Water for Food & Ecosystems Programme project on:
"Promoting the river basin and ecosystem approach for sustainable management of SE Asian lowland peatswamp forest"
Case study Air Hitam Laut river basin, Jambi Province, Indonesia

Regeneration of fire degraded peatswamp forest in Berbak National Park

and implementation in replanting programmes

Pieter van Eijk
Pieter Leenman

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July 2004

Pieter van Eijk
Pieter Leenman

Supervised by: *Drs. W. Giesen, Arcadis Euroconsult*
Prof. Dr. M.G.C. Schouten, Wageningen University

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Contents

Preface

This study comprises our major thesis and is part of our MSc Biology (specialisation Ecology) studies at Wageningen University, The Netherlands. From November 2003 to June 2004 we spent many hours studying peatswamp forest ecology in general and peatswamp forest post-fire regeneration in particular, both in The Netherlands and in Indonesia. In total more than six weeks were spent in Berbak National Park, for acquisition of field data on flora, fauna and abiotic factors. There we soon discovered why so few scientists have ventured into peatswamp forest until now. We had to deal with hazardous ants, angry bees, dozens of snakes, obstructed rivers and strangling fern vegetation. We had to wade or swim through floodplains in search of suitable research locations and spent the night in mosquito infested camps. There we discovered the warmth and friendliness of local fishermen and the people that accompanied us on the trips. We found the beauty and richness of the peatswamp forest that has not yet been affected by the forest fires and experienced the enormous value of this National Park for flora, fauna and local communities. But we also encountered the activities that strongly threaten the parks integrity; the many loggers that deteriorate the park at a terrifying rate, the unsustainable harvest of non timber forest products and poaching of birds and reptiles. The ongoing drainage of farmland and forest concession areas that strongly influence Air Hitam Laut's complete catchment area. And of course the outbreak of forest fires, that already degraded more than ten percent of the park. These activities destroy Berbak at an alarming rate and if they are not stopped on a very short term, Berbak will be lost for future generations. Tigers, rhino's and white-winged ducks will disappear together with a complete ecosystem as already happened in other parts of Sumatra's coastal plain. Still however there remains hope. More and more people recognise the enormous value of peatswamp forests for both communities and nature. They work together to promote sustainable management and are prepared to battle illegal logging and outbreak of wild fires. Ongoing research clarifies patterns in socio-economy, hydrology and ecology in and around peatswamp forests. Information continues to be collected, both from the safe surroundings of a computer desk and submerged in the centre of a flooded peatswamp forest. This report is meant to make a small contribution to the understanding of the ecology of fire-degraded peatswamp forests and it will hopefully help to save Indonesia's peatswamp forests for future generations.

Wageningen, The Netherlands, July 2004,

Pieter Leenman (Pieter.Leenman@WUR.nl)
Pieter van Eijk (Pieter.Vaneijk@WUR.nl)

Executive summary

Background
From September 1997 to May 1998 enormous forest fires spread throughout Indonesia, destroying an estimated total of 13.18 million hectares of forest and farmland. The fires were most destructive in peatlands of Sumatra and Borneo where extensive tracts of peatswamp forest were affected. Extreme El Niño induced draught, combined with logging activities, drainage and other human disturbances were the direct causes of the outbreak of the wildfires. Between 1 and 2.5 billion tons of carbon were released into the atmosphere, contributing to 15 to 40 percent of average global annual carbon emission. Economic damage extended nine billion US Dollar. Fire affected peatlands face extreme flooding conditions, subsidence, erosion, salt intrusion, and many areas are subject to repetitive burning.

Few research on regeneration of fire-degraded peatswamp forests has been conducted. Many sites are known to have a poor rate of development as extreme environmental circumstances inhibit establishment and growth of seedlings. Often these sites were found to be dominated by ferns, grasses or sedges. Lack of knowledge on the link between abiotic circumstances and tree performance caused many replanting trials in peatswamp forest to fail, as they were carried out in areas with conditions unsuitable for reforestation, although over the years several tree species have been identified to have potential for reforestation programmes.

Goal
This report as a part of the Water for Food and Ecosystems project on: *"Promoting the riverbasin and ecosystem approach for sustainable management of SE Asian lowland peatswamp forest"* funded by the Dutch government, describes regeneration of fire-degraded peatswamp forests in Berbak National Park, a 190,000 ha Ramsar site, situated on Sumatra's coastal plain, Jambi Province. The park represents the conditions of many peatswamp forests in Indonesia; More than 17,000 ha were destroyed during the 1997 fires, and the park faces considerable problems with illegal logging and drainage. The survey aims at revealing the link between abiotic factors (flooding depth, flooding duration, peat depth, and fire history) and the extend of regeneration in terms of species composition and forest structure. In addition it identifies species that have potential value for reforestation programmes. This information combined could form the basis for decision making (selection of appropriate sites and species) during future replanting trials in Berbak National Park and part of the information, presented in this report is transferable to other Southeast Asian peatswamp forests.

Methodology
Data on species composition, forest structure and abiotic factors has been collected at 16 different sites throughout burnt areas in Berbaks central zone. These sites differ from each other in fire history, flooding conditions and peat depth.
At each research site five relevees were made along (continuous) transects of 100 x 10 metre, and consequently at all sites together data were collected in 80 relevees. In addition, general observations were made on illegal activities and animals (birds, mammals, reptiles and amphibians) within and in the direct surroundings of the park. The data collected in the relevees were stored in TURBOVEG and analysed in TWINSPAN and CANOCO.

Results

In total 117 plant species have been identified in Berbak's fire-degraded areas and combined with findings during a rapid survey in 2003 (Giesen, 2004), this results in a list of 148 species that were found in burnt areas of Air Hitam Laut's catchment area. 46 Species are considered as common of which 20 trees, eight climbers, seven ferns, five palms, two shrubs, two sedges, one grass and one aquatic herb. 26 Species of surviving trees, palms and climbers have been observed of which eight are commonly encountered.

General observations indicate that illegal logging activities occur year round, but mainly in the western side of the park. Radar evidence clarifies that pre-fire disturbance was more intense than previously assumed. 107 Bird, 13 mammal and 14 reptile species have been noted within Berbak National Park and just beyond its borders. Although the fires caused a significant loss in biodiversity, several species have clearly benefited from the forest fires. Notable is the finding of Sumatra's second breeding colony of Oriental Darter (*Anhinga melanogaster*) in Berbak's burnt core zone.

Species composition, diversity and forest structure are strongly dependent on abiotic factors. Single burnt sites that face shallow and short flooding are rich in species and have a well developed forest structure. Tree diversity is high and many sites are covered with a closed *Macaranga* canopy. Multiple burned sites that face deep and prolonged flooding have a low species diversity and a poorly developed forest structure as they are largely devoid of trees. Sedges, grasses or ferns are dominant. Peat depth is expected to positively effect regeneration and structural development of single burnt sites, although only a weak correlation was found. On the other hand a remaining peat layer causes a significant rise in fire susceptibility and consequently this factor negatively impacts regeneration in many multiple burnt sites.

Burnt peatswamp forests were observed to have a rather strict pattern of regeneration. Sites that are dominated by grasses and sedges become gradually dominated by ferns as accumulation of organic materials slowly decrease flooding depth and duration. On their turn these fern dominated areas are slowly colonised by *Alstonia pneumatophora* and *Macaranga pruinosa* respectively. In subsequent stages *Macaranga* forms a closed canopy layer. This enables typical peatswamp forest species to settle and the fire-degraded area slowly redevelops into its 'original' state. Multiple fires reverse the process and as flooding conditions usually increase after each subsequent fire, these areas slowly turn into floodplains or lake habitats that are very species poor and that do not regenerate on the short term.

Several factors were observed to have a positive effect on regeneration. Formation of deep peat packages consisting of dead and living fern roots and leaves significantly reduces flooding depth and provides an elevated growth medium for trees that are not tolerant to prolonged and deep flooding. Presence of *Licuala paludosa* palms is hypothesised to decrease fire intensity. On the other hand incidental floods that can kill numerous seedlings may negatively influence the regeneration process.

Based on species composition and forest structure, six vegetation types have been identified in Berbak's fire-degraded areas:

Type 1:	*Pandanus* and *Thoracostachyum* dominated lake-type
Type 2:	*Hymenachne* dominated seasonal lake-type
Type 3:	Sedge and Fern dominated early regeneration-type
Subtype 3a:	Sedge dominated early regeneration- type (flooded)
Subtype 3b:	Fern dominated early regeneration- type (less flooded)
Type 4:	*Nephrolepis* dominated tree establishment- type
Type 5:	*Macaranga* dominated early forest- type
Type 6:	*Macaranga* dominated well developed forest- type

These types are strongly correlated to specific abiotic conditions and can be identified based on their characteristic species composition.

Implementation in replanting trials

The different vegetation types can be used to assess an area's suitability for reforestation, as the rate of a type's natural development, represents its potential for replanting programmes. Each type has been assigned a combined suitability/priority ranking, that indicates a site's potential for rehabilitation. Together with assessment of legislational, social, logistical and financial constraints, this should lead the site selection procedure. Type 3b and 4 were found to be the best candidates for reforestation. Type 5 and 6 have a very strong rate of natural development and should not be considered as primary target. Type 1, 2 and 3a have harsh abiotic conditions and are not suitable for replanting. The 20 trees and two palms that were found to commonly occur in Berbak's fire-degraded areas, are most promising for replanting trials, provided that they are planted under circumstances similar to where they naturally occur. They could then be considered as target species. *Macaranga pruinosa* is of interest in particular, as the species was found to strongly promote the natural regeneration process. Other species with high potential are: *Pternandra galeata, Barringtonia macrostachya, Mallotus muticus, Barringtonia racemosa*, *Syzygium zipelliana, Pandanus helicopus, Pholidocarpus sumatranus and Licuala paludosa.*

Most of the information presented in this report is transferable to fire-degraded peatswamp forests in other parts of Southeast Asia. Information on species composition is very site specific and cannot automatically be applied elsewhere.

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Glossary

Asl	Above sea level
AHD	Air Hitam Dalam River
AHL	Air Hitam Laut River
Basal area	Total surface per hectare covered by tree stems exceeding five centimetres in diameter
B.P.	Before present
CCFPI	Climate Change Forests and Peatlands in Indonesia- project
CIDA	Canadian International Development Agency
Core zone	Large burnt area in the centre of Berbak National Park
DBH	Diameter at breast height (1,3 m)
Desa	Village
Dinas Kehutanan	Forestry service
DSS	Decision Support System
ENSO	El Niño Southern Oscillation
Kem	Camp
Ketek	Motorised canoe
NTFP	Non Timber Forest product.
NP	National Park
Parang-men	Locals assisting in cutting transects through vegetation with machete.
Parit	Agricultural drainage canal also used for transport
Peat, ombrogenous	Peat with nutrient poor conditions; purely rainwater fed
Peat, topogenous	Peat with nutrient rich circumstances; groundwater fed
Perahu	Canoe
Pompong	large motor boot, mainly used for fishing purposes and cargo transport
Pt. PDIW	Putra Duta Indah Wood, logging concession company
Ramsar site	Wetland of international importance following the criteria "as adopted by he 4th, 6th and 7th meeting of the conference of contracting parties to the conventtion of Wetlands (Ramsar, Iran, 1971)", which concerns representative, rare or unique wetland types, wetlands that support vulnerable or endangered species or significant numbers of animals.
Rumah Biru	Ranger post at the confluence of Air Hitam Laut River and Simpang Melaka River.
Simpang	Junction
Site	A place where research is conducted, noted with e.g. AHL N, SM A
SM	Simpang Melaka River
Sungai	River

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1. Introduction

1.1. Problem formulation

In September 1997 Indonesia was affected by one of the country's worst natural disasters ever. Enormous fires spread throughout the western part of the archipelago and destroyed millions of hectares of forest and farmland. The fires persisted for nine months and caused a haze of smoke that reached as far as Singapore and Peninsular Malaysia. More than 13 million hectares were estimated to have burnt and economic damage extended over nine billion USD (Siegert *et al.*, 2001[a]). Extreme droughts caused by the El Niño Southern Oscillation (ENSO) event, combined with severe human impacts on the regions ecology and hydrology proved to be the direct cause of the fire outbreaks. Sites that were affected by logging, drainage and agriculture were most susceptible to burning. The fires were most intense in peatlands as they are particularly sensitive to changes in hydrology, have been facing a high level of disturbance during the last decades and contain a huge stock of easily combustible materials. These peat fires brought along a wide range of local, regional and even global problems. Emission of huge amounts of CO_2 due to combustion of the upper peat layer has contributed to global warming (Rieley & Page, 2004; Siegert *et al.*, 2001[b]). Locally, fires lead to unusually high and prolonged flooding in the wet season, subsidence of peat deposits, erosion and salt water intrusion. These processes together act as a positive feedback loop, the disturbance leading to fires and the fires leading to increased disturbance. As a result many peatswamps that burnt in 1997 have faced repetitive fires ever since, forming a constant threat to unaffected peatswamp forests.

Until now the exact relationship between hydrology and forest fires remains unclear and recovery of peatswamp forest after fire is poorly studied. This makes implementation of adequate measurements to protect the land against future fires and to rehabilitate degraded areas very difficult and therefore a wide array of studies needs to be performed on hydrology, socio-economy and ecology to fill the gap of knowledge and to come to a integrated approach of peatswamp forest management.

The Air Hitam Laut catchment area, situated on Sumatra's coastal plain, Jambi province, represents the conditions of many fire affected areas in Indonesia. It is covered by an extensive peat dome, a large part of which is located within Berbak National Park. This 190,000 hectare Ramsar site has a unique flora and high conservation value for (migratory) birds and mammals. The park protects the largest remaining stretch of peatswamp forest and freshwater swampforest in Sumatra, but is under constant and increasing threat of encroachment (in the east) and illegal logging (in the centre and West). In logging concession areas and farm lands that surround the park, extensive drainage systems have been constructed to optimize conditions for agriculture and silviculture. These drainage systems severely impact the park's hydrology. In 1997 a considerable part of the catchment was affected by the fires, and within Berbak NP more than 17,000 hectares of forest was destroyed.

The project *"Promoting the riverbasin and ecosystem approach for sustainable management of SE Asian lowland peatswamp forest "* , further referred to as AHL-project, has selected Berbak NP for a case study. The project aims to " *asses the nature and impact of human activities on the functioning of the greater Berbak ecosystem, analyze the hydrology of the Air Hitam Laut River and the dependency of the coastal communities on the ecosystem health."* This will result in: *" Improved understanding of the hydrological and ecological functioning of Southeast Asian lowland peatswamp forest, and contribution to an enhanced baseline for policy and decision making in relation to integrated management of peatswamp river basins in the tropics and in particular Berbak NP "* (Gevers, 2002).

The project is financed by the Dutch government under the Partners for Water programme and is coordinated and lead by the International Agricultural Centre (IAC), The Netherlands and Wetlands International Indonesia-Programme (WI-IP). The project is implemented by Alterra Green World research (The Netherlands), Arcadis Euroconsult (The Netherlands), WL/Delft Hydrolics (The Netherlands), LEI (The Netherlands), Wetlands International (The Netherlands) and several Indonesian ministries, planning bureaus and Universities. The Global Environment Centre (Malaysia) is involved on a regional level.

Three disciplines work jointly together in this project. The hydrology component deals with collection of environmental and hydrological data, modelling and assessment of the effect of different land use scenario's on the catchment's hydrology. The socio-economic component deals with topics related to local policies and community awareness and requirements for livelihood. The ecology component studies the state of Berbak NP in general, the extend of regeneration of fire-degraded forest and the link between abiotic circumstances and the success of regeneration. In addition it aims to identify possibilities and requirements for reforestation of affected areas. Replanting trials will be conducted and previous trials will be evaluated. This report is part of the ecology component's output and can be regarded as an extension of the report "Causes of peatswamp forest degradation in Berbak NP, Indonesia, and recommendations for restoration" (Giesen, 2004). It provides more detailed information on the floral composition of fire affected areas, on the process of regeneration in general and assesses the influence of several abiotic factors on regeneration speed. Furthermore, it provides additional information on the park's general conditions.

1.2. Goals

Within this study the following goals have been formulated:

- Development of a better understanding of the underlying ecological processes in regeneration of fire affected peatswamp forest in Berbak NP, aiming in particular at the influence of different environmental circumstances (flooding depth, flooding duration, fire history, soil characteristics and peat depth) on the regeneration process and the extend to which species composition reflects a certain stage of regeneration of a fire-degraded peatswamp forest.
- Identification of tree species that are of interest to rehabilitation programmes.
- Development of a Decision Support System (DSS) that is a tool for decision making in peatswamp forest rehabilitation programmes. The DSS can be used to assess to which affected areas funds for rehabilitation should be allocated and indicates which species could be replanted and incorporates a number of legislational, social and logistic constraints.
- Acquisition of additional information on Berbak NP's condition in respect to:
  -Forest fires: distribution and re-occurrence.
  -Illegal activities: logging, poaching and fishing.
  -Biodiversity: occurrence of birds, mammals, reptiles and amphibians.

