3
2.	1 st cycle (wet season)	14,9	11,65	26,25	11,3	9	20,3
3.	2 nd cycle (wet season)	18,9	13,15	32,05	15,3	10	25,3
4.	1 st cycle (dry season)	18,9	13,15	32,05	15,3	10	25,3
	2 nd cycle (dry season)						
1.	Mustard (0,45 Ha in total of main plot)	15,8	12,65	28,45	12,1	10,1	22,2
2.	1 st cycle (wet season)	15,8	12,65	28,45	12,1	10,1	22,2
3.	2 nd cycle (wet season)	20,3	14,15	34,45	16,6	11,1	27,7
1.	1 st cycle (dry season)	7,6	5,9	13,5	5,3	4,2	9,5
2.	Sawi (0,18 Ha in total of home yard)	7,6	5,9	13,5	5,3	4,2	9,5
1.	1 st cycle (wet season)	7,8	6,2	14,0	5,8	4,6	10,4
2.	2 nd cycle (wet season)	7,8	6,2	14,0	5,8	4,6	10,4
	Corn (0,22 Ha in total of home yard)						
	1 st cycle (wet season)						
	2 nd cycle (wet season)						
	Total	150,3	113,25	263,55	116,2	87,9	204,1
	Percentage (P-W)	(57,04)	(42,96)	(100)	(56,93)	(43,07)	(100)

Table 1 Labor Input for Mustard and Corn Farming, in Kalampangan Central Kalimantan Based on 40 Sampled Smallholders, 2006/2007.

SOME REQUIREMENTS FOR RESTORATION OF PEATLAND IN THE FORMER MEGA RICE PROJECT IN CENTRAL KALIMANTAN, INDONESIA: BLOCKING CHANNELS, INCREASING LIVELIHOODS AND CONTROLLING FIRES

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SUMMARY

Restoration of tropical peatland is not just a matter of rewetting the surface by blocking channels but also requires involvement of stakeholders in order to increase their livelihoods and to control fire. Water management to restore degraded tropical peatland is in the early stages of understanding and implementation while local people must be involved by providing them with alternative sources of income to exploitation of peat swamp forest resources and also to encourage them to become custodians of the recovering landscape through empowerment to control fire. The results of pilot projects to raise water table levels in degraded tropical peat, plant 'living trees' to increase incomes of local people and establish fire control and fighting teams consisting of local inhabitants are presented and their effectiveness discussed as models to be applied over larger areas of tropical peatland.

INTRODUCTION

The change of climate in the world that has been confirmed by many kinds of disaster in many countries is a consequence of the over exploitation of natural resources. One of these natural disasters is the big contribution to the green house effect by release of CO₂ and other gases to the atmosphere as a consequence of degradation of tropical peatland. Peatland can be damaged by fire, cultivation for agriculture, digging drainage channels, legal and illegal logging by companies and communities. Over exploitation of peatland has also been caused by inappropriate development programmes that have not taken into account peat characteristics, Government policies that focus on short term incentives and the behaviour of some scientists who have not conducted comprehensive research but sell their professionalism for financial gain.

The significance of climate change in Central Kalimantan has occurred since the Government of Indonesia opened around one million hectares of peat swamp forest for agriculture (Mega Rice Project, MRP) in 1996. Changes in climate have been indicated by increase in the frequency and extent of flooding in the wet season, an extended dry season, irregularly of rain, movement and speed of the wind, and increase in air temperature. The MRP has destroyed the traditional livelihoods source of local communities, e.g. rubber, rattan, purun and fish (“*beje*” system).

It is not possible to allow the MRP to undergo natural succession or self restoration and still try to utilize the existing channels to irrigate rice field and grow non native species, especially on thick peat. This will lead to many kinds of disaster including, fire, flood, typhoon, human disease and plant pests. The damage caused to the peatland in and around the MRP must be repaired soon with a new approach that will benefit the local communities surrounding this area, so that the restoration process can be accelerated and succeed. The key to ensure this restoration will be successful is to involve local communities and devolve responsibilities to them, especially for environmental protection, because all causes of peatland damage are related to human behaviour. Limin (2005) asserted that the major threat to peatland in Central Kalimantan is fire that is started and found where there is human access by road, river, channel and lake or where there are settlements and temporary activities inside the peat swamp forest. To restore the former MRP the Government must adopt a new approach and apply a different strategy, namely to consider the carrying capacity of peatland, the culture of local people around, and the economic status of local people

THE MEGA RICE PROJECT (MRP)

The Mega Rice Project (MRP) was established by Presidential Decree No. 82/1995, following Presidential Decree No.32/1990, which allocated peat of thickness less than 3 metres for agriculture and more than 3 metres for conservation. The excavation of channels commenced in January 1996 and was stopped in 1999 by Presidential Decree No. 80/1998.

Size of the Area

Total area of peat swamp forest allocated for the Mega Rice Project (MRP) is 1,457,100 ha, divided into five blocks, as follows:

- Block A 227,100 ha (15.59%)
- Block B 161,480 ha (11.08%)
- Block C 568,635 ha (39.03%)
- Block D 162,278 ha (11.14%)
- Block E 337,607 ha (23.1 %)

Establishment of Drainage and Irrigation Channels

The total length of channels established in Blocks A, B, C and D is 4,473 km are: Main Primary Channels (SPI) 187.00 km, Large Primary Channels (SPU) 958.18 km, Secondary Channels 913.28 km, Tertiary Channels 900.00 km and Quarter Channels 1,515.00 km.

Focus for Peat Fires

Since 1997, when Indonesia was affected by a major El Niño event, the over-drained MRP area has been subject to severe forest and peat fires.

Negative Impact of MRP

The direct negative impact of MRP was change to the physical condition of this area, especially destruction and disappearance of flora and fauna, including some that were a source of local community income (rubber, rattan, traditional rice fields, fish traps (“*beje*”), destruction of ecosystems, and discontent and destabilization of local communities. In addition, there are many indirect negative impacts caused by the three main direct impacts: (1) changes to hydrology, (2) land and forest fire occur every year, (3) frequency and intensity of floods are increasing, (4) status of traditional rice fields which were formerly saturated have been changed to dry land, (5) the population of plant pests has drastically increased, e.g. rats, (6) local people have become apathetic, feel insecure (7) incomes have drastically decreased, and (8) some local people have become involved in illegal activities (logging and mining).

TESTING FOR RESTORATION THE MEGA RICE PROJECT

The failure to develop the Mega Rice Project (MRP) as a major centre for rice production in Indonesia as planned is because the channels were constructed excessively large and instead of holding water inside the peatland they drained it away to the surrounding rivers. As a result the water table decreased over the entire area causing the remaining vegetation to suffer water stress and become fire prone. The priority for restoration must be to reinstate the hydrological status by building dams to blocking channels.

Blocking channels

Based on dam experiments in the north of Block C the MRP, the water table after dam constructed was raised near to the peat surface. The differences in water table before and after dam construction are shown in Table 1 and Figure 1.

Table 1 Differences in water table before and after dam construction in Block C of the MRP

Year	Transect 1 Water table (m) and point no.	Transect 2 Water table (m) and point no.	Transect 3 Water table (m) and point no.
2004 vs 2005			
September	0.84 (10)	0.87 (13)	1.08 (14)
October	1.51 (13)	1.34 (13)	1.45 (13)
November	1.04 (13)	0.86 (12)	1.12 (13)
2005 vs 2006			
June	0.59 (12)	0.83 (12)	0.41 (21)
July	0.34 (7)	0.27 (12,13)	0.29 (19)
August	0.12 (18)	0.38 (11)	0.09 (21)

Planting Trees for Livelihood of Local people

Planting of native trees will be successful, if financial inducement is given to local people to look after them and the environment. The Buying Living Tree System (BLTS) is one method that will give benefit directly to the community. Based on the BLTS experiments, the percentage of trees alive after one year is higher than using other methods. The BLTS is not just for economic, but also for strategy to educate and increase community awareness.