2. Southeast Asian peatswamp forests and their ecological significance

2.1. Genesis and formation of tropical peats

Over the years peat deposits have established at numerous sites throughout the Southeast Asian region. They developed at different times and under different abiotic circumstances and due to these distinct characteristics the deposits are classified in three types: high peats, coastal peats and basin peats (table 2.1).

Formation of high peats, the oldest deposits in Southeast Asia, started about 9000 years ago (Rieley 1991). After termination of the Würm glaciation ten to twelve thousand years B.P., long periods of rainfall caused strong acidification and leaching of nutrients in elevated watersheds (30-50 m asl) in the interior of Kalimantan. These processes created circumstances suitable for formation of ombrogenous peats that are, referring to their high geographic position, classified as *high peats*. Until now high peats are solely known from Kalimantan, but given the geologic characteristics of some regions in Malaysia it might be possible that they occur (or have occurred) there as well (Rieley, 1991).

Formation of *coastal peat*, started more recently after the sea level ceased rising and stabilised at approximately 5000 B.P.(Rieley, 1991; Silvius *et al.* 1984). Through deposition of clay particles transported by rivers from far inland, alluvial plains were formed in large parts of the Southeast Asian region (figure 2.1). This coastal accretion took place at a rate of 9 to 20 m per year (Silvius *et al*., 1984; Whitmore, 1984), although at periods of volcanic activity deposition of volcanic debris presumably accelerated coastal accretion (Whitten *et al*., 2000). Information derived from old maps indicates that accretion up to 100 m per year occurred along the coastal plain of Sumatra in some periods. A relative drop of sea level ranging from three to six metre that took place in Southeast Asia from about 5000 BP onwards (Diemont, 1988), might explain this rate (Whitten *et al*. 2000). At first the alluvial plains were colonised by mangroves. Within these mangrove swamps abiotic circumstances soon became unfavourable for micro-organisms and the process of biodegradation: lack of oxygen, constant water logging and the presence of toxic substances decreased the rate of decomposition and allowed the formation of organo-mineral complexes and an organic layer. In this way topogenous peat was formed and typical mangrove species, that prefer a clayey soil, were slightly replaced by other plants. As accumulation of organic material proceeded the peat became ombrogenous (purely rainwater-fed and nutrient poor).

As the peat layer develops on the alluvial plains and distance to the sea increases due to coastal accretion, transformation from coastal peat into *basin peat* takes place. This process proceeds very slowly and may take up to 2000 years.

Table 2.1 Different types of Southeast Asian peat and their characteristics.

	Origin	**Range**	**Subsoil**
High peats	Ombrogenous	Elevated watersheds	Podsolised sandy soil
Coastal peats	Topogenous at formation turning in to ombrogenous	Coastal areas	(Reduced) clay
Basin peats	Ombrogenous	Coastal areas, inland	Coastal peat and clay

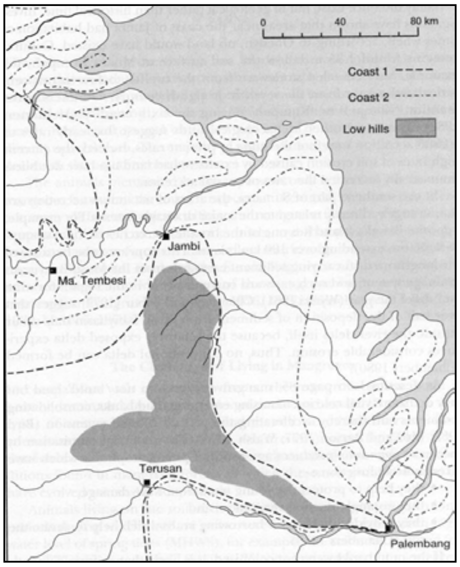

Figure 2.1 Coastal accretion in Air Hitam Laut's catchment area. Dashed lines represent hypothetical coastlines in geologic time.
(After Whitten 2000)

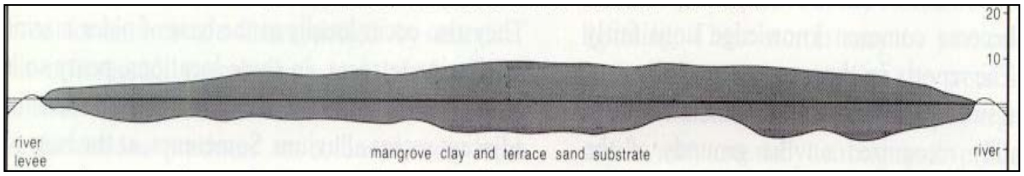

Figure 2.2 Cross-section of a peat dome
(After Bruenig 1990)

Peat accumulation speed depends on the age of the peat soil and declines as peat grows older. Young peats accumulate at a maximum rate of 475 mm per 100 years (Whitmore, 1984). Old peats may grow 223 mm per 100 years, although in most cases the rate of accumulation is much lower and under certain circumstances even oxidation of the upper peat layer may occur (Whitmore, 1984; Rieley *et al*., 1994). The strong correlation between peat age and rate of accumulation explains the shape of a peat dome: the outer slopes of the dome are 'steep'(figure 2.2), because of high accumulation rates, the centre of the dome is almost flat or even depressed because of declined accumulation or oxidation. Today the formation of coastal peat and the slow transformation into basin peat are still taking place. Human influences on hydrology of peatlands however, are significant and may strongly slow down or reverse the process of peat formation in the future (see paragraph 2.5). Measurements within the Southeast Asian region revealed various peat depths within peatswamp forests, depending upon age and abiotic circumstances. Under natural circumstances, tropical peats show a dome shaped appearance, whereby the central part displays the thickest peat layer in contrast to the shallow fringes that are of younger age. The highest peats may reach a depth of 20 (Bruenig 1990, Whitmore 1984, Anderson, 1958) or even 24 metre (Giesen 2004), although abiotic circumstances often stop peat accumulation in an earlier stage.

2.2. Distribution

Tropical peats are widely distributed throughout the world. Small tracts are situated in South and Central America (Brazil, Guyana, Costa-Rica), in parts of the Caribbean (Jamaica, Cuba) and in Africa (Burundi, South-Africa). The vast majority of tropical peat is located in Southeast Asia.
Rieley (1994) states that undisturbed tropical peatlands comprise over 12 percent of the global peat surface, but it is important to realize that accurate up to date estimations are difficult to make as large peat surfaces are constantly prone to strong degradation resulting from drainage and land conversion. Following international accepted criteria for the definition of peat (> 30 percent organic matter in a cumulative layer of at least 40 cm), Rieley (1994) estimates the total area of peat soil in SE Asia to be 33 million hectares. 27 Million hectares are situated in Indonesia, mainly on Sumatra and Kalimantan. Smaller areas are found in surrounding countries (table 2.2).

Table 2.2 Distribution of peat soils within Southeast Asia

Country	**Surface (ha)**	**Source**
Indonesia	27,000,000	*Rieley (1994), (1991)*
Sarawak	1,450,000	*Rieley (1994), (1991)*
Peninsular Malaysia	800,000	*Rieley (1994), (1991)*
Vietnam	183,000	*Giesen (2004) / Rieley (1994), (1996)*
Philippines	240,000	*Giesen (2004) / Rieley (1994), (1996)*
Thailand	64,000 – 68,000	*Giesen (2004)/ Rieley (1991)/ James (1991)*
Brunei	10,000	*Rieley (1991)*

Many countries have already lost considerable amounts of their peat resources. Ongoing activities (land reclamation, drainage, and logging) and repetitive fires will further diminish peat areas in the next decades and therefore a regular update of peat cover estimates is urgently needed. Not all tropical peats are covered with peatswamp forest as some peat soils are covered by other forest types (including plantations), and furthermore logging and land conversion have destroyed large tracts of peatswamp forest over the years. A reliable estimate of the actual coverage of peatswamp forest is currently unavailable but it is clear that the area of remaining peatswamp forest is much smaller then the amount of tropical peat.

2.3. Ecology

During many decades peatswamp forests were little studied by researchers. For years Anderson (1958) was one of few authors who conducted detailed research on the ecology of peatswamp forests, although Giesen (2004) summarises a number of less known publications that contributed to the knowledge of the ecosystem as well.

From the late 1970s onwards, interest in peat soils increased as possibilities for agricultural use were investigated (Radjagukguk, 1997). In subsequent years the importance of the ecosystem for sustainable land use and biodiversity became commonly recognised. Concerns about ongoing large scale destruction of formally pristine peatswamp forest resulted in a number of projects[1] aiming to gain a better understanding of the ecology and hydrology of peatswamp forest and to enhance management of peatland areas. Although knowledge of the ecology of these ecosystems remains far from complete, these projects helped generate additional information concerning diversity, composition and forest structure.

peatswamp forests are often compared to lowland Dipterocarp forest as both ecosystems have many plant and animal species in common. Being poor in nutrients however peatswamp forests support less species than lowland Dipterocarp forests with no more than 234 tree species recorded (Giesen, 2004). The level of endemism is low as the ecosystem originated in historic rather than prehistoric times (Whitmore, 1984). Despite this, peatswamp forests harbour a number of species that are more or less dependent on this ecosystem for future survival (e.g. White-winged duck (*Cairina scutilata)*, Storm's stork (*Ciconia stormi)*, and False gharial (*Tomistoma schlegelii)).* Furthermore a number of formerly widespread species that are now rare throughout their range can be found in peatswamp forests (e.g. Sumatran rhinoceros (*Decerorhinus sumatrae)*, Sumatran tiger (*Panthera tigris sumatrensis)* and Orang utan (*Pongo pygmaeus)* on Borneo). This makes the peatswamp forest-ecosystem, as an important gene-pool, critical for maintaining biodiversity.

The structure of peatswamp forests is unique as extreme environmental circumstances strongly influence forest growth. The numerous adaptations used by plants to cope with the hazardous environment contribute to the unique forest appearance as well.
Trees survive water logged periods through formation of numerous pneumatophores and aerial roots. Seedling successfully colonize local micro-elevations (e.g. fallen logs) to prevent drowning in the first months after germination (Giesen, 2004). To deal with pH values varying between 3,0 and 4,5 (Rieley, 1994; Yonebayashi *et al*., 1997) plants require physiological adaptations. The most influential abiotic factor however is the low nutrient availability in peat soils. To prevent loss of nutrients through herbivory, plants form toxic compounds and strong protecting tissues in fruits, leaves, seeds and other parts. Symbiotic relationships with insects may provide some plant species with an extra source of nutrients (e.g. certain rattans and *Macaranga* sp. have adaptations to attract ants). Carnivorous plants (e.g. *Nepenthes*) are well represented in peatswamp forests, especially at the centre of the peat dome, where nutrients are scarcest.

As a result of the strong correlation between abiotic factors and vegetation, slight changes in environmental circumstances have strong effects on both species composition and forest structure. This can be seen along the peat dome, where tree height, girth and species diversity declines from the edge inwards.

At a peat dome's outer zone trees are generally high (40-75 metre) and basal areas range from 40 to 57 m^2 per hectare (Shepherd *et al*., 1997; Whitten, 2000; Silvius *et al*., 1984). More towards the centre tree height and basal area commonly decrease. In some peat domes on Borneo the trees in the central zone don't exceed a height of 10-15 metres. Here basal areas are low, being 33 m^2 per hectare in the centre of a peat dome on Borneo (Shepherd *et al*., 1997)

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[1] CCFPI (Climate Change Forests and Peatlands in Indonesia -project), Conservation and Sustainable use of Tropical Swamp Forests and associated Wetland Ecosystems-project, and Integrated Management of Peatlands for Biodiversity and Climate Change-project.

In many peatswamp forests, species composition changes along with forest structure. Anderson (1958) described a total of six vegetation types that may occur along the dome of a peatswamp forest in Sarawak. However it is important to realise that this is a theoretical sequence rarely found within the field and most peatswamp forests contain fewer discernable vegetation types. Furthermore, it is important to stress that each peatswamp forest has a unique combination of abiotic circumstances and therefore a unique vegetation composition. Applying ecological knowledge derived in one peatswamp forest to another should be done with great care.

2.4. Values of peatswamp forests

Undisturbed peatswamp forest-ecosystems perform a wide array of functions and uses, and additional values are commonly recognised. Besides their importance for conservation of biodiversity, peatswamp forests play an important role in many global environmental processes. In addition, peatswamp forests may be of considerable economic value, directly through durable harvest of forest products, and indirectly as suppliers and protectors of bordering agricultural lands.
James (1991) and Rieley *et al.* (1994) summarised a number of functions performed by peatswamp forests. A selection of these are listed in table 2.3.

Table 2.3 Long term functions, values and uses of undisturbed peatswamp forest-ecosystems (adapted from James (1991), extended with information derived from Rieley et al. (1994).

Functions:	**Uses:**
Mitigation of flooding	Recreation
Prevention of salt intrusion (coastal peats)	Water supply
Protection against erosion	Forest products
Storage of toxicants/ radioactive fall-out	Research (ecology/hydrology/geology)
Sediment capture	Recreation
Nutrient capture	Shelter for indigenous tribes (e.g. Kubu, Berbak NP)
Water quality maintenance	
Carbon storage	
Biodiversity conservation	

A number of these values apply to Berbak National Park in particular:

Prevention of salt intrusion
As Southeast Asia's coastal plains are situated at a few metres asl, intrusion of saline seawater in coastal agricultural lands can be a serious problem. peatswamp forests combat this intrusion as continuous outflow of freshwater mitigates saltwater inflow. Moreover the waterbodies present in elevated peat domes, buffer upward seepage of underlying saline waters (James, 1991). Despite these capacities, salt water naturally intrudes for several kilometres, mainly during the dry season, as can be deduced from *Nypa fruticans* palms. This species grows under brackish conditions and occurs along rivers from rivermouths to about ten kilometres inland. In areas with deteriorated peat soils, this intrusion is expected to be significantly higher.

Mitigation of flooding, water storage and water discharge
Peat domes have a huge water storing capacity, and as incoming waters are rapidly absorbed, flooding risks of surrounding areas are diminished. In addition, water is discharged slowly so peatswamp forests guarantee a continuous supply of water. Some agricultural lands (e.g. rice paddies in Malaysia) have been found to be completely dependant on this continuous supply

Deleted:

(Rieley *et al.*, 1994). Maintenance of water quality for drinking water and fisheries is another important function.

Conservation of biodiversity
The values for retaining biodiversity have already been dealt with previously and will not be discussed in this section.

Durable harvest of forest products
Peatswamp forests represent a direct economic value as a high diversity of Non-timber forest products can be harvested from the forest. Among others James (1991) and Rieley (2002) mention construction materials, dyes, latex, food and medicine constituents as non timber forest products. Provided that they are collected with care, harvesting will not cause unacceptable damage to the ecosystem.

Shelter for indigenous tribes
Although they have not been recorded in the area for many years, a small number of Kubu-people may still survive in Berbak's most remote zones. This nomadic tribe avoids civilisation as much as possible, and survival of this indigenous group and their culture depends solely on the continuing survival of natural forests such as Berbak NP.

Carbon storage
World wide, peatlands act as important carbon sinks, storing a significant portion of the world's terrestial carbon. Although a minority of the world's total peatland area is situated in tropical regions (nine percent or 38,3 out of 420 Mha), tropical peats in particular are important actors in the carbon cycling as they can reach a considerable depth (up to 24 metres) and have high rates of accumulation (three to six times higher than in temporal peats) (Rieley and Page 2004). Therefore protection of the areas is considered to be very important in the battle against global warming.

2.5. Threats of peatswamp forests

Tropical peatswamp forests have long been regarded as hostile areas, inaccessible, unsuitable for agriculture and of low economic value. As the need for economic development increased, opportunities for reclamation and timber harvest were evaluated and efforts were made to cultivate these areas. This occurred first in mainland Southeast Asia (Malaysia, Thailand) where the vast majority of peatswamp forest has now disappeared through logging and land conversion. peatswamp forests in Indonesia and Sarawak have long escaped this fate, but in recent decades Indonesia has faced a growing number of activities that increasingly affect the ecosystem.
In Indonesia, two policies contributed significantly to these activities. Firstly, the *transmigrasi*-policy, implemented nationally from 1979 onwards, settled millions of Javanese and Balinese people in underdeveloped areas, creating a huge need for development and use of available resources. Secondly, the policy of *decentralisation*, initiated in the post-Suharto era, created new problems with a further increase in inadequate law enforcement. In practise this system, that gives local governments a high level of autonomy, is strongly influenced by local economic interests and therefore sensitive to corruption. This culminated in a number of events and side effects that caused irreversible damage to peatswamp forest-ecosystems.