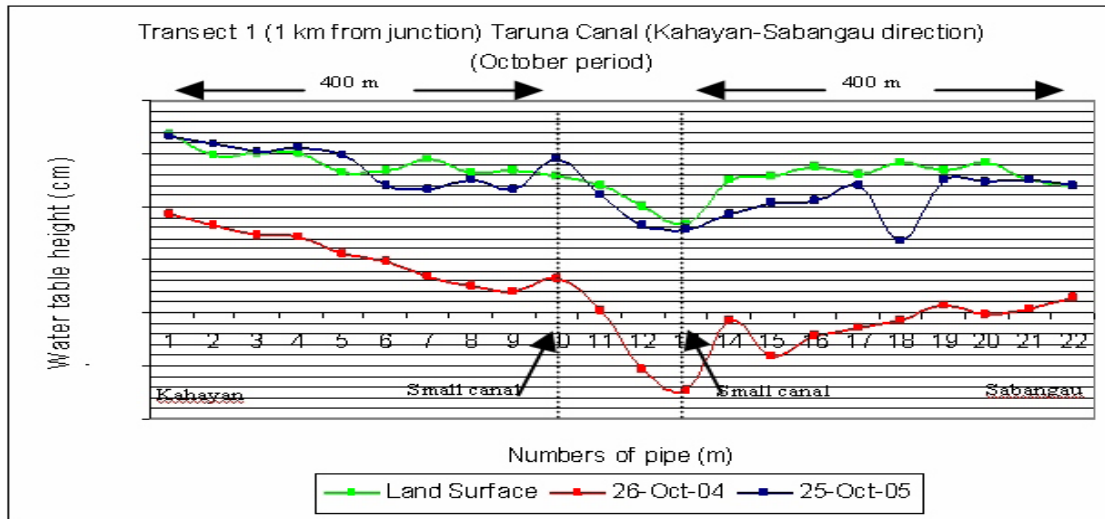


Figure 1 Water table before and after dam construction

Fire Control

The restoration programme in degraded peatland, and the maintenance of conservation areas, will fail if fire is not prevented or suppressed. CIMTROP has established a Fire Fighting Team (Tim Serbu Api, TSA) that is organized and operates according to specific strategies and methods (the TSA Concept). The most important TSA Concept is establishing sources of income for the TSA members to ensure they are always available to undertake their high risk job. In the dry seasons of 2006 and 2007, the TSA protected the Natural Laboratory of Peat Swamp Forest (NLPSF) Kereng Bangkirai Sabangau and the research station in Kalampangan against wild fires.

Redesign of the MRP

The MRP must be redesigned after the hydrological status has been restored so that the utilization of this peatland is based on its carrying capacity. The implementation of inappropriate projects, including transmigration, must be stopped and relocated to other areas where their success is more feasible. Limin *et al.* (2000) suggested that peatland utilization must consider the underlying mineral material (Table 2).

No	Depth of peat (cm)	Underlying mineral material	Hydrology	Recommendations
1.	≤ 50	1.1. Mineral/clay 1.2. Sand/granite	1.1. Full support 1.2. Full support and/or unsupported	1.1. Rice/Corn, etc. and fish in “ <i>beje</i> ” system 1.2. Conservation
2.	50 – 100	2.1. Mineral/clay 2.2. Sand/granite	2.1. Full support 2.2. Full support and/or unsupported	2.1. Rice, Corn, and Plantation commodity 2.2. Conservation
3.	100 - 200	3.1. Mineral/clay 3.2. Sand/granite	3.1. Full support 3.2. Full support and/or unsupported	3.1. Plantation commodity 3.2. Conservation
4.	> 200	4.1. Mineral soil or granite	4.1. Full support	4.1. Conservation

Table 2 Criteria concept for utilization of peatland in Central Kalimantan

DISCUSSION

Restoration of the former MRP will encounter many problems, especially if the regulation of peatland utilization guidance is not revised according to the peat characteristics. Limin (2005) asserted that utilization of peatland in Central Kalimantan will be a major threat to the environmental balance because Presidential Decree No. 32/1990 just allocated peat of thickness less than 3 m for cultivation and more than 3 m for conservation, without considering the material underneath the peat. The inland peat of Central Kalimantan is very different in its characteristics and economic potential compared to peat in Sumatra and West Kalimantan because it is located far from the coast, hills and mineral soils for these to contribute to nutrient enrichment. The Government of Indonesia must be careful to determine the correct criteria for peat utilization, because of the mistakes in the planning and implementation of the MRP that led to many disasters that affected the social economic status of communities and contributed to climate change. The challenge for restoration of the MRP must be to find a new approach that is relevant to the livelihood, culture, mentality, economy and welfare of local communities. The old approach must be changed, because for a long time reforestation programmes have not succeeded as indicated by the large area of abandoned land that increases year by year. According to the Governor of Central Kalimantan (2007) there are now 7.2 million hectares of this ‘critical land’ in Central Kalimantan.

The restoration program should be integrated and must benefit the community and promote environmental recovery. Limin *et al.* (2007) show that restoration of degraded peatland can be implemented by a combination of the TSA Concept and Buying Living Tree System (BLTS). Through these programmes, the community will not only benefit economically, but they will also recover their responsibility and

awareness of environmental functions. The Government's efforts to rehabilitate the former MRP by modifying the existing channels for managing water for agriculture and not returning this peatland to its natural condition will be a major threat to the peatland ecosystem in the future. The old concept that peat utilization must start by land clearing must be changed to the new approach, because peat for forest is also wise use of peatland. Limin (2005, 2007) summarised the failure of peatland utilization in coastal areas as follows: (a) *Handel* system (traditional way), (b) *Anjir* (1880 - 1936 by Dutch Colonials), (c) Polder system (1950 by Schophyus/Dutch Expert), (d) "Garpu" (UGM)/ "Sisir" system (IPB and ITB) (1969 - 1982), (e) "Kolam" system (1980's), (f) Giant canal system (1996, Mega Rice Project).

CONCLUSIONS

- a. The priority for restoration of the former MRP should be to redesign the entire approach through the new Master Plan, but the restoration testing can be conducted during the Master Plan preparation process.
- b. The channel system has created many problems for the peatland ecosystem by lowering the water table, increasing acidity so that the peat has become drier and sensitive to burn and also toxic to growth of crop plants.
- c. All channels that cross the deep peat dome and connect to the major rivers must be blocked to keep water in the peat during the dry season.
- d. The restoration programme and implementation strategy must be relevant to the community's status, social economic needs and cultural heritage. Buying Living Tree System (BLTS) and TSA Concept should be considered as strategies, which will increase the community's welfare through providing regular, fixed livelihood.
- e. The guidelines for peat utilization must be revised based on peat characteristics and field condition.