Logging
On a large scale Indonesian forests are prone to both legal and illegal logging. Each year, large tracts of forest are clearfelled and damaged. An official status (i.e. National Park) by no means guarantees protection against such logging as responsible governmental bodies often don't have enough power or motivation to act against illegal activities. Besides the strong negative impact of

logging on biodiversity and ecosystem balance, there are significant indirect effects as well. Research indicates that the majority of El Niño associated forest fires occur in areas that are degraded through logging as opening up of the forest canopy increases susceptibility to forest fires (Giesen, 2004; Siegert *et al*., 2001[a]).

Cultivation of peatswamp forests

Over the years large surfaces of peatswamp forest have been reclaimed for agricultural and silvicultural purposes. Most land is used for oil palm plantations, smaller areas are planted with commercial (pulp) timber species, coconut and rice. Naturally abiotic conditions of peat soils are unfavourable for crop growth, and consequently active measures are regularly undertaken to improve soil quality. One of the most influential measures is drainage and in many agricultural areas extensive networks of canals are constructed to enable crop growth. As hydrology of peat soils is very sensitive to disturbance, drainage has a huge impact on peat properties, both within the agricultural land as well beyond it's borders in other parts of the catchment. A direct effect of drainage is subsidence and deterioration of the upper peat layer through oxidation. This poses a serious threat to peat soils, as deterioration can destroy a peat soil within one or two decades, or even faster, leaving no more than a poor mineral subsoil that is even less suitable for crop growth. Field studies indicate that both subsidence and oxidation cause a decrease of 20 to 50 centimetres in the first years after drainage. In subsequent years this rate decreases to approximately two centimetres per year, the exact rate depending on the water regime of the area. CO_2 emission in a drained peatswamp in Southeast Asia is significant and is expected to strongly contribute to the green house effect (Rieley & Page, 2004). In a Malaysian peatswamp forest emission was found to be significant, and is estimated to be up to 26,5 tons per hectare per year (Wösten *et al.*, 1997). In other regions similar or even higher rates were found. Drainage strongly influences susceptibility to fires, as drained peat soils burn readily. The effects of these fires can be very destructive mainly in El Niño years when extreme drought further increases fire risk. In 1997 fires destroyed more than 13 million hectares in Indonesia, mainly agricultural land and logged concession areas, but also adjacent pristine forests (figure 2.3). Recovery of those burnt areas is difficult and they are very sensitive to repetitive burning. Disappearance of peat through oxidation and fire further increases drainage, thus creating an almost irreversible positive feedback process. Saline intrusion and coastal erosion may follow degradation of the peat soil, posing another threat to people and nature.

Figure 2.3 Fires initiated to clear land from vegetation for agriculture or building purposes, easily turn into wild fires that can destroy thousands of hectares.

2.6. Forest fires in Indonesia

Before the 1980s, forest fires in Indonesian peatswamps were exceptional. Even during extreme El Niño associated droughts that were present in the beginning of the 20th century fires outbreaks were uncommon (Siegert *et al.*, 2001[a], Siegert et al, 2001[b]). During the 1983 El Niño event however, large fires burnt 3,5 million hectares, mainly on Borneo (Siegert *et al*, 2001[b]). Sites that were previously disturbed by human activities, proved to be most affected by the fires. In contrast pristine forest areas stayed relatively unharmed.

Clearing or logging of pristine forest strongly increase fire susceptibility. Combustible materials left behind on the forest floor, will be the fuel for a possible fire. Moreover, as the canopy is opened, sunlight can reach the forest floor, resulting in increased growth of understorey vegetation, increased temperatures, reduced humidity and a lowering of the soil moisture content. In addition, the increase of wind flow will both dry out the area and help to spread a fire. In contrary, pristine forest is not susceptible to fires, not even in the driest periods. The closed canopy retains the moist microclimate on the forest floor, and little vegetation is present in the lower height classes that can be subject to burning (Dawson, 2000). Forests that have been degraded by human activity or a previous fire become more susceptible to subsequent fires, and will often burn until all combustible material has disappeared.

All forest fires start as a ground fire, only setting fire to the litter layer, undergrowth and the lower part of tree trunks at a speed of up to several metres per minute. If conditions are suitable, this ground fire can develop in either a tree crown fire or a peat fire. The first can travel at enormous speed (more than 100m/min) through the canopy high above the ground, burning only leaves and twigs (Artsybashev, 1984). In more severe situations the fire is bound to one area, leaving charred trunks behind. In peatswamp forests, the effect of peat fires is even worse. A severe drought can desiccate peatsoils to a great extent, and they are then easily affected when a ground fire penetrates into the peat horizon. The fire will burn a pit, and slowly travels through the combustible peat deposits horizontally (figure 2.4). As peatswamp forest tree species are mainly anchored into the upper peat layer, they will be uprooted as their root system is affected when the surrounding peat is burnt (Artsybashev, 1984).

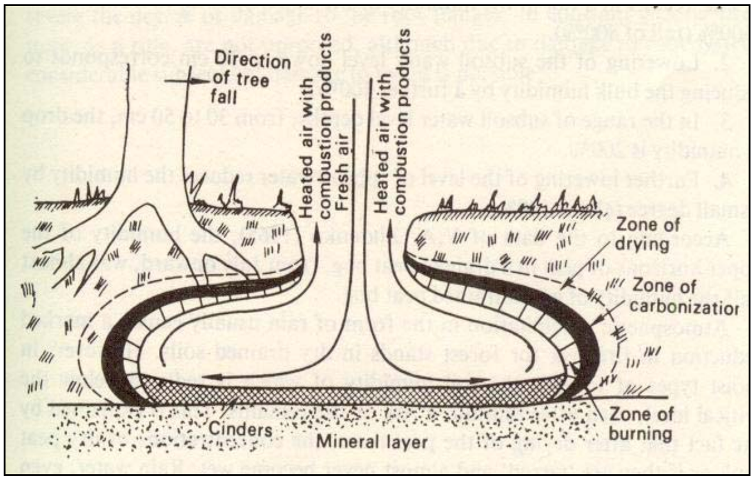

Figure 2.4 Typical occurrence of peat fire pits that originate from ground fires and move horizontally in the peat soil.
(after Artsybashev, 1986)

More than a decade after the 1983 forest fires human influences increased rapidly as large areas were cultivated, (illegally) logged and severely drained (paragraph 2.5). These developments made the 1997/1998 forest fires, again associated with El Niño, the worst Indonesia ever experienced. The estimated area that was affected by the fires increased to 13,18 million hectares, whereas earlier studies estimated a lower amount of 3,06 and 6,5 million hectares respectively (Siegert *et al.*, 2001[a]). At least 1,4 million hectares consisted of peatland (Siegert *et al.*, 2001[a]). Economic consequences where significant, and it was estimated that the fires caused direct damages of nine billion USD, while an additional 300 million USD was spent on medical services (Parish, 2004).

The fires were most intense in peatlands as dry peat soils contain huge stocks of easy inflammable materials. Burning of the peat and aboveground biomass caused emission of significant amounts of carbon and enormous clouds of smoke covered large parts of Indonesia and extended to the mainland of Southeast Asia. During the 1997 forest fires, between 1 and 2,5 billion tons of carbon was released in to the atmosphere, contributing to 15-40 percent of average global annual carbon emission (Rieley and Page, 2004; Siegert *et al.*, 2001[b]). This is the highest emission ever measured since the monitoring started in 1975. Burning of the upper peat layer destroyed up to 150 cm, the exact amount of deterioration depending on the intensity of the fire and the ground water level (Siegert *et al.*, 2001[a]) and caused excessive flooding. In subsequent years, peat fires occurred annually, further burning the upper peat layer and increasing flooding time after time.

2.7. Natural regeneration: State of the art

The regeneration of forest after peat fires has been poorly studied. Regeneration of peatswamp forests is known to proceed slowly where flooding and soil quality are expected to be important factors in the process (Giesen, 2004). Flooding is known to influence regeneration, as seedlings are not able to withstand prolonged flooding conditions and there seem to be critical levels in flooding depth and duration that determine a species' possibility to establish. Peat depth is expected to be of influence on regeneration, as conditions for establishment of peatswamp forest-species are relatively positive on peat soils, in contrast to the underlying subsoil that is often a poor medium for plant growth. However, exact relationships between peat depth, flooding and regeneration are not yet fully understood.

Many peatswamp forests revert to species poor vegetation types after burning, and are dominated by ferns (e.g. *Stenochlaena palustris, Blechnum indicum*), sedges (e.g. *Scleria purpurascens*) and grasses (*e.g. Hymenachne amplexicaulis*), the exact species composition depending on the extend of flooding in the area. Nonetheless, Giesen (2004) identified a total of 87 species within burnt sites of BNP, some of these were only found in riparian vegetation along Air Hitam Dalam in the north-west of the park in a site that is temporally influenced by the intrusion of nutrient-rich water originating from the Batanghari River. The others were found in the central zone and west of the park in areas that are only rainwater-fed. This indicates that under certain circumstances diversity can be relatively high.

Few studies have focused on rehabilitation of peatswamp forest, although planting trials on the mainland of Southeast Asia and Borneo identified a number of species that are promising for replanting[2] (Giesen, 2004). Based on this experience CIDA, Dinas Kehutanan and Wetlands International started a number of replanting trials in Berbak National Park. The trials failed, because they were carried out under sub-optimal conditions. These were situated close to the river where flooding is deep and prolonged and initiated at the wrong time. Consequently the majority of seedlings did not survive. This indicates that appropriate site selection and additional measures are essential for successful replanting and that a suitable baseline for decision making in replanting trials urgently needs to be identified. Mounds (artificial micro-elevations constructed with clay or peat) seem to be an important tool for peatswamp forest replanters, but detailed studies on optimal mound height and construction are still underway.

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[2] It should be noted however, that most of these trials were situated in areas that were degraded by (selective) logging rather than by burning.

3. Berbak National Park[3]

The 190,000 hectare Berbak National Park is situated on Sumatra's coastal plain, in the eastern part of Jambi Province, Indonesia. The park is bordered by the Benu River in the South, extends just beyond Air Hitam Dalam River in the north-west and lies in close proximity to the South China sea with which it used to border before Buginese settlers reclaimed the coastal fringe and thus forced officials to adjust its borders (figure 3.1). Berbak received protection as far back as 1935 when the area was proclaimed as Game Reserve by a decree of the governor of the Netherlands-Indies government. In 1991, after Indonesia ratified the Ramsar convention, Berbak became its first Ramsar site as the park was recognized as a wetland of international importance for flora, fauna and migratory birds in particular. One year later Berbak's status was further upgraded and it became one of Indonesia's 33 National Parks.

Most of Berbak is covered by a dome-shaped peat layer. The peat dome reaches a depth of over ten metres in the western part of the park, becoming gradually thinner towards the coast. The inorganic (mineral) subsoil is very flat throughout the park, rising slightly further inland, with (local) elevations never exceeding more then several metres above sea level. The dome is drained by three rivers: Air Hitam Dalam, Air Hitam Laut and Benu. These are called black water systems, as they transport blackish waters, coloured by phenolic acids and tannins. The systems are ombrogenous as the catchments are purely rainwater fed and do not receive nutrient-rich water from elsewhere. The only exception is Air Hitam Dalam River in the north-west of the park, that merges with the Batanghari River and regularly receives nutrient-rich water at high tides and during floods.

Formally, six vegetation types were described to occur in Berbak National Park (table 3.1). peatswamp forest and freshwater swampforest are most common with an estimated cover of 110,000 and 60,000 ha respectively before the 1997/1998 fires. The other types covered smaller areas within the park's borders: Mangrove forest and Dry beach forest are not found anymore within the park, after reclamation and adjustment of its boundaries. Due to the forest fires that destroyed large areas of forest, the cover of different vegetation types has changed drastically. Most areas are recovering and or are still mired in an early stage of succession. Some parts may never turn into forest again, while others may develop into new vegetation types or even aquatic ecosystems.

Table 3.1 Main vegetation types occurring in Berbak National Park before reallocation of its boundaries (1984).

Vegetation type	Surface (ha)	Original cover
Peatswamp forest	110 ,000	58 %
Freshwater swampforest	60,000	32 %
Mangrove forest	20,000	10 %
Riverbank vegetation	< 1,000	< 1 %
Riverine forest	< 1,000	< 1 %
Dry beach forest	< 1,000	< 1 %

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[3] This chapter summarizes findings of Silvius *et al.* (1984), Giesen (1991,2004) and is extended with observations made during the present survey.

Entering Berbak from the East along the Air Hitam Laut River one will first observe dense growth of salt resistant *Nypa fruticans* palms. These palms grow in single species stands for many kilometres in a narrow fringe along the river, as high tides bring brackish waters far upstream. One kilometre upstream of the junction of Simpang Melaka and Air Hitam Laut and at the rivers branches (Simpang Melaka and Simpang Gajah) the salt level drops below a critical level. Here *Pandanus helicopus* and *Hanguana malayana* take over from *Nypa*, the former dominating river side vegetation, the latter floating in dense clumps on the river often preventing transport by boat further upstream.

Away from the riverbank, Fresh water swamp forest is found, dominated by *Alstonia pneumatophora, Antidesmum montanum* and *Licuala paludosa*. Further inland, as the peat layer becomes thicker, the Fresh water swamp forest changes into peatswamp forest with *Koompassia malacensis, Diospyros bantamensis* and *Stemonurus secundiflorus* as common tree species. Tree height and girth decrease with increasing peat depth, while tree density is higher on deep peats.

The vegetation along Air Hitam Dalam in the north-western part of the park is by no means comparable with that along Air Hitam Laut, as the former receives eutrophic waters from the Batanghari River. Species common here, not found along Air Hitam Laut, include *Cerbera odollam, Dillennia excelsa, Gluta renghas* and *Ficus microcarpa*. As a result of those eutrophic conditions species diversity along Air Hitam Dalam is twice to four times as high as in Air Hitam Laut (Giesen, 2004).

Until now, several scientists have conducted studies on flora and fauna in the park. In 1981, Franken and Roos were the first to publish an overview of the flora of the park. The most detailed inventory in Berbak was executed by Silvius *et al*. (1984), who compiled extensive lists on flora and fauna and did research on physiognomy, soils, and demography. Much information in this chapter is derived from their study. Giesen (1991) extended the flora list of Berbak, and did some additional animal observations. Over the years, observations on mammals and birds were made by several study teams in the park, and crocodile inventories were carried out twice.

In total 261 plant species have been recorded (Giesen, 2004) in the Park. The bird list exceeds 250 species. Rare species include White-winged duck (*Cairina scutulata*), Storm's stork (*Ciconia stormi*), Milky stork (*Mycteria cinera*) and Wallace's hawk eagle (*Spizaetus nanus*). During the present survey the second breeding colony of Oriental darter (*Anhinga melanogaster*) for Sumatra was recorded. The mammal list extends over thirty species, with Sumatran rhinoceros (*Dicerorhinus sumatrensis*), Sumatran tiger (*Panthera tigris sumatrae*), Malayan sun bear (*Helarctos malayanus*) and Malay tapir (*Tapirus indicus*) as notable species. The reptile list is far from complete, but River terrapin (*Batagur baska*), Estuarine crocodile (*Crocodilus porosus*) and False gharial (*Tomistoma schlegelii*) have been recorded. Invertebrates have barely been surveyed.

Since Berbak received a protected status in 1935, the park has had to deal with numerous problems threatening its integrity. Encroachment by local farmers and forest concession holders and unsustainable harvest of forest products have been the largest threat. Already between 1936 and 1939 villagers reclaimed 205 ha within the park's borders for farming purposes. From the 1950s onwards, large areas were cultivated around the Tanjung Jabung area by Buginese settlers. A second wave of settlers in the 1970s, further increased the rate of land conversion. In a period of ten years they converted almost the complete fringe of Berbak National Park in farm land, making it necessary for the government to adjust it's boundaries. In order to drain the soil for cultivation of rice and coconut, the farmers constructed parits[4] , thus affecting Berbak's hydrology. These activities led to the forest fires, that destroyed several thousands of hectares in

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[4] Parits are small canals up to 3400 metre long, two metres wide and 1,5 metres deep often extended with 250 metre side canals that are constructed at regular intervals perpendicular to the main channel (Silvius, 1984)

1982 in the coastal region and along Sungai Benu. Illegal logging activities were already on their way in the early 1980s in the park's Southern part. These increased considerably from the 1990s onwards throughout the park, but mainly in the West and along Air Hitam Dalam. A short description of the events that took place from 1983 to 2003 is presented in chapter 5. For a more exhaustive overview see Giesen (2004). Forest concession companies posed a threat throughout the years, as some concession areas were allocated within the park's boundaries. Changes in hydrology caused by drainage of concession areas have significantly affected the parks ecosystem. Together with activities of illegal loggers it was the onset of forest fires that occurred in the park during the last decade. The 1997/98 fires were the most extensive, burning 17,000 ha (about 10%) of the park. Since then, fires have re-occurred annually, mainly at sites that were already fire affected. Poaching of reptiles and birds is a threat to the park as well, although there are no detailed studies that evaluate the extent and impact of these activities.