REFERENCES

- Governor of Central Kalimantan. 2007. Article. (in Public Dialogue on 4.6.2007 and in Kalteng Pos on 8.6. 2007)
- Limin, S. H., Saman, T. N., Putir, P.E., Darung U., dan Layuniyati. (2000). Concept for peat swamp forest utilization in Central Kalimantan. *Paper presented in National seminar on Management of Peatswamp Forest and Research's expose in Wetland*. Banjarmasin, 9th March 2000. CIMTROP, The University of Palangka Raya. Palangka Raya. 8pp.
- Limin, S. H., Saman, T.N. and Alim, S. (2005). Giving full responsibility for local community as one way of fire management in Central Kalimantan: TSA's Concepts. *Proceedings of the International Symposium and Workshop on "Restoration and Wise Use of Tropical Peatland: Problems of the Biodiversity, Fire, Poverty and Water Management"* pp. 190-198, 21 – 24 September 2005, Palangka Raya (Ed. J. O. Rieley). CIMTROP UNPAR, Palangka Raya, Indonesia.
- Limin, S. H., 2007. *Management and Development of Tropical Peatland in Central Kalimantan Indonesia*. (PhD thesis). Hokkaido University, Japan.
- Limin, S. H., Sampang G., Agung R. S., Yuda P., F. Darma and Suparjo. 2007. Buying Living Tree System for Successful of Reforestation Program in

Indonesia. *Poster at the International Symposium and Workshop on Tropical Peatland Yogyakarta, 27 – 31 August 2007.*

A GLOBAL EXCHANGE OF PEATLAND RESTORATION INFORMATION WITH SPECIAL ATTENTION TO THE RUOERGAI PLATEAU (CHINA)

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SUMMARY

A science based and practical guide to peatland restoration has been prepared within the framework of the UNEP-GEF project “Integrated Management of Peatlands for Biodiversity and Climate Change” of which some general principles are presented. Restoration entails a clear formulation of aims, i.e. of the peatland function(s) to be restored. The restoration perspectives strongly depend on the actual condition of the peatland in question, because different degradation stages imply different potentials and demand different restoration techniques. A case study from the Ruoergai Plateau (China) illustrates how the root causes of present-day degradation go back to soil hydraulic changes caused by thousands of years of traditional grazing. The consequent increased vulnerability to degradation and desertification only became apparent through overgrazing and drainage as a consequence of socio-economic changes in the last decennia. The scale and complexity of the problems require international cooperation to understand and solve them.

Keywords: peatland, management, guidelines, restoration, China

INTRODUCTION

The UNEP-GEF project “Integrated management of peatlands for biodiversity and climate change” (2003 – 2006) aimed to assess the impacts of management practices on peatland carbon stores and biodiversity and to determine appropriate mitigation or restoration measures. One of the key outputs of the project was a Global Handbook for Peatland Restoration (Schumann and Joosten, 2008). The Handbook summarizes the options, aims, and techniques of peatland restoration. A great variety of links to and information on projects from all over the world, but with special attention to the pilot regions of the UNEP-GEF-project (Indonesia, China, West-Siberia and Europe), promotes international exchange of experience and knowledge. This paper presents some central aspects of peatland restoration planning and exemplarily discusses peatland degradation processes and restoration options for the Ruoergai mountain peatlands (China).

PEATLAND RESTORATION

Restoration is the activity of trying to bring something back that has been lost. Ecosystem restoration aims at initiating or accelerating processes that return a degraded ecosystem to a state that is more like a former state. The term “restoration” can only be used sensibly when simultaneously the aim of the restoration project is explicitly and clearly set. Basically there are three questions that should be answered before starting a restoration project:

- What would you like to have back?
- Is it possible to get it back?
- What do you have to do to get it back?

A full regeneration to its original, natural state can only be achieved in the earliest stages of peatland degradation, because initial degradation leads rapidly, through positive feed-back, to more and irreversible degradation. Therefore the first goal of every restoration practise should be to limit further degradation.

PEATLAND FUNCTIONS

The products and services (“functions”) that mires and peatlands may provide are manifold (for an overview, see Joosten and Clarke, 2002). Some of these functions can be performed only by pristine mires; others can also or even be executed better by peatlands that have been modified by human action. Some functions are sustainable, i.e. they can be exploited infinitely; others destroy their own peatland resource base and can only be provided for a limited period. It is important to formulate the aims of a restoration project (which peatland functions have to be restored?) clearly, in priority order, and concretely. This is necessary to:

- Identify adequate methods (different aims require different methods).
- Prioritize between conflicting aims (too often mutually incompatible aims are formulated).
- Enable effective evaluation (unspecific aims, e.g. restoration to a “functioning wetland”, cannot be evaluated).

Stratigraphical and palaeoecological studies and the comparison with less disturbed reference sites may give insight into the original functioning and functions of the peatland before degradation.

DEGRADATION STAGES AND RESTORATION OPTIONS

Specific peatland functions require specific conditions. Peat accumulation and associated carbon sequestration, for example, take place only when both a suitable hydrology and the appropriate vegetation prevail. To assess the restoration potential of a degraded peatland it is necessary to analyse its current vegetation, the properties of its peats, and the hydrology of both the peatland and its water catchment area. The degradation stages (see Table 1) differ fundamentally from each other. Stronger degradation not only implies a more intense modification of the same component, but also a quality leap to other and ecologically more important peatland components. Therefore more severely degraded peatlands are increasingly difficult to restore and

require explicit attention to components that have not been directly impacted. In general, peatland restoration should start with restoring the components with the most functional impact (the ones further to the right in Table 1) because these determine the condition of the weaker components (those further to the left in Table 1). It makes, for example, little sense trying to restore the vegetation by planting or seeding peatland/wetland plants, when the hydrology has not yet been repaired.

Degradation stage	Peatland components						Peat accumulation rate	Site characteristics
	Fauna / flora	Vegetation	Hydrology	Soil hydraulics	Form and relief	Peat deposits		
No	Not -	Not -	Not -	Not -	Not -	Not -	> 0	Undrained, without human impact except for some hunting and gathering; virgin mires with natural wild vegetation
Minor	Slightly -	Slightly -	Slightly -	Slightly -	Not -	Not -	> 0 (≤ 0)	Not to slightly drained; harvesting of natural biomass (low-intensity grazing, mowing or forestry); paludiculture; ± some pedogenesis
Moderate	Strongly -	Strongly -	Strongly -	Strongly -	Slightly -	Not -	> 0 - << 0	Drained, often fertilized, and ploughed; harvesting of cultivated biomass (grazing, mowing, forestry, low-intensity agriculture); strong pedogenesis
Major	Strongly -	Strongly -	Strongly -	Strongly -	Strongly -	Strongly -	< 0 - <<< 0	Intensively drained for cultivated plants; inundated for pisciculture; peat extraction; very strong pedogenesis or decapitated profile
Extreme	Strongly -	Strongly -	Strongly -	Severely affected	Severely affected	Severely affected	< 0 - <<<< 0	Severely drained, extreme soil degradation making agricultural exploitation impossible ("peatland desertification")

Not -
 Slightly -
 Strongly -
 Severely affected

Table 1 Functional peatland degradation stages

RESTORATION TECHNIQUES

Key principles with respect to peatland restoration not only comprise ecological engineering techniques (that should be adaptable to individual needs and possibilities), but also include objective setting, cost benefit analysis, environmental impact assessment, legal concerns, stakeholder consultation, contract management, monitoring strategies, and long-term catchment and site management plans. A special case is nature conservation, as restoration opposes the essence of nature: spontaneity. In nature conservation the "means" are an implicit part of the "ends". Every deliberate act increases the artificiality and decreases the naturalness of the resulting patterns and processes. You cannot make an ecosystem more natural; it can only become more natural. Restoration for nature conservation should therefore restrict the intensity and frequency of the techniques employed to the minimum (Joosten, 1996).

PEATLANDS ON THE RUOERGAI PLATEAU

The Ruorgai marshes (470,000 ha) in the northeast of the Qinghai-Tibetan Plateau (alt. 3400 to 3900 m) constitute one of the world's largest expanses of high-altitude peatland (Schumann et al., 2008). As the headwater of the Huang He (Yellow River), they have high importance for regulating water storage and supply. They are of global significance for biodiversity conservation and carbon storage. The Ruorgai peatlands are subject to immense losses of grazing land by erosion and desertification (see Figure 1). To counteract the rapid devastation of wetlands the Chinese Wetland Action Plan and China's Agenda 21 propose to introduce sustainable management practices. This requires, as a first step, an analysis of the root causes of the degradation.