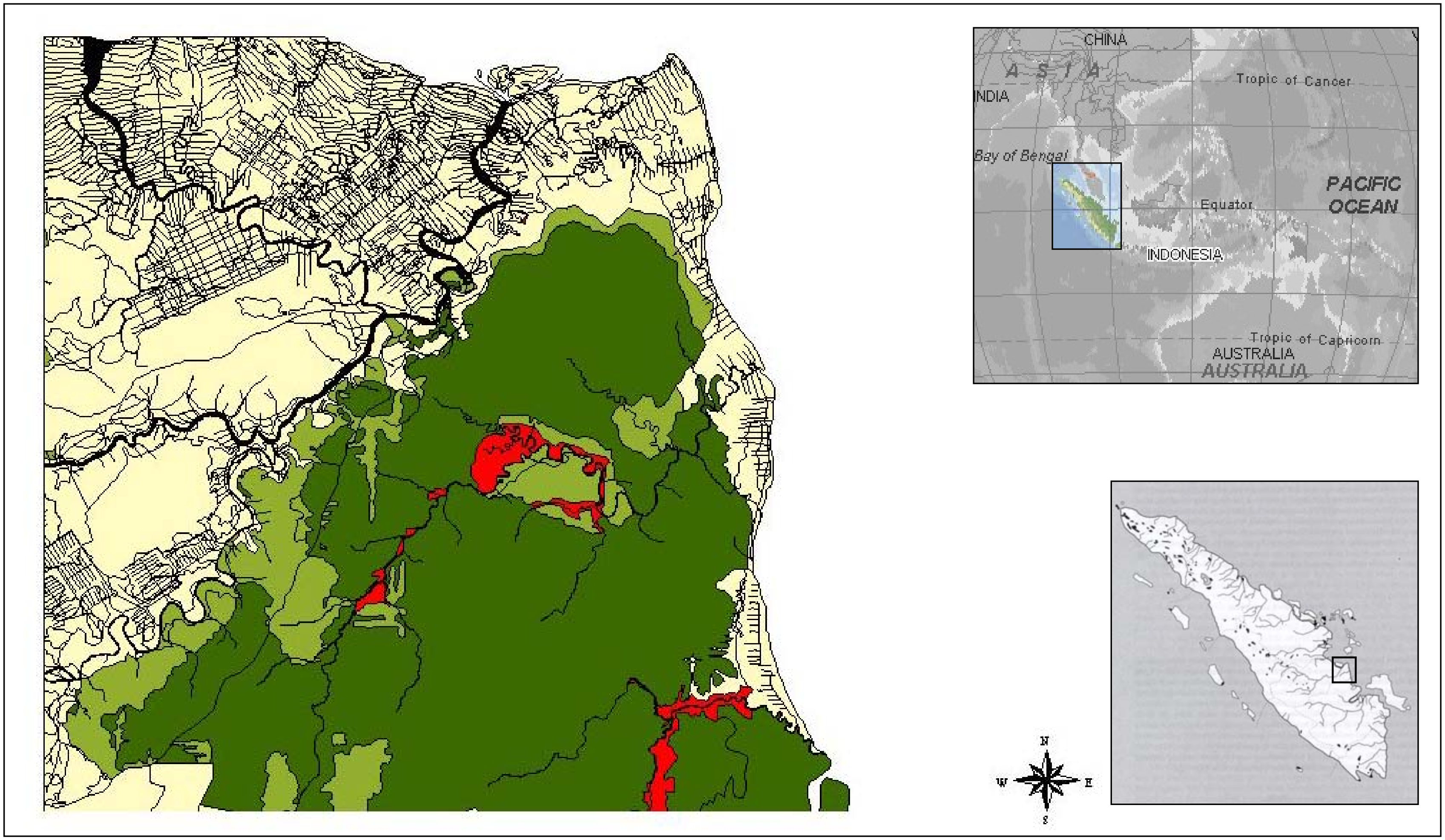

Figure 3.1 Geographical position of the research location. Large map depicts Berbak NP and surrounding forest concession areas (dark green). The burnt core zone and the burnt area along Simpang Melaka River are situated in the centre of the Park.

4. Methodology

4.1. Selection of research sites

Prior to the field trips, satellite data were used to make a selection of appropriate research sites. Landsat images of 1983, 1989, 1992, 1997, 1998, 1999 and 2002 covering the majority of the park, give a clear overview of fires and disturbances that occurred within the park's borders and its direct surroundings. To reveal the exact locations of fires that occurred in more recent years a HotSpot[5] data file, covering all HotSpots in Jambi province between 2001 and 2003, was obtained from Dinas Kehutanan. The geometric location of each HotSpot was transferred into a Geo Information System and an overlay was produced in order to combine the HotSpots from all the years into one image (annex 1).
Together the Landsat images and the GIS-HotSpot overlay were used to select a number of locations with different fire histories as potential research sites. The exact geometric location of these sites as deduced from GIS-images and stored in a Global Positioning System.

The following sites were selected:

- Single fire sites, burnt in 1997.
- Multiple fire sites, burnt two or more times.

Unfortunately, it proved impossible to select single burnt sites that had already burnt before 1997. Selection of sites that burnt for the first time after 1997 was also not successful, as the HotSpot data and satellite images indicate that most fires reoccur in areas that have already burnt in 1997. The HotSpot file contains a few HotSpots that indicate fires in pristine forest after 1997, but these sites are difficult to reach and most are situated at the borders of the National Park were human activities are evident. During the field trips these sites were not visited and therefore their current condition remains unclear.

All sites selected were situated within National Park borders because outside the park (e.g. west of the park in Pt. PDIW's concession area) human impacts are so prominent that they render the study of natural regeneration impossible. It was decided not to collect data near the Air Hitam Dalam River as this river regularly receives eutrophic water from the Batanghari River and is therefore by no means comparable to other sites. The forest surrounding the river can be considered as freshwater swampforest, not as peatswamp forest. Burnt areas to the South of the park, along Sungai Benu River were not selected because the situation in that

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[5] The NOAA (National Oceanic Atmospheric Administration) satellite, which was developed for weather and oceanic purposes, is now commonly used for fire monitoring in large remote areas. This satellite is equipped with an AVHRR (Advanced Very High Resolution Radiometer) sensor that is able to detect differences in surface temperature at a maximum spatial resolution of one square kilometre. The cell is only depicted as potential HotSpot or High Temperature Event (HTE) if the surface temperature is above the threshold value, which ranges between 303º and 308º Kelvin for night-time images (Hoffmann, 2002). An HotSpot is not always indicative of a fire but can also be caused by another hot object, leading to a misidentification up to 50 percent of the initial recorded points (Stolle, 2000). Moreover a HotSpot gives no information about the number, size and intensity of the potential fires, and due to the resolution of the sensor and the process of geo referencing the spatial error of NOAA-AVHRR HotSpots is estimated at about 3 km (Hoffmann, 2002).Therefore HotSpot data should be interpreted with great care.

region is unstable resulting from a conflict between park rangers and local villagers about demarcation of the National Park.

Following selection of sites based on satellite data, a definitive selection of appropriate research locations was made in the field, as many site characteristics are only visible on location. In the field, sites were selected that were expected to differ in flooding depth, flooding duration and peat depth. In between actual fieldwork activities, regular explorations were undertaken to ensure a balanced selection of research locations.

4.2. Itinerary and logistics

The park was visited from three directions:

- Three times from the East, from Desa Air Hitam Laut upstream on the Air Hitam Laut River to the centre of the core zone, on the Simpang Melaka River about two kilometres upstream of the National Park's replanting trials and on Simpang Kubu River, to the point were the river enters pristine forest.
- Two times from the West, from Pt. PDIW's railroad downstream on the Air Hitam Laut River, one kilometre east of Simpang-T and two kilometres upstream of Simpang-T River.
- One time from the north on the Air Hitam Dalam River, for general exploration and collection of herbarium specimens for the project's reference collection.

Figure 4.1 depicts the exact routes undertaken in the field. An itinerary summarizing research proceedings in the field and activities in office in Jambi and Bogor can be found in annex 2.

Transport to and between research locations was mainly by:

- Speedboat: Transport Jambi-Nipah Panjang (4-5 hours).
- Pompong: Transport Nipah Panjang-Desa Air Hitam Laut (4- >7 hours, depending on weather conditions) and on the Air Hitam Laut River downstream of the burnt core zone.
- Ketek to navigate the smaller rivers (e.g. upper reaches of AHL).
- Small canoe (perahu) to enter flooded research locations and very small rivers (e.g. upper reaches of Simpang Melaka).
- Rail: Pt. PDIW's railway infrastructure was used to approach the park from the West.

Transport from rivers inland, to locations of interest, proved to be very difficult due to deep flooding, the presence of dead tree trunks covering the soil and excessive growth of two metre high ferns. Sometimes explorations inland could be made by canoe, but often dead tree trunks already blocked the path within a distance of 50 metres. Wading through waist-deep water was the only solution in these cases. At somewhat dryer locations *Stenochlaena* and *Nephrolepis* ferns made access very difficult. Cutting a path through this vegetation is very time consuming and it takes, with the help of two local *parang-men*, two to five hours to proceed for one kilometre. For this reason and because of limited time for the study, we did not proceed further inland than two kilometres.

The five field trips (8 to 10 days per trip) enabled data collection at 16 locations (see figure 4.1). General observations were conducted at numerous other sites, including pristine forest close to the R*umah biru* ranger post. The Air Hitam Dalam River was visited for three days. Nights were spent in the parks rangerposts, on pompongs and in local fishermen's camps.

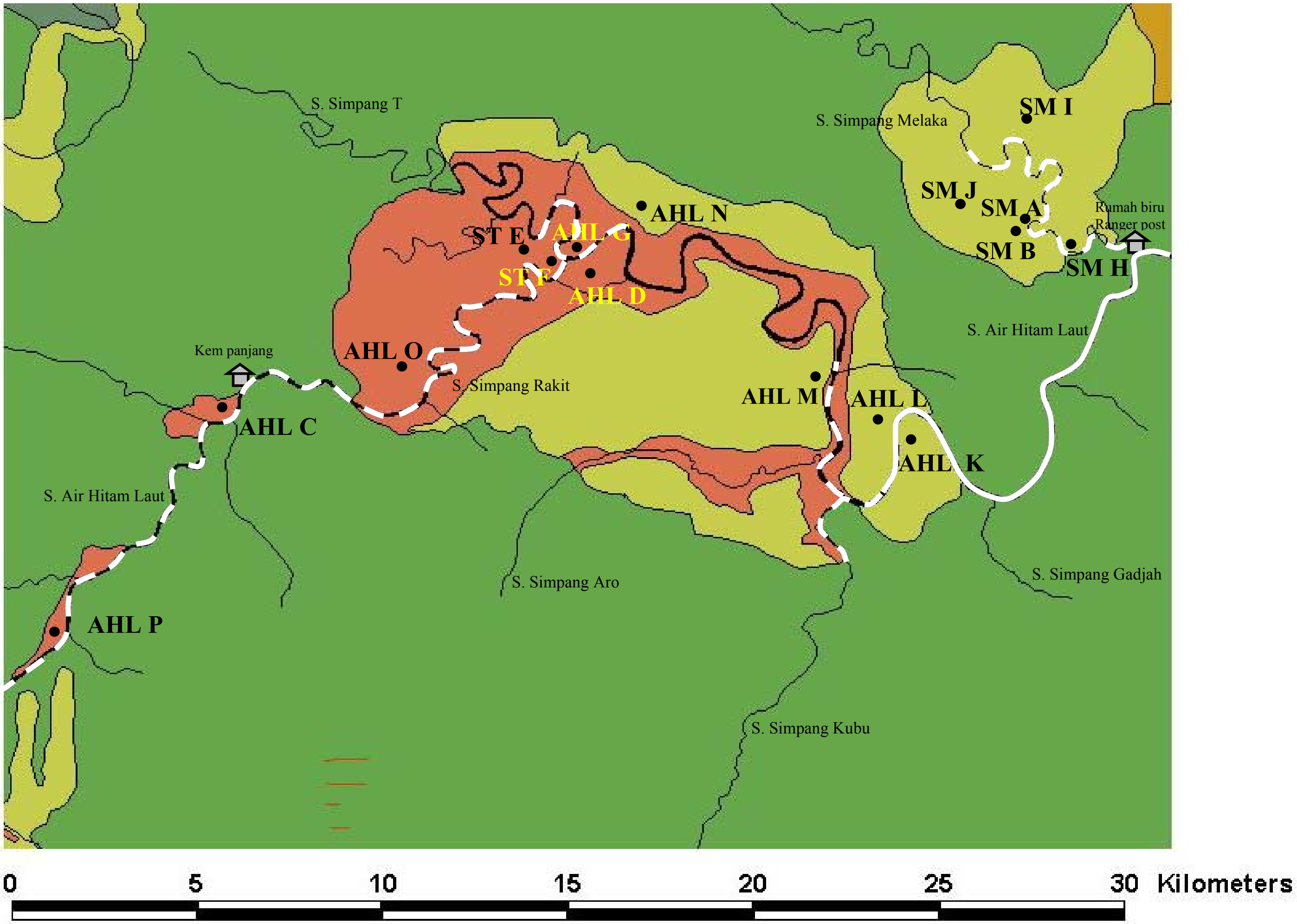

Figure 4.1 Location of research sites in the centre of Berbak NP; Striped lines represent the route undertaken with canoe or Ketek and solid line visualizes the route with pompong.

4.3. Data collection

4.3.1. Positioning of transects

At each selected site, transects measuring 100 x 10 metre were laid out. Assessment in the field indicated that the size is most suitable to acquire reliable data on vegetation composition. In some well developed areas a longer transect would have been more appropriate, but accessibility and the time available prevented to chose larger transects. With the assistance of local villagers, a central path was cut through the vegetation, leaving a strip of 100 x 5 metre on each side of the path. Along this central path both biotic and abiotic data were recorded. Transects were situated parallel to the river, to ensure that river-influence was equal along the whole transect. To exclude direct river impacts all research locations were situated more than 175 metre inland. Transects were situated at least 400 metre from pristine forest to exclude edge effects and direct influence of the forest on the regeneration process. Transects were situated as much as possible in homogeneous sites, as too much heterogeneity in abiotic conditions affects statistical analysis. To reveal the actual amount of variance within a site, a total of five transects were sampled at each location. They were situated parallel to each other at a distance of 10 to 15 metre (figure 4.2). The correct length of the transects was measured with a rope. For correct positioning of each transect relative to the river, both GPS and compass were used.

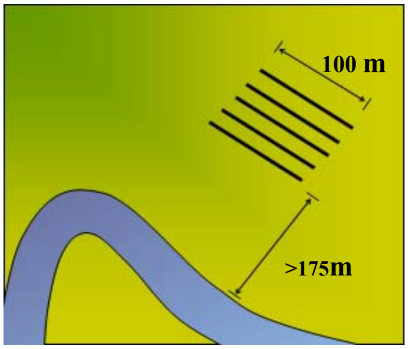

Figure 4.2 Positioning of transects relative to the river.

4.3.2. Collection of biotic data

Floristic data

Within each transect, data were collected on floristic composition, using the relevé method to assess presence and abundance of individual species. A scale derived from the Braun Blanquet scale was used to estimate cover of each species (Table). Some of the species were recognized in the field. Others were collected[6] and submitted to Herbarium Bogoriense for identification. On a few occasions, locals provided vernacular names. A second set of specimens was collected as a reference collection, to be handed over to National Park staff after the end of the project. Each collected specimen was described and documented with a digital camera for later identification. Plants that were difficult to collect due to their size were only photographed. For trees, notes were taken on origin (from seed, resprouting from charred trunk or surviving aboveground) and for resprouters and survivors viability (high, medium, low) was recorded. It was not necessary to use two different plot sizes for recording of trees and herbs respectively as the number of herbs was low and dominated by a few conspicuous species.

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[6] The Schweinfurth method was applied to ensure conservation of the specimens. After pressing the specimens with a field press overnight, they are transferred to a polyethylene bag and treated with methylated spirit. In Jambi each specimen was dried using artificial heat during the night, and a sun warmed concrete floor during daytime.

Table 4.1 Ordinal coverscale used for estimation of species cover.

Abundance	Cover scale
1 – 5	**1**
5 – 100	**2**
> 100	**3**
5 – 12.5 %	**4**
12.5 – 25 %	**5**
25 – 50 %	**6**
50 – 75 %	**7**
75 – 100 %	**8**

In each transect, data was collected on forest structure, by estimating the cover of both herbs and woody species (trees, shrubs, palms and climbers) in five different height classes (0-1 m, 1-2 m, 2-5 m, 5-10 m and 10- 20 m; see also figure 4.3). Basal area was measured for all trees exceeding a DBH of five centimetres. Before measuring circumference of the trees, all stems were cleared of climbing ferns and vines as they prevent accurate measurements.

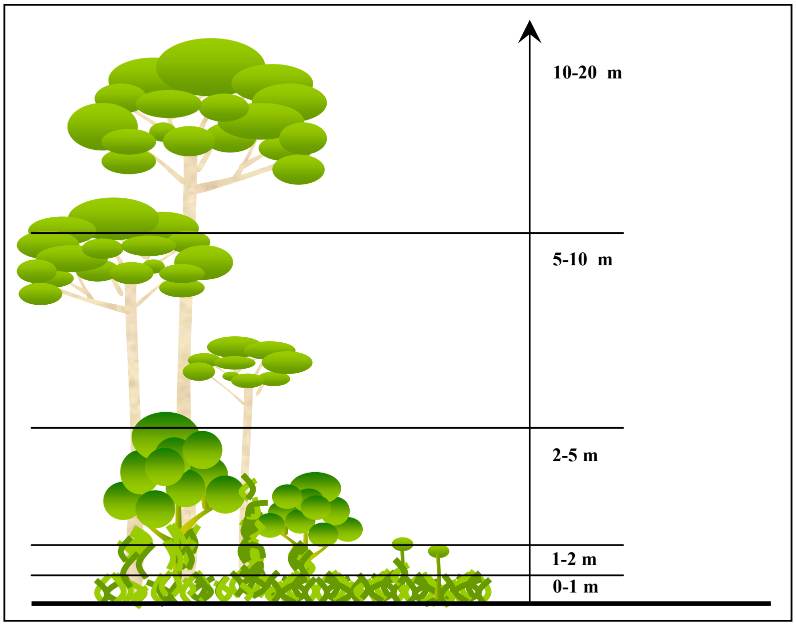

Figure 4.3 Different height classes used for characterization of herb and tree structure respectively within a regenerating forest.

Faunistic data

During the field trips, observations were made on the occurrence of birds, mammals, reptiles, amphibians and, to a lesser extent, invertebrates in both burnt and pristine forest. As areas surrounding Berbak are of interest to conservation as well, sightings just outside the parks border are included in this report. The observations are not exhaustive as the main focus of this study was on vegetation and most observations were made from base camps and while travelling by canoe, ketek or pompong, often under difficult circumstances (e.g. during rainfall). Moreover, as the vast majority of the fieldwork was spent in burnt areas, observations in pristine forest and at sea are even less complete than observations in fire-degraded areas.

4.3.3. Collection of abiotic data

Besides the information on fire history of the research sites, which was already analyzed during the site pre-selection procedure, a number of abiotic factors were recorded in the field. In general each factor was recorded five times along each transect, once every 20 metres. In some cases when abiotic conditions proved to be very uniform, fewer measurements were found to be sufficient. In cases of small-scale heterogeneity a larger number of measurements were taken. Local fishermen were interviewed regularly to acquire additional information on the duration and occurrence of flooding and general abiotic characteristics of the study area.

Waterlevel and maximum flooding

In each transect, water levels relative to the soil surface were measured. Maximum flooding depth[7] which is often represented by a very clear vegetation dying zone[8], was recorded as well (figure 4.4). The maximum flooding depth that has been measured, is the maximum water level reached by the December 2003 floods. This maximum level differs from year to year and as the 2003 floods were exceptional, it is expected that the average maximum flooding depth is lower than the level measured during the present survey. As water level measurements were taken over a time span of about two months, comparison between all sites requires correction for water level changes over time. To enable this, two sites, one in the core zone and one in the burnt area of Simpang Melaka, were chosen as reference points. During each trip these points were re-measured and changes in water level were extrapolated to actual water level measurements in the core zone and Simpang Melaka respectively. Both reference points were situated far enough from the river to exclude influences of tides. Tidal influence at the research locations was absent or low, being nowhere more than several centimetres. Both correction for water level changes over time and exclusion of too much tidal influence give the water level measurements a high level of precision.

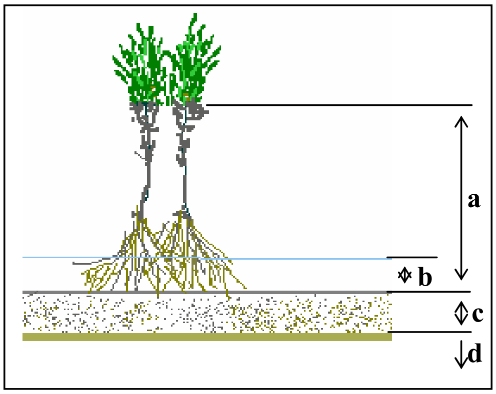

Figure 4.4 Measurements taken in the field: a.) Maximum flooding depth; b.) current water level; c.) Peat depth; d.) Mineral subsoil.

Figure 4.5 Vegetation dying zone.

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[7] Maximum flooding depth is defined as the maximal depth where water stagnation occurred at least for several days, killing lower parts of plants and creating a demarcation line.

[8] In many herb and fern species, leafs and branches that undergo prolonged flooding, die and remain withered and dried on the plant. The height to where this withering has occurred is the same among species and is referred to as dying zone. This zone is also clearly visible at tree stems, where a black demarcation zone remains after flooding (figure 4.5).

Peat depth and subsoil
A peat measuring stick was used to measure peat depth and obtain samples of the subsoil (figure 4.4). For the subsoil, observations were noted of soil structure (clay, sandy clay) and soil type (reduced, oxidized).

Flooding duration
Flooding duration was assessed with a series of Radar images obtained from JAXA Kyoto & Carbon Initiative, dating from 1992 to 1998. Each radar image reflects flooding conditions in the park at a certain time of the year, and as for some years there are several images available, changes of flooding over time can be translated into flooding duration. An ordinal class has been assigned to each area representing its specific flooding characteristics: sites that are flooded almost year round are rated with a 6, whereas locations that have low water tables and are hardly flooded during the year are represented by class 1.

General notes
General observations were recorded on fire intensity. This included the number of surviving trees, the amount of fallen logs and the extent of charring of branches and tree trunks, together with the amount of peat deterioration, these are all indicators of the extent of fire degradation. However, it proved to be difficult to get detailed information on the exact fire intensity. Consequently, it was not possible to incorporate fire intensity in the statistical analysis. Oxidation of the remaining peat layer and degradation of tree trunks was also noted as this provides important information on year-round flooding conditions of the area, and future developments (e.g. increase of flooding through disappearance of the remaining peat layer). Orientation of research location relative to river and forest edge were described as well. Notes were taken on micro-relief, and general notes were taken on illegal activities throughout the area.

4.4. Data storage and analyses

4.4.1. Data storage

During the fieldwork, a wide range of data was collected and noted on a data relevé sheet, specially designed to fulfil the requirements needed for systematic data collection (annex 3). The sheet was used for storage of information on abiotic factors, (geographical) location, species composition, plant cover and forest structure of each individual relevé. Back in office, these hand written data relevé sheets were transferred into TURBOVEG (a computer programme that can store large sets of biotic and abiotic data). Again this programme was adapted to the specific needs: a list with plant species encountered during the survey was created and a new header data form was designed. With this the TURBOVEG database is the digital equivalent of the sheets drawn up in the field. The data on species composition and cover were saved in a species output file, whereas the site factors were recorded in an environmental data file. These Cornell Condensed output files have been used for further analyses in TWINSPAN and CANOCO (a programme for ordination of sites and species based on similarities in species composition).

Characteristics of the plants collected, were described in an herbarium note book (annex 4) and submitted to Herbarium Bogoriense together with the specimens. A photographical record was made of both specimens and characteristics of the research locations.

Data on forest structure, including forest structure diagrams and basal area measurements, were processed separately from the other data. The data on cover of both woody and non woody species within the five height classes were stored in Excel. For calculation of the basal area, the same programme was used.

To gain insight in the species composition of burnt areas in Berbak NP, four species lists have been composed. One list further expands the total number of species found during the present survey. The second covers all species that are identified in burnt areas within the present survey and by Giesen (2004). Next a list was composed representing all species commonly occurring in burnt areas, as identified during the present survey and by Giesen (2004). The fourth list summarizes all species that are observed to be a survivor of forest fires. Lastly, an enumeration was made of all species that survived fires, either resprouters or aboveground survivors.

4.4.2. Analysis

After all data were stored in the correct format, analysis mainly focused on the relationship between environmental circumstances and the performance of vegetation. Moreover, the relevees were clustered into different vegetation types that are unique in terms of species composition and have a characteristic set of abiotic circumstances. TWINSPAN[9] was used to divide all sites into clusters that have a similar occurrence of species. The programme identifies indicator species for each division, that are present in one sub cluster and absent in the other. All default settings of the parameter input were chosen to obtain the TWINSPAN table.

Correspondence analysis was carried out in order to obtain better understanding of environmental preferences of species and regeneration possibilities in different sites. As not much research has been conducted on the relation between abiotic factors and the performance of regenerating vegetation, an indirect gradient analysis was applied. With this type of analysis, an ordination is made, only on the basis of species composition. Environmental factors are excluded during the actual ordination and were put into the figure in a later stage. Afterwards it is necessary to ecologically interpret the results, in contrast with a direct gradient analysis. As direct gradient analyses assume a known distribution of species and relevees along a gradually changing environmental gradient, this method cannot be applied for assessment of possible relations in a poorly studied ecosystem (Kent & Coker, 1992). Therefore Principal Component Analyses were conducted on both species composition and forest structure. Bi-plots were made to visualize correlation with environmental factors and clustering of sites based on forest structure and species composition respectively. Moreover one Bi-plot was composed to reveal preferences of individual species for certain environmental factors.

Both TWINSPAN and PCA-analyses arrived at a certain clustering of sites. These results were combined to come to a final clustering of vegetation types found in regenerating peatswamp forest.

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[9] TWINSPAN or Two-Way Indicator Species Analysis is an ordination programme widely used by ecologists and phytosociologists for classification of a set of relevees. TWINSPAN uses ‘Reciprocal Averaging’ as an ordination method to classify the relevees, followed by an ordination of species, based on their ecological preferences. These two classifications are used to obtain a TWINSPAN Two-Way table. In this table divisions are being made on the basis of occurrence of indicator species, which are not occurring commonly but are restricted to certain clusters. For each division the indicator species and the eigenvalue is given. Moreover every bifurcation is accompanied by a ‘+’ or a ‘-’ that indicates if the indicator species is present or absent in the following divisions. After each step one cluster is divided into two new clusters explaining the same amount of variance (Barel, 1986).

5. Results

5.1. Analysis of satellite imagenary and pre-selection of research locations

5.1.1. Landsat and HotSpot

The series of satellite images obtained from Landsat, provides a clear overview on distribution and abundance of forest fires between 1983 and 2002 and the disturbances that took place before the 1997/98 fires. Giesen (2004) provides a detailed analysis of activities that affected Berbak before 1997 and their probable link with fire outbreaks. This report suffices with a short overview of major events and some additional comments, based on the satellite images.

1. In the early 1980's the park was still in a relatively pristine state (figure 5.3a). Although the east and South side of the park were encroached upon by farmers and loggers (and affected by fire in 1982) the 1983 satellite image indicates that the core zone and western part were still unharmed. There were no signs of logging trails or clear-felling.
2. By 1989 the situation had changed (figure 5.3b). West of the park, just outside its borders, fires had degraded small patches of forest. In the satellite image the slightly lighter green colour of the core zone relative to its surroundings, might be an indication of human impact.
3. By 1992 forest fires also occurred within the park. Two sites situated at relatively deep peat deposits along the upper reaches of Air Hitam Laut, were affected (figure 5.3c). On other images large logging trails extending from the north-west of the park running towards Air Hitam Laut River are clearly discernable.
4. Since then the situation progressively worsened. The 1997 image clearly indicates increased human activities in the core zone (figure 5.3d) Several small fires already occurred along the Air Hitam Laut, in the centre of the core zone that was later affected by the 1997/98 fires. Clear-felling is visible in a square 120 to 150 ha site between Simpang Kubu and Simpang Aro. During a short visit to the site no survivors or dead standing trees were observed and all trees had presumably been cut. The reason for this practice remains unclear, but it seems improbable that the site was felled for logging purposes. Reaching the site is only possible by canoe and transport of logs out of the area would be very difficult due to large floating beds of *Hanguana malayana* that block the river. Maybe the site had been used for agriculture, although it seems not very suitable as it is deeply flooded in the wet season. The presence of approximately 10 large huts along Simpang Kubu River, very close to the clear felled site might support this theory (figure 5.2). The huts are dilapidated and some of them have collapsed. Fishermen reported that more than thirty people lived in the camp. According to them, the camp was inhabited for one year until the beginning of 2003, when the inhabitants left the area because their fishing revenues collapsed. They reported to know nothing about the clear-felled site. The fishermen's statement might have been true, as the camp was clearly used for fishing purposes. On the other hand the camp looks very old, and given the extent of the settlement it is well possible that the inhabitants, if the camp was built earlier than the fishermen suggested, collectively cleared the land for agriculture.
5. Several weeks after the image had been recorded, the 1997/98 fires destroyed more than ten percents of the park. Sites that were degraded by logging were most severely affected and there seems to be a direct link between logging and outbreak of fires. The results of the 1997/98 fires are visible in figure 5.3e. In subsequent years fires reoccurred in many burnt sites mainly in the west of the core zone and along the upper reaches of the Air Hitam Laut River (figure 5.3f,g and h). This pattern of reoccurrence was of importance for the selection of the final survey locations.

Figure 5.1 Part of 1992 Radar image that indicates clear-felling in Berbak's core zone. *(D.H. Hoekman, JAXA Kyoto & Carbon Initiative)*

Figure 5.2 Large camp along the Simpang Kubu River.

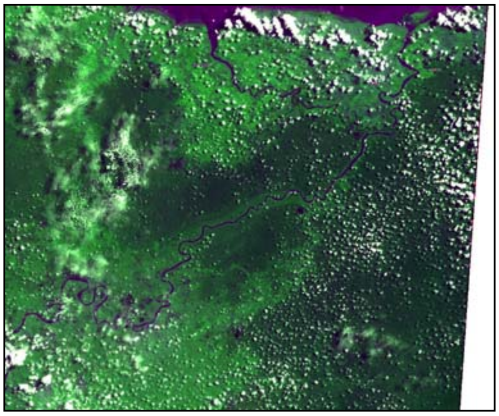

Figure 5.3a Satellite image 16 April 1983.

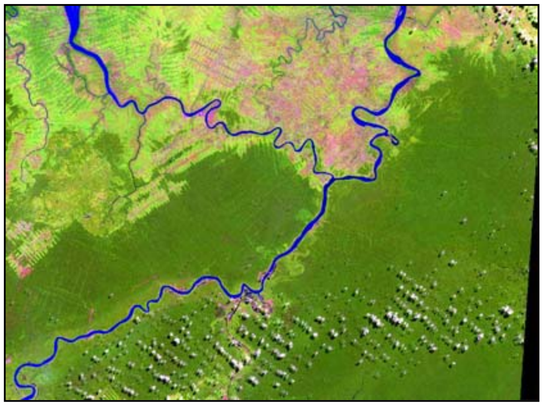

Figure 5.3b Satellite image 9 June 1989.

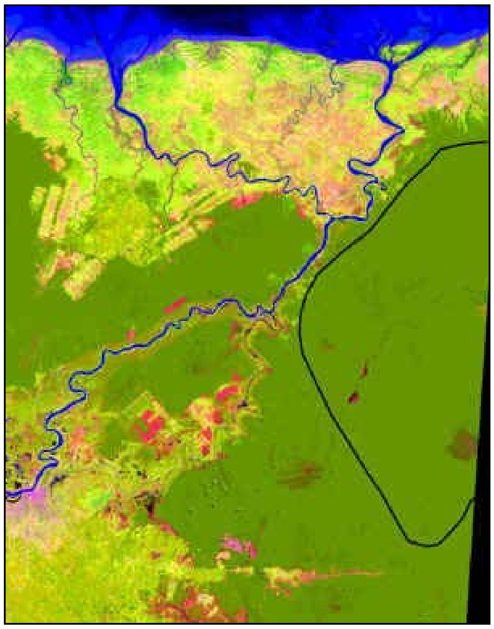

Figure 5.3c Satellite image 16 May 1992.

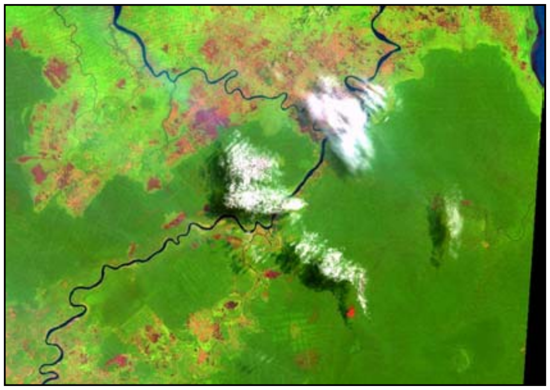

Figure 5.3d Satellite image 18 August 1997.