Preliminary studies (Thelaus, 1992, Frenzel et al., 1995, Schumann and Joosten, 2007) indicate that since the start of grazing on the Ruorgai Plateau the rangeland ecosystems, both on mineral and organic soils, have changed substantially. Before the establishment of human settlements percolation mires dominated most of the peatlands on the plateau. Their vegetation was dominated by *Carex* spp. and *Kobresia* spp. that formed a homogenous, hardly decomposed peat with poor mineral content (Thelaus, 1992 and Björk, 1993). Its large pore-volume and high water-conductivity allowed the water to flow diffusely (percolate) through the peat mass. The capacity to shrink and swell enabled the peat to respond to the changing water supply (oscillation) and maintain a stable base flow. The peat was spongy enough to keep the surface permanently water saturated. These conditions caused a high rate of peat accumulation (Thelaus, 1992) through high vegetation productivity and reduced peat mineralization.



Figure 1 Pristine and degraded peatland in Ruorgai and Hongyuan County (China)

Since the start of grazing on the Ruorgai Plateau, 5000 years ago (Wu, 2000 and Wiener et al., 2003), the ecosystems on mineral and organic soils have changed substantially (see Figure 2).

Grazing and deforestation of the higher mineral ground led to erosion and deposition of clastic sediments in and over the peatlands. Together with the increase in trampling through long-term grazing, this caused compaction of the existing peat, more rapid decomposition of new peat, a substantial decrease in peat accumulation rate and major changes in peatland hydrology (Figure 2). The more strongly decomposed, compact,

and less elastic peat forced the water to flow over the peatland surface, leading to the surface-flow mires that currently dominate the area. This major change in hydrology has changed the functioning of the peatlands of the Ruorgai Plateau fundamentally and probably irreversibly with major effects upon the peatlands themselves and their mineral surroundings, both up and downstream (Joosten et al., 2008). In contrast to the former percolation mires, the current surface flow mires show peak discharge consequent on precipitation and little base flow during drier periods. The increased peak interflow from the less vegetated uplands has to be transported over the peatland surface, which leads to the development of preferential flow paths and an increased incidence of surface erosion, certainly after damage of vegetation and surface peat through intensive grazing. The increased peak flow leads to gully erosion that extends into the underlying mineral substrate and to an increase in catastrophic flood occurrences in downstream areas.

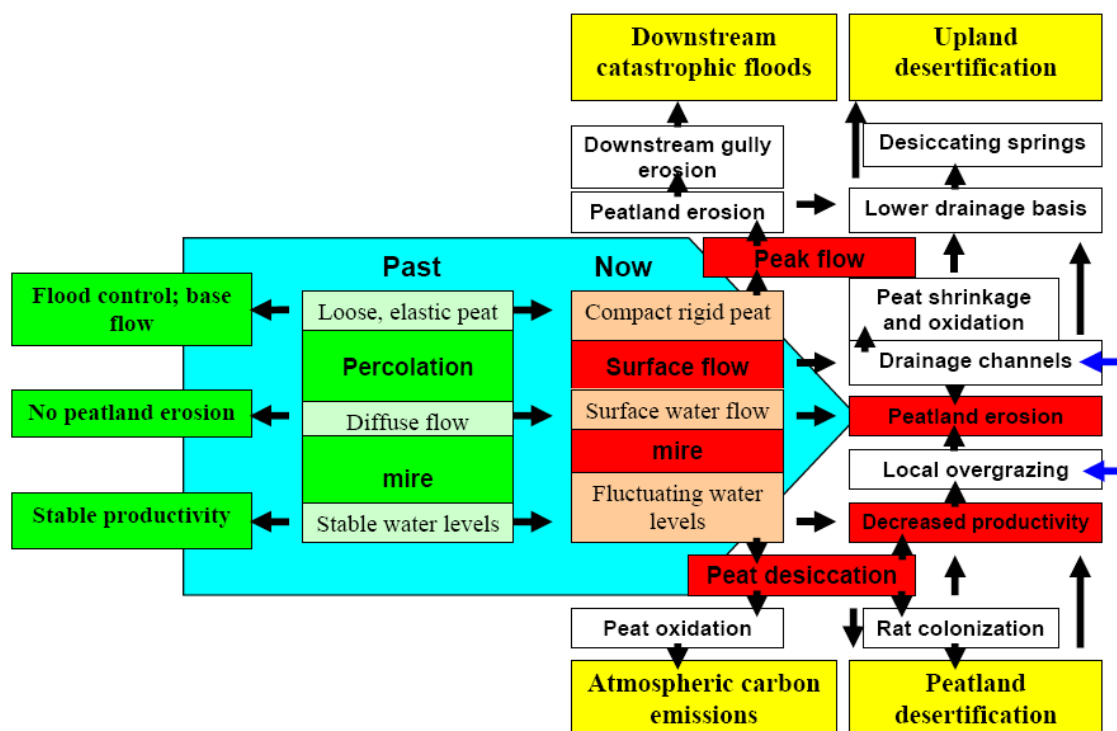


Figure 2 Environmental changes in the peatlands, uplands and downstream areas of the Ruorgai Plateau (China) as a result of thousands of years of grazing

Shrinkage of the peat through drainage, the origin of erosion gullies, peat oxidation, and the digging of drainage ditches have lowered the drainage base in the peatland basins, causing a lowering of the groundwater head in the adjacent uplands, with consequent drying out of hill slope springs, drought stress on the upland vegetation, increased desertification and, again, increased erosion and deposition of clastic sediments over the peatlands.

The strongly decreased storage coefficients of the compacted peat lead furthermore to much lower peatland water levels in dry periods, to drought stress of the vegetation in the peatlands, and to colonization of the dried out peatlands by rats. All of these

processes decrease vegetation productivity and increase wind and water erosion and mineralization/oxidation of the dry peat (Figure 2).

CONCLUDING REMARKS

The example of the Tibetan Plateau shows how thousands of years of yak grazing (cf. Wiener et al., 2003) has led to a change in soil hydraulic conditions, that have made the peatlands vulnerable to overgrazing and degradation. Efforts in recent decennia to drain the peatlands in order to increase vegetation productivity and livestock carrying capacity have lead to the opposite, namely, degradation, desertification, decreased productivity and associated negative impacts. Considering the huge areas of degraded peatlands, the complexity of the problems, and the lack of local peatland knowledge, international cooperation is needed to understand and solve the problems.

The substantial changes in peat-hydraulic conditions must be kept in mind when planning restoration measures. It will not be possible to restore the peatlands to their original state as percolation mires, as peat compaction and decomposition are largely irreversible. The management of drainage systems and of grazing intensities (marked with blue arrows in Figure 2) seem to be the only possibilities to control this complex system. Although currently the overwhelming majority of the peatlands of the Ruoergai Plateau consist of surface flow mires, percolation mires have survived or regenerated locally. This is probably owing to exceptional hydrological and geomorphological conditions and to a limited historical use of these sites as grazing lands. It is of utmost importance that these sites are identified and protected as centres of biodiversity, as nuclei for future regeneration, and as reference sites to increase the knowledge base, all of which are necessary for successful restoration of the degraded peatlands.