5.1.2.

Figure 5.3e Satellite image 1 May 1998.

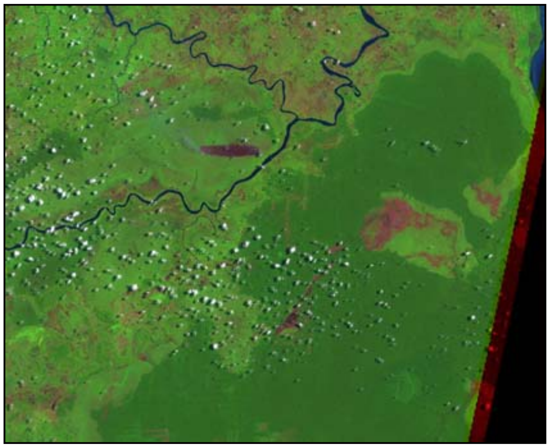

Figure 5.3f Satellite image 1 September 1999.

Figure 5.3g Satellite image 8 August 2002.

5.1.3. Radar

The set of radar images available (17 in total) ranges from 1992 to 1998 and gives, similar to the Landsat images, a clear view on pre-fire disturbances. In addition it provides insight in flooding duration. Disturbances are evident north-west of the core zone, where logging trails can be clearly discerned (1998 images). Other impacts are visible in the east of the core zone (figure 5.1). The square clear-felled site, visible on the 1997 Landsat image, is already present in the 1992 radar image, indicating that this disturbance already occurred several years earlier than formerly was presumed. It was not visible on the 1992 Landsat image as it was just out of reach of the satellite's sensor. Several kilometres to the north the image reveals a second similar sized and clear felled rectangle. This site is also visible on the 1997 Landsat image, but is much less clear than the other square, probably because regrowth of vegetation obscured the extent of disturbance.

The pre-1998 images show that flooding in the core zone (indicated by light grey tones) increased over the years. On the oldest images flooding is mainly present in the direct vicinity of rivers. Later images indicate that flooding extends over a much larger area exactly covering the site that burnt in 1997. Of course the extend of flooding may change from year to year but it is probable that this pattern is caused by a structural change in hydrology, presumably induced by human influences (e.g. logging, drainage). The area seems to face relatively deep flooding in the wet season and relatively strong desiccation in the dry season, and consequently may have become more susceptible to fires.

The 1998 images were used to make an assessment of flooding duration. By comparison of the four images available for that year (figure 5.4a,b,c and d), a distinction could be made between six classes of sites ranging from areas that face very long flooding (black colour for rivers and lakes, white colour for floodplains) to locations that face very short (several weeks or months) flooding (dark grey on radar). In this way, each site could be assigned to a certain flooding class. However, the exact duration of flooding for each class is impossible to determine and to do this a larger database of radar images would have been necessary. Measurements in the field that were originally meant for determining flooding duration (current water level, level of maximum flooding, water level retreat) were combined with observations on the extent of decomposition of logs[10], and used to test the reliability of the classes discerned, derived from the radar images.

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[10] Logs that remain submerged, were observed to have a low rate of decomposition. Areas that face short flooding contain strongly decomposed logs, although the exact rate is also dependant on the type of wood.

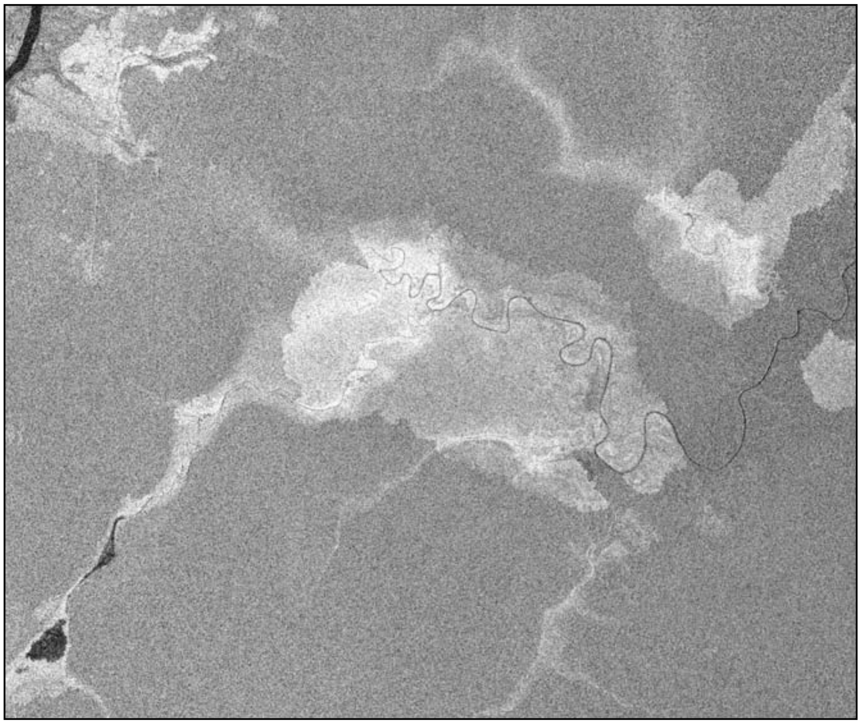


Figure5.4a Radar image 4 Augustus 1998. (After: D.H. Hoekman, JAXA Kyoto & Carbon Initiative, 2004)

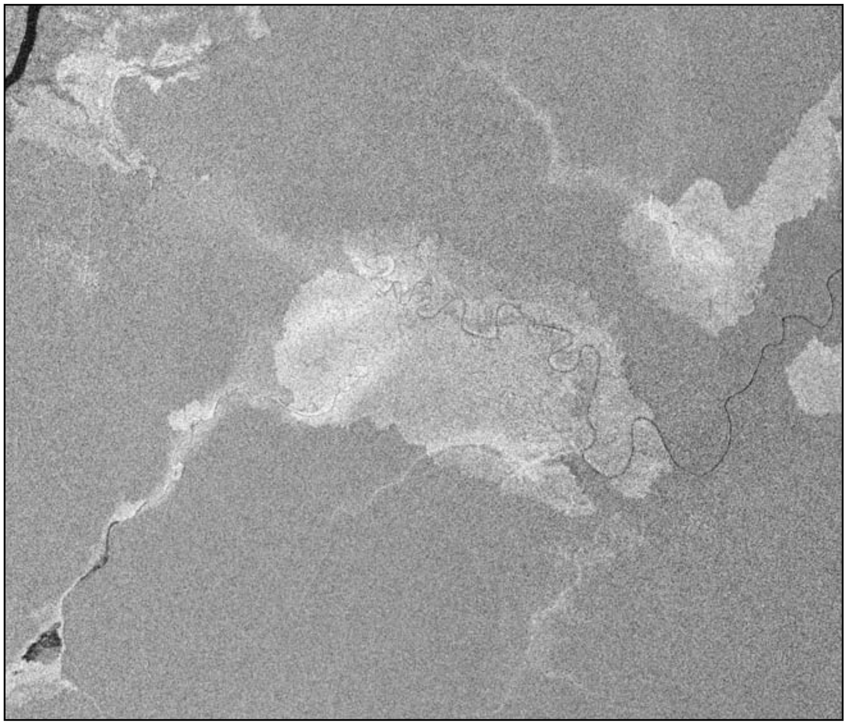


Figure 5.4b Radar image 17 September 1998 (After: D.H. Hoekman, JAXA Kyoto & Carbon Initiative, 2004)

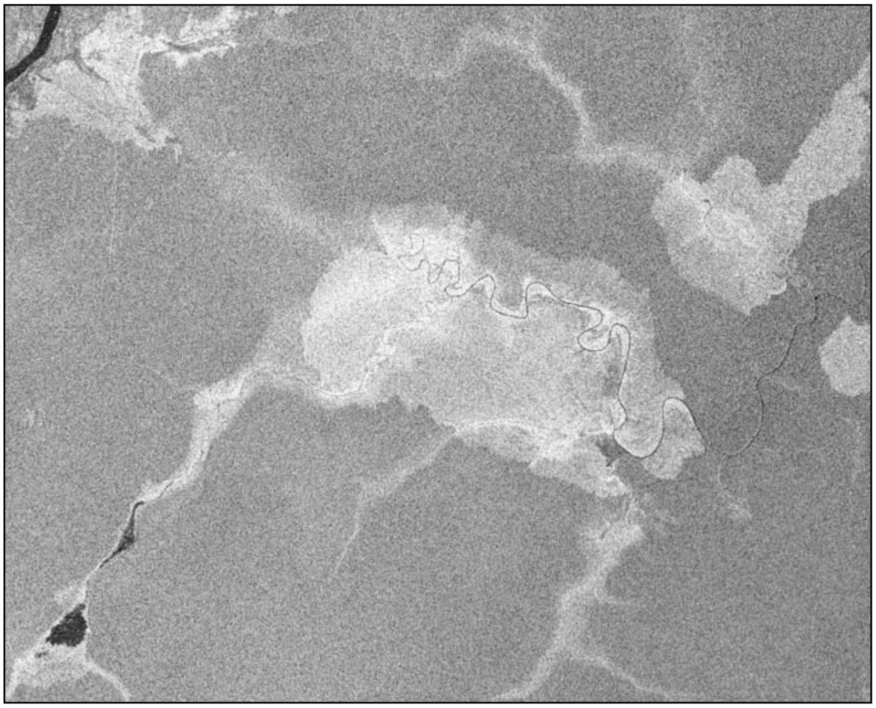


Figure5.4c Radar image 25 March 1998.(After: D.H. Hoekman, JAXA Kyoto & Carbon Initiative, 2004)

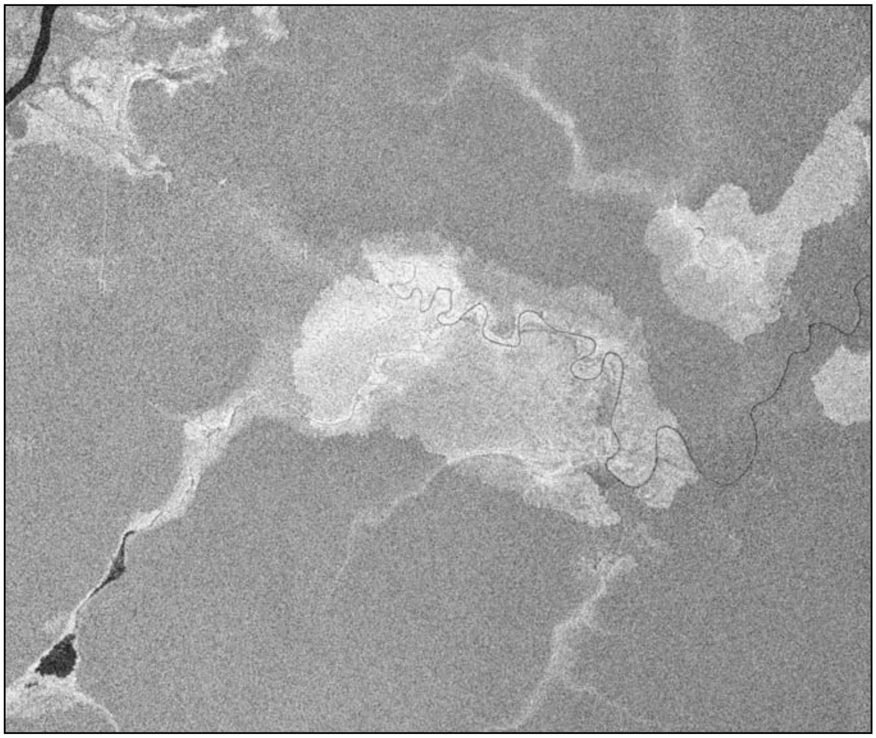


Figure 5.4d Radar image 8 May 1998.(After: D.H. Hoekman, JAXA Kyoto & Carbon Initiative,2004)

5.1.4. Results of site selection

For the selection of potential sites the 1998 Landsat image (figure 5.3e) was used as a starting point, as it depicts the most extensive 1997/98 fire. The 1988, 1992 and 1997 images were used to assess occurrence of previous fires. To find out which sites suffered from repetitive burning since 1997/98, satellite images from 1999 and 2002 were studied. However the images available do not provide a year to year view on fire occurrence. To make the picture more complete an overlay containing HotSpot data was composed (annex 1). These HotSpot data are rough data and should be interpreted with care as not each HotSpot represents a fire and the exact location of a fire does not always coincide with the location indicated by an HotSpot. The reliability of the HotSpots indicated on the map however could be easily verified during the visits in the field. In the site selection procedure a distinction has been made between areas with different fire histories. This is visible in figure 5.5, where the data of the Landsat images are combined with the HotSpot data for the central part of the park. This figure is not exhaustive, but is meant to be a rough indication. The figure indicates that 40-50 percent of the burnt area in the park's central zone burnt twice or more. Multiple fire locations are mainly situated in the west of the core zone and close to rivers where extreme flooding (deep flooding in the wet season and extremely dry conditions in the dry season) or deep peat deposits lead to increased fire susceptibility. Within these differentiated areas the potential research sites were selected and in the field a final choice was made, the exact location depending on abiotic factors. Because satellite information on fire history has been unavailable for some years, additional field observations were necessary to gain complete insight. By careful assessment of resprouting branches and charred trunks it was often possible to acquire additional data and check the reliability of the satellite image analysis. Interviews with locals provided additional information as well. During pre-selection based on the computer data, sites were often selected several kilometres away from the river. Due to extreme field conditions however, some of these sites proved to be inaccessible and thus forced selection of sites closer to the river.

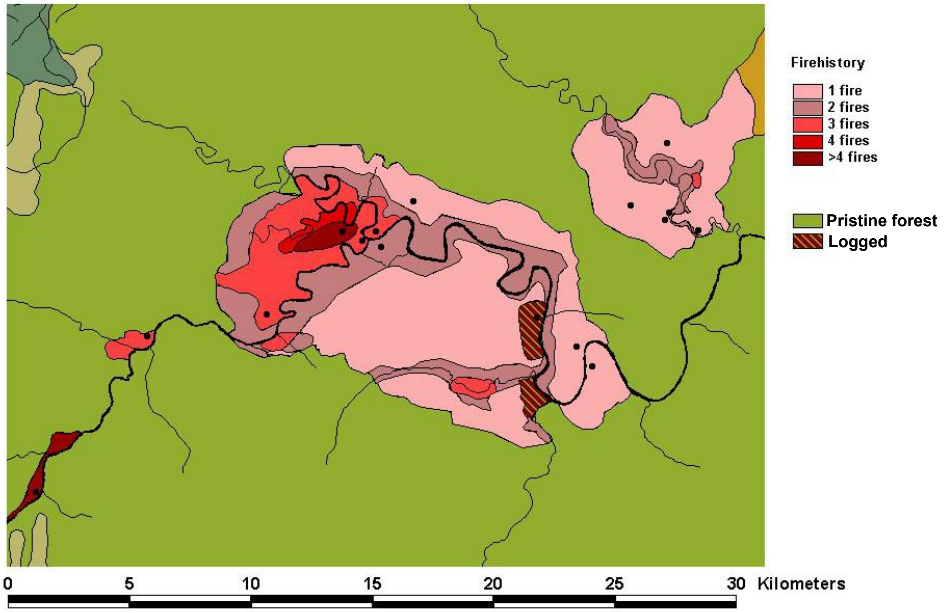


Figure 5.5 Occurrence of fires in Berbak's central zone.

5.2. Site descriptions

This paragraph provides a general overview on the conditions in the sixteen sites that were investigated during the survey. A characterization of each site individually is provided in annex 5. Eight of these sites burnt more than once, the other eight were only affected by the 1997/98 fires. Five sites, indicated with the prescript SM, are located in the 4,133 ha burnt area along the Simpang Melaka River. Nine sites are situated in the 12,669 ha burnt core zone of which two sites along the Simpang-T (coded with ST) and seven sites along Air Hitam Laut (Coded with AHL). Two sites were visited in smaller patches further upstream along Air Hitam Laut (Coded with AHL). See picture 4.1 and 5.5 for their exact location and fire history.

Fire history, peat depth, duration of flooding and depth of flooding are highly variable among sites and as a result species composition and forest structure differ significantly among sites. Many of the single burnt sites are remarkably well developed. In six of them a closed canopy, consisting of ten metre high *Macaranga pruinosa* trees, has formed. Typical species, mainly ferns, climbers and trees, that prefer the shadow rich forest floor and understorey, have established here. Species diversity is high with up to 33 species recorded in a single relevé. All these sites are only affected by shallow and relatively short flooding. Two of the single burnt sites have a more hazardous flooding regime. Although these sites are rich in species, they do not yet have a closed canopy. The places that faced multiple burning are much less well developed. Some of them have lost a deep layer of peat and have been converted into (seasonal) lakes. *Pandanus helicopus* and the sedge *Thoracostachyum bancanum* are often dominant at these species-poor and barely vegetated sites. Sites that face deep flooding, but experience a somewhat shorter flooding duration, are often covered by the floating grass *Hymenachne amplexicaulis* and the aquatic species bladderwort *Utricularia exoleta* and water lily *Nymphaea stellata.* These areas are not permanently wet and do not sustain the seasonal lake species mentioned above. They are species-poor and often do not show more than five species per 0,1 ha. Sites with less extreme flooding conditions are dominated by sedges such as *Scleria purpurascens*. If flooding further decreases, the ferns *Stenochlaena palustris, Blechnum indicum* and *Lygodium microphyllum* become dominant, often reaching a cover close to hundred percent. At the driest sites *Blechnum indicum* is replaced by *Nephrolepis bisserata*. Typical trees that emerge at these sites are *Alstonia pneumatophora* and *Macaranga pruinosa*.

Homogeneity differs from site to site, probably depending on small scale variation in fire intensity and natural variance in abiotic circumstances. Some sites were highly homogeneous, while others had differences in peat depth and extent of flooding. The relevees however, were situated in subsections of an area that were as homogenous as possible. Fire intensity was different among sites. In general, areas with a peat soil have been most severely affected. Forest that grows directly on a clayey soil is less affected as mineral subsoil protects root systems against the flames and inhibits the outbreak of intense ground fires. From all sites that are surveyed, fifteen were used for further vegetational and structural analyses. One site (AHL M) was excluded in a later stage, as a Radar image (figure 5.1) indicated that the site had been severely degraded due to illegal activities already before outbreak of the 1997/98 fires.

5.3. Floral diversity

5.3.1. Species composition

In total 117 plant species were observed during the survey (annex 6). On average a research location contained 21 species per 0,5 hectares, ranging from four species in the poorest site (AHL P) to 33 species in the best developed site (AHL N). Extended with species observed during a rapid survey in

October 2003 (Giesen, 2004) inside and west of the park (annex 7), this results in a total of 148 species observed in burnt areas in the Air Hitam Laut catchment. Observations in burnt areas along the Air Hitam Dalam are not included in the list because these areas are under direct influence of the nutrient-rich Batanghari River and consequently have a different (freshwater swampforest) vegetation composition. Many of the 61 species observed by Giesen (2004) have not been found during the present survey, mainly because the majority of his research locations are situated in direct proximity of the river. The sites visited during the present survey were situated more inland and consequently 84 out of 117 species (72 %) were not observed by Giesen (2004). In total 46 species were observed that were found in more than three locations during the present survey, by Giesen (2004) or during both surveys combined: 20 trees, eight climbers, seven ferns, five palms, two shrubs, two sedges, one grass and one aquatic herb. They are listed in table 5.1. Among these common species there are 23 trees and two palms that have potential for rehabilitation programmes. Table 5.2 lists under which circumstances these species were encountered.

Table 5.1 Species common in burnt peatswamp forest in Berbak NP identified by Van Eijk and Leenman (2004) and Giesen (2004).

Species	**Habit**		**Species**	**Habit**	
Actinodaphne macrophylla	Tree	9	*Flagellaria indica*	Climber	32
Alstonia pneumatophora	Tree	1	*Mikania cordata*	Climber	31
Archidendron clipearia	Tree	8	*Morinda philippensis*	Climber	23
Artocarpus gomeziana	Tree	13	*Poikilospermun suaveolens*	Climber	17
Barringtonia macrostachya	Tree	10	*Uncaria acida*	Climber	33
Barringtonia racemosa	Tree	11	*Uncaria gambir*	Climber	34
Combretocarpus rotundatus	Tree	22	*Uncaria glabrata*	Climber	35
Diospyros siamang	Tree	2	*Uncaria sp.*	Climber	36
Elaeocarpus petiolatus	Tree	3			
Eugenia spicata	Tree	18	*Calamus sp*	Palm	37
Ficus sp 2	Tree	14	*Korthalsia flagellaria*	Palm	38
Ficus spp.	Tree	15	*Licuala paludosa*	Palm	39
Ficus virens	Tree	16	*Nenga pumila*	Palm	40
Glochidion rubrum	Tree	4	*Pholidocarpus sumatranus*	Palm	41
Macaranga amissa	Tree	5			
Macaranga pruinosa	Tree	6	*Dioscorea pyrifolia*	Shrub	44
Mallotus muticus	Tree	7	*Melastoma malabathricum*	Shrub	45
Pandanus helicopus	Tree	21			
Pternandra galeata	Tree	12	*Thoracostachyum bancanum*	Sedge	46
Syzygium zipelliana	Tree	20	*Thoracostachyum sumatranum*	Sedge	47
Blechnum indicum	Fern	24	*Hymenachne amplexicaulis*	Grass	43
Gleichenia linearis	Fern	26			
Lygodium microphyllum	Fern	30	*Utricularia exoleta*	Aq. Herb	48
Nephrolepis bisserata	Fern	27			
Nephrolepis cordifolia	Fern	28			
Pteridium aquilinum	Fern	29			
Stenochlaena palustris	Fern	25			

Table 5.2 Abundance of tree species, that commonly occur in fire-degraded areas of Air Hitam Laut's catchment under different environmental circumstances. (++ = very common; + = common; - = uncommon) Types refer to vegetation types as described in paragraph 5.4.

Species	Low and short flooding **(Type 5 and 6)**	Medium high/ medium long flooding **(Type 4 and 3b)**	High/long flooding **(Type 2 and 3a)**	Very high/very long Flooding **(Type 1)**
Actinodaphne macrophylla		+		
Alstonia pneumatophora	++	++	-	
Archidendron clipearia		+		
Artocarpus gomeziana	++			
Barringtonia macrostachya	+	++		
Barringtonia racemosa		+	++	-
Combretocarus rotundatus			+	
Diospyros siamang			+	
Eleaocarpus petiolatus	+			
Eugenia spicata		+		
Ficus sp.	+			
Ficus sp. 2	++			
Ficus virens	+	+		
Glochidion rubrum	+			
Licuala paludosa		+	+	
Macaranga amissa	++	+		
Macaranga pruinosa	++	++	-	
Mallotus muticus		++	++	-
Pandanus helicopus			-	++
Pholidoarpus sumatranus	+	+	+	
Pternandra galeata	+	++		
Syzygium zippeliana		++	++	++

5.3.2. Occurrence of surviving trees

In total 26 species were observed at, or in direct proximity of the research sites to have survived the 1997/1998 forest fires (Annex 9). Of these, seven species were resprouters from charred trunks or surviving underground root systems. Twelve species were recorded as aboveground survivors and seven species were found as both resprouters and aboveground survivors (figure 5.6).

Eight species were found to occur in more than three sites or in more than three transects of a single site as survivors and are regarded as common (table 5.3). All of them are of potential interest to rehabilitation schemes. Two palms, *Pholidocarpus sumatranus* and *Licuala paludosa* are obvious aboveground survivors. Particularly old and tall *Pholidocarpus* palms are highly fire resistant. The species was observed to be able to survive up to five fires and the only direct threat seems to be instability due to combustion of underlying peat packages. Smaller palms, *Licuala* and young *Pholidocarpus,* are less fire resistant as their vulnerable meristemes more easily come in close contact with fire. However, they are still able to survive up to three fires. Another species with a high aboveground survival rate is *Pternandra galeata*. Although the tree normally is small, the thin branches are remarkably fire resistant and the species was commonly encountered in sites that burnt up to two times.

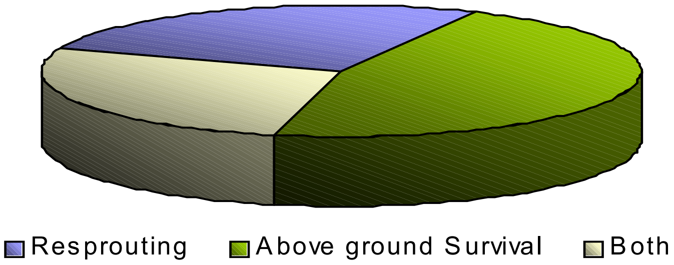


Figure 5.6 Occurrence of different fire survival mechanisms in trees.

Table 5.3 Tree and palm species commonly occurring as survivors in burnt peatswamp forest, Berbak NP

Family	***Species***
Arecaceae	*Licuala paludosa*
Arecaceae	*Pholidocarpus sumatranus*
Elaeocarpaceae	*Elaeocarpus littoralis*
Euphorbiaceae	*Mallotus muticus*
Fabaceae	*Dialium maingayi*
Lecythidaceae	*Barringtonia macrostachya*
Lecythidaceae	*Barringtonia racemosa*
Melastomataceae	*Pternandra galeata*

Barringtonia racemosa is the most resistant of the resprouting trees. Although this small tree is easily destroyed by fire, the remaining root system and stem are strongly viable. In some sites individuals were found that resprouted after three subsequent fires (figure 5.7). *Mallotus muticus* has strong surviving capacities both as an aboveground survivor and as resprouter. Normally the thick protecting bark enables the tree to remain as an aboveground survivor. Sometimes however, intense or repetitive fires destroy the tree. In this case the species shows its strong resprouting capacity. Many trees were only incidentally found to occur as survivors. For these species it is difficult to make an estimation of the extent of fire resistance. Some of them might be individuals that accidentally escaped burning due to locally decreased fire intensity or protection by surrounding species (e.g. *Alstonia pneumatophora* protected by *Licuala paludosa*, see paragraph 5.5). Other species may have been naturally rare and were therefore recorded in numbers too low to conclude something about their fire resistance.

Viability was highly different among survivors. In general, resprouters were in relatively good condition and the young stems did not show any sign of damage, illness or hampered growth. Some of the aboveground survivors were in good condition as well. They were not affected by the fires (e.g. *Alstonia*) or had recovered from their damage (e.g. *Tetractomia tetrandum*). Others were strongly affected and had hardly recovered since 1997/98. Some of them were dying. Several of the more healthy survivors were flowering or fruiting. This might positively impact regeneration, but additional information should be obtained to clarify this process. Many of the aboveground survivors had a thick protecting bark. This is in accordance with finding on east Kalimantan, where species with a thick bark were found to be significantly more resistant to fires (Delmy 1991).

Figure 5.7 Barringtonia racemosa has strong resprouting capacities and is able to resprout after several subsequent fires.

The list provided in annex 9 is not complete. Although the more common survivors probably have been noticed during the survey, there are a lot of species that have a scattered spatial distribution. Many of them are so scarce that they were not present within or in the vicinity of the research locations. To include them in the list, an inventory of survivors should be executed at a larger scale. In addition there might be a number of species that can only tolerate very little damage. They probably only occur at forest edges where the fire was not intense. These sites have not been studied and therefore they were not recorded during the present survey.

5.4. Influence of abiotic factors on vegetation

The large data set that was stored in TURBOVEG data files, has been used to analyse both species composition and forest structure in relation to environmental conditions. The applied techniques, group corresponding relevees together and indicate to what extent there is correlation between species composition, vegetation structure and abiotic factors. In addition, the different clustering procedures identify a number of vegetation types that comprise one or more visited locations, each having their own characteristic species composition, structure and unique set of environmental factors.

5.4.1. Species composition in TWINSPAN

TWINSPAN is used to make a division of relevees based on species composition and abundance. The grouping created, is depicted in the TWINSPAN Two-way table (figure 5.9). The first column of the table summarizes all species recorded, whereas each following column represents a single relevé, made during the fieldwork period. Each relevé-column is coded with a letter. These correspond to the names used in the site descriptions found in annex 5 and to names on the overview map provided in figure 4.1. Every column contains numbers ranging from one to eight, corresponding to the coverscale assigned to a species (see paragraph 4.3). For example all relevees of AHL N contain many *Macaranga pruinosa* trees with a cover up to 75 % .

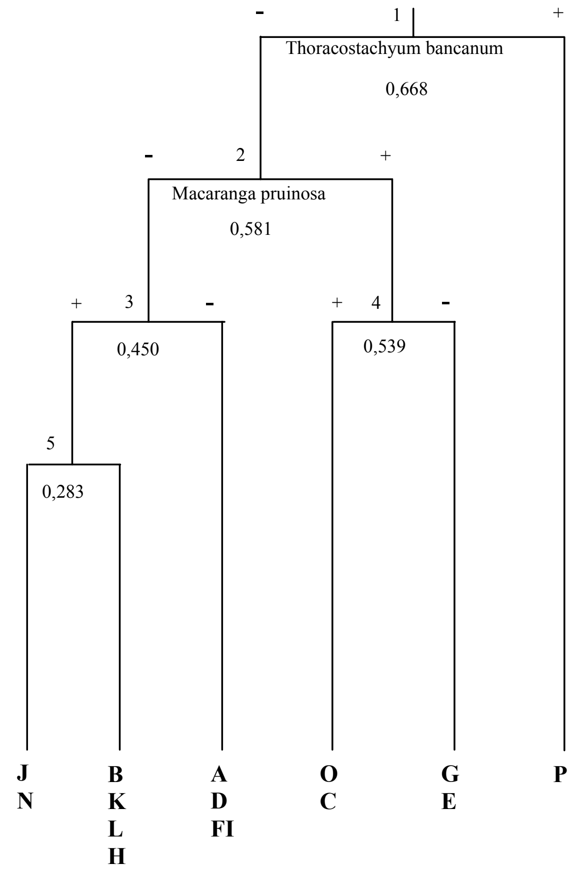


Figure 5.8 Dendrogram representing the divisions made by TWINSPAN on the basis of indicator species: Division 3 Nephrolepis bisserata; Division 4 Stenochlaena palustris; Division 5 e.g. Pternandra galeata.

Figure 5.9 (next page) TWINSPAN Two-way table indicating TWINSPAN clusters and final vegetation types (yellow: common companions; orange: differentiating spcies)