REFERENCES

- Björk, S. 1993. The Hongyuan Wetland Research Project, an ecological and technical feasibility study of peat mining in Hongyuan, Sichuan, China. Department of Limnology, University of Lund, Sweden. 100 pp.
- Frenzel, B., Li J. and Liu S. 1995. On the upper Quaternary paleoecology of eastern Tibet. Preliminary results of an expedition to the eastern Tibetan Plateau, 1992. *Science in China, Series B: Chemistry Life Sciences and Earth Sciences*, 38(4): 484-494.
- Joosten, H. 1996. Naturalness and the nature of conservation. *Mires Research News*, 7: 2-4.
- Joosten, H and Clarke, D. 2002. *The Wise Use of Mires and Peatlands*. International Mire Conservation Group and International Peat Society, 304 pp.
- Joosten, H, Haberl, A. and Schumann, M. 2008. Degradation and restoration of peatlands on the Tibetan Plateau. *Peatlands International*, 1: 31-35.
- Schumann, M., Joosten, H. 2007. Development, degradation and restoration of peatlands on the Ruoergai Plateau: A first analysis. *Wetlands International China Programme*, Beijing, 52 pp.
- Schumann, M. and Joosten, H. 2008. *Global peatland restoration manual*. Downloadable from: www.imcg.net/docum/prm/prm.htm

- Schumann, M., Thevs, N. and Joosten, H. 2008. Extent and degradation of peatlands on the Ruoergai Plateau (Tibet, China) assessed by remote sensing. Proc. Int. Peat Congress Tullamore, p. 73-76.
- Thelaus, M. 1992. Some characteristics of the mire development in Hongyuan County, Eastern Tibetan Plateau. Proceedings of the 9th International Peat Congress, Uppsala, Sweden, 22-26 June 1992, Volume 1, p. 334-351. International Peat Society, Jyväskylä, Finland.
- Wiener, G., Jianlin, H. and Ruijun, L. 2003. The Yak, 2nd edn. Food and Agriculture Organization / Regional Office for Asia and the Pacific, Bangkok. 460 pp.
- Wu, N. 2000. Vegetation pattern in Western Sichuan, China and humankind's impact on its dynamics. Marburger Geographische Schriften, 135: 188-200.

**Symposium Statements on Restoration and Wise Use of Tropical
Peatland**

PALANGKA RAYA STATEMENT ON RESTORATION AND WISE USE OF TROPICAL PEATLANDS

Problems of restoration of tropical peatland following inappropriate land use change, illegal logging and fire were addressed at the **International Symposium and Workshop** on “*Restoration and Wise Use of Tropical Peatlands: Problems of Biodiversity, Fire, Poverty and Water*” held in **Palangka Raya, Central Kalimantan, Indonesia on 20-24 September 2005**. These meetings were attended by over 200 peatland scientists from Indonesia and 14 other countries, including land managers, representatives of national and local government, NGOs and community groups, and the private sector. The symposium focused on measures needed urgently for biodiversity maintenance, fire control and water management linked to sustainable livelihoods of local people in order to alleviate poverty and reduce natural resources and environmental degradation. The workshop participants assessed specific problems of peatland restoration in the former Mega Rice Project and the Sebangau catchment areas of Central Kalimantan, and incorporated the views of specialists and stakeholders into an holistic approach to identify solutions using the “**Wise Use**” approach. The importance of peatlands to national and regional economies and the environment was stressed in opening statements by the Governor of Central Kalimantan and the Indonesian Deputy Minister for Research and Technology. The Governor expressed his concern over the current situation and made a strong commitment to support positively, initiatives to solve the problems of fire and water management through sound science and wise use. He invited the participants to submit to him their conclusions and recommendations.

The International Symposium and Workshop:

NOTES that there are serious problems facing the peatlands of Central Kalimantan as a result of the failed Mega Rice Project, illegal logging and fire. These are affecting negatively the livelihoods of local people and the natural resource functions of the remaining peat swamp forest;

WELCOMES the positive opening statements made by the Deputy Minister for Research and Technology who outlined the importance of tropical peatlands and peat and the Governor of Central Kalimantan who made a plea for assistance to help solve the problems of peatland restoration confronting his province;

RECOGNIZES that peatland and forest fires, promoted largely by land use change, illegal logging and peatland agriculture, are a major environmental problem in Southeast Asia that results in a noxious atmospheric haze affecting both people and the environment;

IDENTIFIES key issues affecting the biodiversity of natural peat swamp forest and recognizes the difficulties and possible methods to combat fire employing appropriate measures for awareness, control, water management, wildlife conservation and poverty alleviation;

URGES the Indonesian Government to prevent further development projects on peatland, especially on peat over three metres thick and on shallower peat where the underlying substrate is nutrient deficient or potentially toxic, and support the Government’s ‘**Ad Hoc Team**’ in its efforts to find an integrated and acceptable solution to the problem in partnership with stakeholders;

WELCOMES the acceptance of Indonesian National and Provincial Governments of the need for peatland restoration, linked to fire prevention, poverty alleviation and water management, and their commitment to charting a new course for tropical peatlands through the ‘**Wise Use**’ approach.

ENCOURAGES investment by Indonesian and international governments, donor agencies and the private sector in the conservation and restoration of tropical peatland while also **PROMOTING** wise use and participatory management of this ecosystem in partnership with local communities;

EMPHASIZES the need for accountability and transparency, new partnerships, community participation, capacity building and application of appropriate technology as key elements of such investment;

RECOMMENDS that the action points identified by the workshop expert groups on biodiversity, fire, poverty and water be acted upon and implemented as matters of urgency (appended).

Endorsed by the participants at the International Symposium and Workshop on Restoration and Wise Use of Tropical Peatlands, at Palangka Raya, Central Kalimantan Indonesia at the final plenary session on 24th September, 2005.

BIODIVERSITY

Peat swamp forests (PSF) have high natural biodiversity in unique and variable habitats. This should be conserved and enhanced. Conservation of the PSF habitat must include all fauna, flora and ecological and physical processes necessary to ensure its long-term survival. Wherever possible, and especially where fragments remain, peat swamp forest should be rehabilitated to increase the area of this ecosystem in order to provide the maximum habitat for its biodiversity. Conservation areas should be managed according to 'Wise Use' principles and contribute to the livelihoods of local people in a sustainable manner.

Problems

- Lack of awareness of the rules/laws governing the PSF area and lack of adequate law enforcement/resources to combat threats to PSF.
- Fires, drainage channels and illegal logging extraction canals; habitat loss and fragmentation.
- Over-exploitation of natural resources from PSF.
- Lack of knowledge and understanding locally about the importance and functions of PSF (local, regional and global) and the importance of conserving the PSF for the future.
- All forest (including PSF) in Central Kalimantan has been divided up and extraction allocated to logging companies (HPH) so that local people no longer have feelings of ownership and respect and hence have little concern for biodiversity or resource deterioration and fire susceptibility.

Priority Actions

- Map locations of all remaining peat swamp forest and assess their condition. Incorporate this information into a unified, integrated plan for conservation and enhancement of PSF biodiversity, linked to aspirations and needs of local people.
- Prevent inappropriate drainage and fires (see Fire and Water recommendations)
- Maintain and/or create adequately sized corridors between forest fragments to assist biodiversity conservation and gene flow, especially in Ex-PLG/MRP; link fragments into larger units by enrichment planting of peat swamp forest trees of local provenance.
- Establish local patrol teams (Tim Patroli CIMTROP; Rhino Patrol, Sumatera etc) to protect biodiversity and inform local people of its importance. These teams can also be used for fire awareness and control purposes.
- Local people should be made aware of rules, laws and regulations, clearly and positively; these must be enforced with severe penalties for non-compliance to act as deterrents.
- Local government must commit to conservation with vision and mission statements.
- Undertake targeted research and make results available to local people and local development professionals (i.e. translate into Indonesian).
- Promote education to explain the ecological processes of PSF to local people, local government and decision makers; enable local professional development; introduce environmental awareness into school curricula.
- Promote the 'Wise Use' use of peatland resources to avoid over-exploitation.

Constraints

- Lack of funding for targeted research and local, national and international education.
- Lack of local knowledge about the importance of the peat swamp and potential opposition to biodiversity conservation as a result.
- Lack of grass-roots capability to empower local communities to be custodians of their biodiversity.
- Short-term settlement of people from outside of the Province onto peatland areas where there is no likelihood to obtain a sustainable livelihood.

Resources needed

- Research and conservation capability and resources.

- Firm commitment from local, national and international governments, and multi-nationals, NGOs and the private sector to conservation and wise use of PSF.
- Alternative sources of funding to promote alternative sustainable livelihoods to over-exploitation of natural PSF resources (see Poverty recommendations).

FIRE

Forest and land fires have become an annual event that causes public health and socio-economic problems locally, nationally and internationally and unwanted trans-boundary smoke/haze across the Southeast Asian region. Fires remain the primary tool for land-clearing, although fire is not acknowledged as a major problem by the Indonesian Government at local and national levels as shown by the lack of funding and control resources allocated by them. A lead agency, staffed with experienced people, utilizing local communities, supported by proper legislation, funding, and fire mobilization capabilities, is essential to assess existing resources, determine requirements and coordinate activities on the ground within Central Kalimantan in order to prevent and combat fire.

Problems

- Forest and peatland fires have become a regular event that causes unwanted trans-boundary smoke/haze, degrades the environment, increases poverty and harms human health.
- Over exploitation of forests, land use change and improper water management (MRP) are the main causes of these fire events.
- Fire is always caused by people and starts where they gain access to forest and peatland for human activities, e.g. roads, channels, rivers and lakes.
- Fire is the main tool for communities to establish land tenure outside of towns and villages and along roads, and land owners/licenseses to achieve land-clearing objectives prior to development, and for disposal of unwanted waste.
- Current coordination of fire suppression activities has not resulted in effective actions.
- Community participation is lacking in fire management activities because most land and forest is allocated to logging companies (HPH).
- A lack of adequate firefighting equipment, operational funding, training, and fire prevention awareness contributes to the annual smoke/haze events.
- The conclusions of the April 2003 Workshop on Fire, which recommended the TSA concept be adopted, especially to empower local communities in and around the areas most susceptible to fire, have not been implemented.

Priority Actions

- Establish and empower a lead coordinating agency at Provincial level that integrates activities in the regencies and villages, for example, a TSA Foundation that is supporting the local government but gives full responsibility and trust to local communities.
- Prepare an inter-agency fire management response plan.
- Ensure budgets and resources (human and operational) are available before emergency fire events.
- Ensure enforcement of existing fire laws/regulations and enact new ones if required.
- Involve stakeholders in solving fire issues and problems.
- Provide education, training and awareness for fire management.

Constraints

- Lack of coordination, funding, planning and on the ground experience and training.
- Fire is not prioritized as a main problem for which government funding is required.
- Peatlands are viewed as marginal land that does not require significant investment.
- Lack of understanding of the special characteristics of tropical peat and peatland, especially the high value of its biodiversity and carbon store and the impact of fire upon these.

Resources needed

- Skilled people, suitable quantities and types of firefighting equipment
- Sufficient funding for operational management
- International support and expertise

POVERTY

People's ability to escape from poverty is critically dependent on their access to livelihood maintaining assets. The sustainable livelihoods (SL) approach seeks to determine poor peoples' livelihood priorities and link these to different socio-economic solutions depending upon specific circumstances. By developing a detailed understanding of the factors lying behind peoples' choice of livelihood, the sustainable livelihoods approach seeks to reinforce the positive aspects and mitigate constraints and negative influences. Emphasis should be placed on reducing vulnerability and, simultaneously, promoting improvements to income availability, well-being, food security and sustainable natural resource use. The overall research emphasis of the SL approach is participatory in nature. SL options for communities living near peat swamp areas include: the potential of different land uses, integrating the conservation and development of tropical peatland, and forging partnerships between local communities, local governments, DC government agencies, NGOs and international donors and experts in order to promote the sustainable restoration and management of peat swamp forest and peatland in Central Kalimantan.

Problems

- Lack of human capital (technical support and entrepreneurial skills)
- Dispersed population with inadequate means of communication and transportation
- Poor quality produce of low value and absence of marketing network
- Lack of political representation for local communities
- Price of commodities (e.g. rattan, rubber, palm oil) depends on world market price

Priority Actions

- Focus on indigenous knowledge and employ participatory approaches that prioritize local development aspirations.
- Promote development of skills and market knowledge/information through continued technical support.
- Empower local communities to restore and manage their peatlands according to principles of 'wise use'.
- Generate alternative income earning opportunities especially for agribusiness, social forestry and ecotourism.
- Institute community-based fire control.
- Ensure cultural sensitivity towards user and ethnic groups.
- Establish marketing network with developed countries.
- Establish value adding processing industries (e.g. furniture, palm oil, rubber) within Central Kalimantan to reduce outflow of capital and profits.

- Promote alternative approaches to funding local communities to be custodians of the natural environment, e.g. through Biorights and carbon off-set mechanisms.

Constraints

- Resource degradation
- Intra and inter-community conflict
- Low soil productivity
- Changing sources of income, i.e. rice, rubber and rattan to timber, mining and oil palm
- Top-down approach in government policies
- Lack of education and technical skills

Resources needed

- Greater community representation within local government
- Land-use mapping as a guide to wise use of peat land areas
- Greater government accountability and transparency regarding infrastructure
- Emphasis on investment-based rather than project-based participatory development
- Expansion of human resources in monitoring the costs and benefits of projects implemented
- Implementation of alternative means to provide income from 'wise use' management of peat swamp forest and its natural resources (e.g. develop Biorights and carbon trading mechanisms)
- Institute agribusiness schemes for farmers in areas surrounding peat swamp forest funded by small loans from a local development or land bank with low rates of interest.

PEATLAND RESTORATION AND WATER MANAGEMENT

Peat Swamp Forests (PSF) are unique ecosystems with many complex interrelations. Until recently they were regarded as waste land that had to be put into use for humankind. Recent fire, erosion and flood events show the need for restoration of degraded PSF. Restoration is the process of bringing something back that has been degraded or lost. That means it is initiating or accelerating the recovery of the ecological functions of peatland ecosystems, as far as possible, for a variety of uses including forestry, agriculture, agro forestry, wildlife conservation and nature conservation. Because peat occurs, and is maintained, only under water saturated conditions, water management is the basis of peatland restoration. Very little of the knowledge that is available concerning peatland restoration can be used in the tropics because tropical peatlands differ in many of their characteristics from peatlands in the boreal and temperate zones.

Problems

- Degraded tropical peatlands are changing from carbon sinks to carbon sources, emitting large amounts of carbon dioxide.
- Downstream water quality has deteriorated, leading to reduction in fish populations, increasing poverty and damaging human health.
- Dry and open peatlands face a high risk of fire.
- Numerous drainage channels and the extermination of the forest lead to an immense water runoff far too rapid to maintain a sustainable water balance, i.e. flooding in the rainy season and drought in the dry season.
- A complex, dome-shaped ecosystem that requires appropriate and specific restoration techniques.

Priority Actions

- Limit further degradation by regulation of the water level because prevention is much cheaper than restoration (highest principle); keep the optimum amount of water in natural peat swamp forest.
- Prevent fire (see Fire recommendations); stop illegal logging.
- Prepare an integrated multiple land use plan that identifies areas with different restoration objectives and potential.
- Attract private and governmental investors to support an integrated research program that can lead to successful restoration activities.
- Implement an approach that integrates biodiversity maintenance and enhancement, fire control, poverty alleviation and water management (including supply of potable water to local communities) (see biodiversity, fire and poverty recommendations).
- Reforest deep peat areas using natural tree species of local provenance (not seed) as a means to raise and stabilize the water table.

Constraints

- An indeterminate number of channels that prevent water saturation has been established by illegal loggers in remaining peat swamp forest.
- Public awareness and acceptance is inadequate and must be increased, otherwise local people will not support restoration measures.
- Insufficient knowledge of the functioning of tropical PSF.
- Lack of coordinated action and appropriate land use planning to resolve social conflicts and solve technical problems.
- Lack of funding.

Resources needed

- Exchange platform of knowledge and data (such as DEM, GIS, climate, hydrology...)
- Funds are needed to implement measures
- Government agencies and NGOs must agree and implement a common approach to peatland restoration and water management.



INTERNATIONAL SYMPOSIUM AND WORKSHOP ON TROPICAL PEATLAND

| YOGYAKARTA, INDONESIA | 27-31 AUGUST 2007 |

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STATEMENT

Issued by participants of the

**International
Symposium, Workshop and Seminar on Tropical Peatland,
Yogyakarta, Indonesia,
27 - 31 August 2007**

***“Carbon - Climate - Human Interactions - Carbon Pools, Fire,
Mitigation, Restoration and Wise Use”***

organized by

**Department of Soil Science,
Faculty of Agriculture,
Gadjah Mada University,
Indonesia**

in association with

**Indonesian Peat Association
International Peat Society
BAPPENAS**

On behalf of the

EU CARBOPEAT AND RESTORPEAT RESEARCH PARTNERSHIPS



**YOGYAKARTA STATEMENT ON CARBON-CLIMATE-HUMAN
INTERACTIONS
ON TROPICAL PEATLANDS**

Problems of fire, mitigation, restoration and wise use of tropical peatland were addressed at the **International Symposium and Workshop on “Carbon-Climate-Human Interactions on Tropical Peatlands”** held in **Yogyakarta, Indonesia on 27-29 August 2007**. These meetings were attended by over 200 participants from Indonesia, Malaysia and Vietnam and 13 other countries, including scientists, politicians, legislators, land managers, representatives of national and local government, NGOs and community groups, and the private sector. The symposium consisted of seven technical sessions, with 38 papers, dealing with the following important issues concerning tropical peatlands and peat:

1. Evolution, extent and natural resource functions;
2. Biodiversity and biological, chemical and physical characteristics;
3. Restoration and water management;
4. Carbon dynamics;
5. Socio-economics and land management;
6. Fire: detection, impacts, awareness and control;
7. Carbon payments, avoided deforestation and cultivation of plantation crops.

The workshop commenced with a ‘Stakeholder Forum’ at which views were expressed by representatives of regional governments, agro-industries, researchers, and others on current and pressing issues related to tropical peatland utilization, particularly in the context of climate change and biodiversity conservation. These major issues were analysed and discussed in greater depth in four breakout sessions that prepared outline actions plans and contributed towards the symposium/workshop statement. Uniquely all parties recognized each others needs with regard to peatland management and during the meeting they worked together to develop appropriate strategies and action plans to address current issues facing the tropical peatland resource.

The Yogyakarta International Symposium and Workshop:

WELCOMES the attendance of the representative of the Minister of Environment, Rektor of Gadjah Mada University, President of the International Peat Society, Governor of Yogyakarta, Ambassador of Finland and the First Secretary of the Netherlands Embassy in Jakarta; their support indicates a high level of awareness of tropical peatland problems and a desire for these to be resolved as matters of urgency.

NOTES the international interest in and concern for tropical peatlands and acknowledges that there are serious problems facing Governments in the ASEAN Region as a result of land use change and fire that are causing transboundary haze and a large increase in greenhouse gas emissions (GHG).

RECOGNIZES that all development on tropical peatland has associated environmental impacts while inappropriate or poorly managed development, especially over drainage, leads to peat subsidence and fire, which affect severely local and regional biodiversity, natural resource functions of the remaining peat swamp forest, and livelihoods and health of local people.

URGES the Indonesian and other ASEAN Governments to promote responsible management of peatlands, based on an ecohydrological approach that should prioritize

the protection of high conservation value peat swamp forests, including semi-pristine and logged-over forests, and the rehabilitation of deforested, degraded peatland areas.

ENCOURAGES investment by all interested parties including international governments, donor agencies and the private sector in the conservation, rehabilitation and restoration of tropical peatland, and the improvement of existing peatland management practices by promoting wise use, including participatory management of this ecosystem in partnership with local communities;

EMPHASIZES the need for all stakeholders involved in peatland management to operate with accountability and transparency, develop new financial mechanisms and partnerships, undertake capacity building and apply appropriate technology in order to achieve success;

RECOMMENDS that land use planning of peatlands be optimized to promote their wise use and reduce greenhouse gas emissions.

**Endorsed by participants of the International Symposium and Workshop on
“Carbon-Climate-Human Interactions on Tropical Peatlands” at the final
plenary session held in Yogyakarta, Indonesia on 29th August 2007.**

Mitigation and Financing Initiatives to Increase/Maintain Carbon Stores in Tropical Peat

Carbon emissions from peatlands in Indonesia constitute a large problem causing haze, contributing to climate change processes, increasing loss of biodiversity and livelihood problems. This chain of events needs to be interrupted.

Carbon investments should take on board both poverty reduction and biodiversity in order to increase performance and sustainability of carbon investments. To generate capital and increase the returns on these investments, contributions of governments, industries (e.g. palm-oil and paper and pulp) and financial parties are crucial. To reduce risks and safeguard carbon investments in peatlands in Indonesia, two essential factors related to fires have to be addressed:

1. Poverty;
2. Reduction of excessive drainage (closely related to the uncertainty of precipitation changes).

Need for innovative financial mechanisms:

- a. Globally:
 - i. REDD; special peatland focused facility
 - ii. Voluntary (private sector and public) investment schemes
- b. Nationally: multi-donor trust fund
- c. Regionally/provincially: provincial trust funds; private sector taxes (CSR)
- d. Community level: micro-credit facilities and Bio-rights mechanism (www.bio-rights.org)

Need for new Institutional and management arrangements:

The financial mechanisms need to be backed up by new institutional finance management structures, policy and legislative frameworks and legal mechanisms to regulate, monitor and guide this new emerging market.

These should include

- e. Consideration of the level, transparency and stakeholder involvement of governance of the funding, and facilities for pro-poor investment (e.g. integration of carbon conservation, poverty reduction and biodiversity conservation)
- f. Recognition of customary rights
- g. Monitoring and audit or certification mechanisms
- h. Avoidance of leakage and perverse incentives through imbalanced land use planning: need for Master Plans for national and regional/local peat carbon emission reduction.
- i. Standards and criteria for:
 - i. Reduced emissions from avoided peat swamp forest deforestation and degradation,
 - ii. Reduced emissions from optimization of water management in plantations (within a wise use approach)
 - iii. Carbon sequestration through reforestation
- j. Policies and legislation that can provide the necessary long-term guarantees for long-term carbon store conservation, including tenure aspects.
- k. Hedge against risks (e.g. fire, natural disasters) through insurances and bank guarantees.

Need to show political will and stop expansion of the problem:

Evidence of political will is the key to attract investment. Indonesia's peatlands and current peatland issues provide for a potential avoided emissions of around 1.6 G ton (1.4 Gt from fires and 0.2 Gt from drainage (e.g. 30% of current annual drainage emissions)). A moratorium will be a strong signal and can be a first step in countering

peatland degradation and to buy time to maximize the new opportunity of carbon finance. A moratorium needs to be part of a longer-term strategy of land use planning.

Development of Tropical Peatland for Agriculture and Forestry

Aims:

To promote responsible land-use development on peatlands that result in environmentally well-managed, highly productive and socio-economically beneficial agricultural/forestry development whilst at the same time protecting a representative sample of Indonesia's unique and biodiverse peatland heritage and minimising carbon loss.

Recommendations:

Land use planning

- Create a 'one stop centre' for peatland management, which simplifies institutional responsibility and accountability, integrates different land-use plans, requires better inter-agency cooperation and implements a high level of stakeholder (including local community) involvement.
- Develop an inventory and classification (definition) of existing peatlands, which can be used to identify appropriate land-use at the District level; future land use planning should:
 - be based on current peatland status including semi-pristine forest, irreversibly degraded/illegally logged peatland, agricultural peatlands and peat-based (including smallholder) plantations.
- Prioritise (using wise use criteria) and protect peatland for conservation according to hydrological status, size, habitat condition, biodiversity, ecological uniqueness, peat carbon storage capacity, substrate and different stakeholders' (including local communities') needs; these peatlands should remain under good forest cover and not be converted to plantations/ buffer zones.
- Use the eco-hydrological approach instead of the (3 m) peat thickness criterion for land-use planning, as greater biodiversity often occurs on shallower peat that may also be inappropriate for agriculture.
- Identify areas most suitable for the promotion of alternative livelihoods (such as agri-business and integrated agro-forestry systems including animal husbandry) to provide food and cash and also biogas.

Involvement of stakeholders/local communities

- Establish proper coordination between government agencies and involve local communities and other stakeholders in the development of peatland for agriculture and forestry and the promotion of sustainable livelihoods. In particular:
 - stakeholder awareness of and involvement in fire prevention should be increased.
 - water and forest restoration should be community-based using wise use management principles.

Fire

- Prevention of fire should be proactive and based upon peatland status, i.e. semi-pristine forest, irreversibly degraded /illegally logged peatland, agricultural peatlands and peat-based (including smallholder) plantations.

Irreversibly degraded/illegally logged areas.

- Properly define degraded forest; prioritise future agricultural/plantation development on irreversibly degraded/deforested land.
- Promote more effective law enforcement targeted towards financiers and the market.

Semi pristine forests

- Maintain high water levels in semi-pristine and lightly logged forests by aiming for zero drainage and the restoration of their former hydrology by blocking existing drainage canals.

Existing major plantations

Advanced plantation management practices that aim to minimise carbon loss should be promoted and extended. Examples of existing wise use practice to build upon include:

- Development of advanced water and related peat resource management systems that seek to minimise drainage (e.g. the identification of species that will grow under waterlogged conditions).
- Development of integrated hydrological management plans for peatland which deal with the whole river basin and engages with different stakeholders that are active within the area.
- Active prevention of fire both within and adjacent to plantations.
- Inclusion of buffer zones and conservation areas on deepest peat/most important forest.
- Promotion of sustainable forest management as per government recommendations for plantations.
- Emphasis on stakeholder involvement in decision-making and income-earning opportunities for local people.

Rehabilitation and Restoration of Tropical Peatland

Needs:

- Government should revise the classification of ‘production forest’ with regard to peatlands, to take into account present levels of degradation (undamaged and primary, secondary and severely degraded land). Accurate maps are required of areas set-aside for different land uses. Management options should reflect these classifications and maps.
- Improve and up-date data base on peat area, depth, profiles and volumes.
- Prepare strategies for peatland:
 - *Conservation* – Locate and actively protect remaining peat swamp forest ecosystem.
 - *Rehabilitation* - Repair of degraded ecosystem,
 - *Restoration* - Back to original ecosystem,
 - *Reforestation* - Plantation activity, recovers some ecosystem function and some benefits,
- Ensure rehabilitation and restoration promote recovery of ecological and hydrological functions, including favourable carbon balance in line with wise-use principles, and that they have historical fidelity and improve local livelihoods.

Aims:

- Undamaged: rehabilitated forests can act as buffer zones, reducing need for activity in and access to pristine forest while providing alternative livelihoods.
- Primary degraded land should be enriched by planting native species; further degradation must be prevented, and local people should benefit.
- Secondary degraded land, owing to repeated logging/active degradation, requires positive rehabilitation through enrichment planting with native species, fire prevention, and hydrological recovery. These areas should be restored and used by local communities in a sustainable manner.

- Severely degraded land that has suffered from repeated disturbance is difficult to rehabilitate. Instead consider conversion to another land use, for example, plantations, but applying wise-use principles.

Recommendations:

- Conserve the remaining peat swamp forest; reinstate hydrological processes, through construction of water flow retarders, especially on thick peat.
- Implement fire-fighting strategies to prevent and suppress wildfire, establish dedicated fire-fighting teams that are supported by a regular income.
- Commence scientifically based and community-informed rehabilitation programs that promote:
 - Planting of native, locally useful, marketable trees,
 - Recovery of ecosystem function, historical fidelity and
 - Improvement of livelihoods of local people.
- Government should:
 - Apply unified policies, enforce the law and apply sanctions;
 - Raise public awareness and knowledge; educate small businesses and local communities;
 - Involve all stake holders (National and regional government, local communities, large and small private businesses) at each stage of land rehabilitation, through to long-term management;
 - Support community development programs, including local, regional and provincial involvement, through grass-roots programs, with education, long-term management and investment. Need for short-term monetary incentives and long-term beneficial outcomes for local communities, leading to ownership and tenure rights, and increased responsibilities.
- Further research is vital, especially
 - by establishing research sites across the peatland areas to increase site-specific knowledge,
 - by increasing rehabilitation knowledge, e.g. to identify native, but productive trees that can tolerate different environments, under different degradation levels, and will create incentives for local communities, e.g. jelutung, meranti, ramin, gemur.
 - by implementing alternative land clearing methods instead of fire.
- Generate funding guidelines for NGOs and other bodies

The Tropical Peatland Carbon Budget: Sinks, Stores and Losses

Background

Peatlands of the tropics represent archives of carbon. They have formed and vanished or buried over the last few million years – at present, few peatlands in SE Asia are older than 20,000 years; most of them are less than 10,000 years. These peatlands can therefore represent BOTH a carbon sink for, and source of, CO₂ and other gases from/to the atmosphere. Peatland use changes over the last few decades have necessitated drainage that has caused peat subsidence and a significant net carbon loss, which has been enhanced by accelerated decomposition and more frequent and severe fires.

The carbon cycle in tropical peatland

The carbon cycle on tropical peatlands differs under natural and land use changed conditions and is influenced by:

- Temperature, light, nutrients, water table;

- Biological: vegetation type, e.g. natural forest, arable cropping, plantations (biomass differs);
- Physical: wild fires, storms, etc;
- Management: cropping regime (no cropping, cyclic cropping, accidental cropping), water management (water table depth), soil management (tilling, burning, fertilisation, etc.)
- Change in C stock (peat structure, peat depth, peat area, soil gas fluxes, vegetation type).

What are Greenhouse Gas Emissions (GHG) from tropical peatland and how do they vary?

- The focus has been on CO₂ but CH₄ is important when water tables are high and N₂O is released under drained conditions when the water table is around 20 cm below the surface;
- There are diurnal and seasonal variations in GHG emissions;
- Addition of lime and fertilizers may change GHG emission patterns;

Factors affecting the tropical peatland carbon budget

- Logging (authorised and illegal); deforestation; drainage; subsequent land management and fire leading to:
- Cessation of carbon sink function, oxidation, increased decomposition, subsidence and increased GHG emissions;

Needs

It is urgent that:

- Different researchers collaborate to share data and standardize methods and analysis procedures;
- Gaps in knowledge are identified and more studies carried out of GHG emissions in ALL types of tropical peatland focussing on spatial and temporal variations over long periods (only three comprehensive studies have been carried out so far);
- Detailed study is made of the effect of biomass changes and crop composition on hydrology and soil structure that impact upon the peat carbon store and lead to loss of carbon to the atmosphere;
- Decomposition and subsidence that occur during development of tropical peatland are quantified better in order to solve some of the problems with data on the emission status of different peatland types;
- More and better information is obtained on the relationship between fire-releasing carbon, intensity and frequency, and the amount of biomass (fuel), water table and land use.
- Fire control and management should be prioritized in order to reduce GHG emissions from tropical peatland;
- Data presentation and synthesis are provided for policy decision makers.