Vegetation types	**Type 6**	**Type 5**	**Type 4**	**Type 3b**	**Type 3a**	**Type 2**	**Type 1**
Twinspan vegetation types	**Type VI**	**Type V**		**Type IV**	**Type III**	**Type II**	**Type I**
	J J J J J N N N N N	B B B B B K K K K K L L L L L	H H H H H	A A A A A D D D D D F F F F F I I I I I	O O O O O C C C C C	G G G G G E E E E E	P P P P P
Musaenda frondosa	- 1 - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Dyera lowii	- - 1 - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Sandoricum emarginatum	- - 1 1 - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Nauclea officinalis	- - 1 - 1 - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ficus sp 1	- - - - 1 - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Antidesma montanum	- - - 1 1 - 1 - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Eleaocarpus sp. 1	- 2 1 1 - - - - 1 -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Smilax leucophylla	2 1 - - - 1 1 1 2 2	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ficus sp 4	- - - - - - 1 - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Elaeocarpus petiolatus	- - - - - - - 1 - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ziziphus horsfieldii	- - - - - - - - 1 -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Davalia denticulata	- - - - - - 1 1 - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Litsea machilifolia	- - - - - - - - 1 -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Fibraurea chloroleuca	- - - - - - - - 1 -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Sauropus rhamnoides	- - - - - - - - 1 1	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Dehaasia incrassata	- - - - - - - - - 1	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Hopea pachycarpa	- - - - - 1 - 1 1 1	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Forrestia mollissima	- - - - - 2 2 3 1 2	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ficus sp 2	2 1 1 - 2 - - - 1 1	- - - - - - - - 1 - - - - 1 -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Pteridium aquilinum	1 1 1 1 2 1 - - 1 1	1 - - 1 1 - - - - 2 - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Mikania cordata	1 2 2 1 2 1 1 1 - -	1 2 3 - 2 - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Dioscorea pyrifolia	- 2 - - 1 - 2 2 1 -	2 - - - 1 2 - - - - - - - - -	- - - - -	2 - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Artocarpus gomeziana	- 1 - - - - - - - 1	- - - - - 1 - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Hypolytrum nemorum	- - - - 2 - - - - -	- - - - - 1 - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Glochidion rubrum	- 1 - - - - - - - -	- - - - - - 1 - - 1 - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Poikilospermum sp	- - - - 1 - - - - -	- - - - - - - - - - - 1 - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ficus annulata	2 1 - - - - - - - -	- - - - - - - - - - - - - 1 -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Croton laevifolius	- - 1 - - - - - - -	- - - - - - - - - - - 2 - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Homalomena sp.	- - - - - 2 - 2 - -	- - 2 2 - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Spatholobus ferrugineus	- - - - - - - - 1 1	1 - 1 - - - - - - - 2 - - 4 4	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ficus drupacea	- - - - - - - - 1 1	- - - - - - - - - - 1 1 1 - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Eleiodoxa conferta	- - - - - 1 - - - -	- - - - - - - - - - 1 - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Aphanamixis polystachya	- - - - - - - - - 1	1 - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Dracontomelon dao	- - - - - - - - 1 -	- - - - - - - 1 1 - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Microsorium scolopendria	- - - - - - - - - -	1 - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Cissus nodosa	- - - - - - - - - -	- - - - 1 - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Rhaphidophora foraminifera	- - - - - - - - - -	1 - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Pholidocarpus sumatranus	- - - - - - - - - -	4 2 2 4 1 - - - - - - - - - -	- - - - -	- - - - - - - - - - - 1 - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Kortahalsia flagellari	- - - - - - - - - -	2 - 2 2 1 1 - 2 - - - 1 - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Artocarpus elasticus	- - - - - - - - - -	- 1 2 - 2 - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Caryota mitis	- - - - - - - - - -	1 - 1 1 - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Derris scandens	- - - - - - - - - -	1 1 1 - 1 - - - - - - 2 2 - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Gardenia tubifera	- - - - - - - - - -	- - - - - 2 1 - - 1 - - - - -	- - 1 - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Helicia serrata	- - - - - - - - - -	- - - - - 1 1 1 1 1 - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Shorea rugosa	- - - - 1 - - - - -	- 1 - 1 - - - - - - - - - 2 1	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Dialium maingayi	- - - - - - - - - -	- - - - - - - - - - - 4 - - 1	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Dalbergia junghuhnii	- - - - - - - - - -	- - - - - - - - - - - 1 - 1 -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ficus sp.	2 2 2 2 2 - - - - -	- - - - - - 1 - - - 1 - - - 2	- - 1 1 -	- - - - - - - - - - - - - - - - 1 - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ardisia lanceolata	1 - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - 1	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Actinodaphne macrophylla	- - - - - - - - - -	- - - - - - 1 - - - - - 1 - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Gigantochloa sp.	- - - - - - - - - -	- - - - - - 4 - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Nephrolepis cordifolia	3 3 3 3 3 3 3 3 3 3	3 3 3 3 3 - - - - - - - - - -	1 1 2 - 1	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Nephrolepis bisserata	6 6 6 7 7 7 7 7 6 7	4 5 5 4 4 4 4 4 5 5 6 6 6 6 6	7 2 7 7 7	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Macaranga amissa	- - - - - 5 4 2 5 4	1 - - 1 - 1 2 - 1 - - - - - -	1 - - - -	- - - - - - - - - - - - - - - 1 - - - 1	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Garcinia parvifolia	- - - - - - - - - -	- - - - - - - - - - - - - - -	1 - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Casearia sp	- - - - - - - - - -	- - - - - - - - - - - - - - -	1 - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Petunga microcarpa	- - - - - - - - - -	- - - - - - - - - - - - - - -	- 1 1 - 1	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Poikilospermum suaveolens	- - - - - - - - - -	- - - - - - - - - - - - - - -	- 1 - 1 1	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ixora blumei	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - 1 -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Teijsmanniodendron pteropodum	- - - - - - - - - -	- - - - - - - - - - - - - - -	1 1 1 1 1	- - - - - - - - - - - - - - - - - - - 1	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Dischidia imbricata	- - - - - - - - - -	- - - - - - - - - - - - - - -	1 1 - - -	1 - - 1 - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Crudia havilandii	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	2 - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Horsfieldia glabra	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - 1 - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Xanthophyllum elliptic	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - 1 1 - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Neesia altissima	- - - - - - - 1 - -	- - - - - - - - - - - - - - -	- - - - -	- - - 1 - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Alstonia pneumatophora	2 4 2 2 2 5 2 2 2 2	2 - 2 2 2 2 4 4 2 2 4 2 4 4 4	4 4 4 4 4	2 1 2 2 - 2 3 2 - 2 - 1 - - 1 - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Gleichenia linearis	- - 3 - 2 1 - - 3 3	2 3 3 3 3 4 4 4 4 4 4 4 4 4 4	- - - - 2	- 2 2 - - 3 - 2 - - - - - - 2 - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Imperata cylindrica	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - 3 4 4 4 5 - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Baccaurea pubera	- - - - - - - - - -	1 1 - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - 1 - 1 - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Artocarpus kemando	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - 1 1 - - - - - 1 - 1 - - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Calamus sp.	- - - - - 1 1 1 2 -	- 2 3 2 2 2 2 2 2 2 1 - 1 1 1	- - - - -	1 - 2 - - - - - - - - - - - - - - - 1 2	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Pternandra galeata	- - - - 1 - - - - -	2 - 2 2 1 2 4 4 4 4 4 4 2 4 4	1 2 1 - -	- - - - - - 2 2 1 1 - 1 1 1 2 - - - 2 -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Syzygium sp.1	- - - - - - - - - -	- - - - - 2 - 1 - - - - - - -	- - - - -	- - - - - - - - - - - - - - - 1 - 1 - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Nauclea sp.	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - 1 1 1 2 2	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Rourea mimmosoides	- - - - - - - - - -	- - - - - - - 1 - 1 - - 1 - 1	- - - - 1	- - 1 - - - - - - - - - - - - - - - - 1	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Archidendron clipearia	- - - - - - - - - -	- - - - - 1 - 1 1 1 1 4 - - -	- - - - -	- - - - - - - - - - - - - - - - 1 - - 1	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Licuala paludosa	- - - - - - - - - -	- - - - - - - - 4 1 - - 2 2 -	- - - - -	- - - - - - - - - - - - - - - 6 5 4 6 6	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Connarus monocarpus	- - - - - - - - - -	- - - - - - - - 1 - - - - - -	- - - - -	- - - - - - - - - - - - - - - 2 2 2 - 2	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Diospyros pseudomala	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - 1 - 1 - - - - - - - - - 1 -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Uncaria gambir	- - - - - - - - - -	- 2 2 2 2 2 2 - - - 1 - 2 2 2	1 - - - -	1 - - 1 2 - - - - - - - - - - 1 - 1 - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Barringtonia macrostycha	- - - - - - - - - -	- 1 2 1 1 - 1 1 - 1 2 1 - - -	2 2 2 1 2	- - 1 1 2 1 1 - - - - - - - - - 1 2 - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Ficus virens	- - - - 1 - - - - -	1 1 - - - - - - - - - - - - -	- - - - -	- 1 1 - 1 - - - - - - - - - - - - 1 - -	- - - - - - - - - -	- - - - - - - - - -	- - - - -
Macaranga pruinosa	6 7 7 7 6 7 7 7 7 7	7 6 7 6 6 6 7 7 6 6 6 5 6 5 6	2 2 2 2 2	2 2 2 2 - 3 4 2 2 - 1 1 2 2 2 2 2 2 2 2	1 1 - - 1 - - - - -	- - - - - - - - - -	- - - - -
Elaeocarpus littoralis	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - 2 2 - 2 2	1 1 - - - - - - - -	- - - - - - - - - -	- - - - -
Eugenia spicata	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- 1 - - 1 - - - - -	- - - - - - - - - -	- - - - -
Stemonurus scundiflor	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- 1 1 1 - - - - - -	- - - - - - - - - -	- - - - -
Nymphaea stellata	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - 2 - -	- - 1 1 - - - - - -	- - - - - - - - - -	- - - - -
Uncaria sp	4 4 4 4 5 2 4 2 2 2	2 2 2 - 1 - - 2 2 2 1 2 1 - 2	1 - - - -	- 1 1 - 1 2 - 1 - - - - - 1 - - - - - -	2 2 2 2 - 2 - 1 - -	- - - - - - - - - -	- - - - -
Stenochlaena palustris	5 4 4 4 5 4 4 4 6 4	7 7 6 6 6 4 5 4 5 5 6 6 6 6 5	7 7 7 7 7	7 7 7 7 7 7 7 7 6 5 5 4 4 3 4 5 5 5 6 5	5 6 6 6 6 7 6 7 7 7	- - - - - - - - - -	- - - - -
Uncaria acida	- - - - - - - - - -	- - - - - - - - - 1 - - - - -	- 1 - 1 -	- - - - - - 2 - - - 1 1 - - - 1 1 1 - -	- 1 - - - - - - 1 2	- - - - - - - - - -	- - - - -
Nenga pumila	- - - - - - - - - -	- - - - - 2 4 2 2 2 - - - - -	- - - - 2	1 - - - - 1 1 1 - - 1 - - - - - - 1 - -	- - - - - 1 1 - - -	- - - - - - - - - -	- - - - -
Ficus sumatrana	- - - - - - - - - -	- - - - - - - - - - - - - - -	1 - 1 - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - 1 - -	- - - - - - - - - -	- - - - -
Ficus sp 3	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - 1 - - - - - - - - - -	- - - - - 1 - 1 - -	- - - - - - - - - -	- - - - -
Ormonsia cf macrodisca	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - 1 - - - -	- - - - - - - - - -	- - - - -
Magnifera quadrifida	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - 1	- - - - - - - - - -	- - - - -
Melastoma malabathricum	- - 1 - - 1 1 - 2 2	2 2 2 2 - - 2 2 2 2 2 1 2 2 2	1 1 1 1 2	1 1 1 1 1 4 2 4 2 2 2 2 2 2 2 - - 1 - -	- - - 1 1 - - - - 1	- 1 - - - - - - - -	1 - - - -
Flagellaria indica	- - - - - - - - - -	- 1 1 - - - - - - - - 2 - - 2	- - - - -	- - - 1 - - - - - - - - 1 1 - - - - - 1	- - - - - - - - - -	1 - - 1 - - - - - -	- - - - -
Ottochloa nodosa	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - 4 3 3 - - - - - - - - - -	- - - - - - - - - -	6 6 6 4 4 - - - - -	- - - - -
Blechnum indicum	- - - - - - - - - -	- - - - - - - - - - - - - - -	1 - - - 1	7 7 7 7 7 7 6 6 6 4 4 3 3 3 3 - 7 6 7 6	3 4 3 3 3 6 5 5 5 6	- 1 - - - - - - - 2	- - - - -
Lygodium microphyllum	- - 3 - - 1 1 - 1 -	3 2 3 2 3 3 3 3 3 3 3 3 3 3 3	3 3 3 3 3	2 3 3 3 - 4 - 3 3 3 2 3 3 3 3 3 3 3 3 3	1 2 2 2 2 3 3 3 3 3	2 3 3 3 3 2 2 2 2 -	- - - - -
Mallotus muticus	- - - - - - - - - -	1 - - - - - 1 - - - - 1 - - -	2 - - 1 2	2 2 2 2 2 1 1 - - - 1 - - - - - 2 1 1 1	1 1 - 1 - 1 1 1 2 2	- - - - - - 1 - - -	- - - - -
Scleria purpurescens	- - - - - - - - - -	- - - - 2 - - - - - - - 2 2 -	- - - - -	- 3 3 3 2 6 4 4 5 5 4 3 3 3 3 2 3 3 - 2	3 3 3 3 3 7 7 7 7 7	5 5 5 5 4 2 2 2 1 2	- - - - -
Utricularia exolata	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - 1 1 -	2 2 2 3 2 - - - - -	- - - - - 2 3 3 3 3	- - - - -
Hymenachne amplexicaulis	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- 3 3 3 3 - - - - - - - - - - - 3 5 3 3	- - - - - - - - - -	5 5 5 7 7 8 8 8 8 8	- - - - -
Barringtonia racemosa	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - 2 2 2 1 2 - - - - -	- - - - - 1 1 2 1 1	2 1 2 2 2 - - - - -	- - - 1 -
Syzygium zipelliana	- - - - - - - - - -	- - - - 1 - - - - - - - - - -	1 1 - 1 -	- 4 2 2 2 - - - - - - - - - - - - - 1 1	2 1 1 1 - - - - - -	- - - - - - - - - -	1 1 1 1 -
Pandanus helicopus	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	1 - - 1 - - - - - -	- - - - - - - - - -	- 4 4 4 4
Tetractomia cf- tetran	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - 1 - - - 1 -	- - - - - - - - - -	- 1 - - -
Thoracostachyum bancanum	- - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - -	- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -	3 2 3 2 2

The divisions made by TWINSPAN are also presented in figure 5.8 as well. Site AHL P was identified as the first group that is significantly different from the rest, *Thoracostachyum bancanum* being the indicator species. (eigenvalue of 0,668). Considering the site's extreme characteristics (heavily flooded for most of the year and accommodating only four species), this division is not surprising. The second division (eigenvalue = 0,581) was made based on the presence of *Macaranga pruinosa* in ten of the 14 remaining sites, clustering the four heavily flooded locations with poor regeneration together. These four sites are further subdivided in two clusters: OC and GE. Sites O and C mainly differ from G and E in the presence of *Stenochlaena palustris*. Cluster OC contains more species than cluster GE, a group that faces more intense flooding. Sites A,D,F and I were set apart from the remaining sites, because the lack *Nephrolepis bisserata,* a species that only occurs in the other sites that are characterized by shallow and short flooding. Cluster ADFI is still in a very early stage of regeneration and is characterized by a relatively low species diversity. The last division, made within the remaining group of well developed forest is less clear than all the others, having an eigenvalue of 0,283. Several indicator species (e.g. absence of *Lygodium microphyllum* and *Pternandra galeata)* separated J and N from B,K,L and H. Plant diversity, exceeding 30, species is higher in J and N than that of all other clusters and indicates the high level of development of this group.
After all divisions were made, relevees and sites are automatically sorted in the order that is present in both the dendrogram and the TWINSPAN Two-way table. This order coincides with a range of environmental conditions that determine the success of regeneration; Site AHL P, situated on the right, is the site that is worst affected by fire and flooding. During most of the year the area is flooded and species can hardly survive. SM J and AHL N are placed to the far left. They faced single burning, short and shallow flooding and are best developed in terms of species composition.

5.4.2. Description of vegetation types based on species composition (TWINSPAN)

Based on the clusters in the TWINSPAN table, six vegetation types (Type I to VI) can be discerned. They are shortly described below. In paragraph 5.4 a new description of vegetation types is provided, that also incorporates additional information derived from the PCA analyses and is extended with structural characteristics of each type. This final description is most useful for assessment of an area's suitability for rehabilitation.

Type I (Site P) is strongly differentiated form all other types in terms of diversity and species composition. Diversity is very low(4 species per 0,1 ha) and each species has a low cover. Ferns are absent and the semi-aquatic species *Thoracostachyum bancanum* and *Pandanus helicopus* differentiate this type from others. **Type II** (Site G and E) is poor in species. Trees and ferns are almost absent. The floodplain grass *Hymenachne amplexicaulis* differentiates B from the others. Diversity is higher in **type III** (Site O and C), although tree diversity remains low. The table does not contain clear differentiating species, but a high cover of *Scleria purpurascens,* the relatively low cover of *Utricularia exolata* combined with the absence of *Pandanus, Thoracostachyum* and *Hymenachne* differentiated it from other clusters. **Type IV** (Site A,D,F and I) is strongly dominated by a large variety of ferns. The high cover of *Blechnum indicum* differentiates this type from all other types, although the species also commonly occurs in type C. *Mallotus muticus, Syzygium zipelliana* and *Barringtonia racemosa* commonly occur in this type and differentiate from many of the dryer types. **Type V** (Site B,K,L and H) is very rich in species, mainly trees and climbers. Ferns are less dominant, although *Nephrolepis bisserata* differentiates this type form type A to D. *Korthalsia flagellaria* and *Derris scandens* are differentiating species. Species diversity is even higher (>30 species per 0,1 ha) in **type VI** (Site J and N) and consist of a large number of trees and climbers as well. Fern composition is similar to Type E. *Smilax leucophylla* and *Forrestia mollissima* together with a high diversity of *Ficus* species differentiate this type from others.

5.4.3. Forest structure

For each relevé the cover of both trees and herbs was estimated in five different height classes (0-1m; 1-2m; 2-5m; 5-10m; 10-20m). Graphs representing the average cover per class per site can be found in annex 10. These illustrate that multiple burnt sites are mainly dominated by herbs. Only a few surviving trees contribute to tree cover and as little regeneration has taken place since the latest fire, tree cover remains very low. For these sites, the first two light coloured bars (herb covers in the first height classes up to two metre) are the result of excessive growth of *Stenochlaena* and *Blechnum* ferns. The sites in the graph have been sorted according to their position in the TWINSPAN table. Locations that have most favourable conditions for regeneration are situated right in the forest structure graph. It is clearly visible that this TWINSPAN order also represents an increase in structural development. For areas that burnt once, a same pattern is visible. The herb cover in the first two height classes is still high in sites SM H and SM I, which are still in an early stage of development. When trees grow more dense and reach a height of up to 20 metre, they outcompete the ferns and inhibit growth in the lower classes. This can be concluded from sites N,B,K and L which show good regeneration during the last six years due to optimal hydrological circumstances.

5.4.4. Basal area

Another method to map forest structure is to measure the Basal area, expressed as the surface per hectare covered by stems exceeding five centimetres in diameter. Among sites there was a wide variety in basal area. A relevé in site AHL D contained two trees resulting in a Basal area of only 0,042 m^2/ha, whereas 239 trees were recorded in a relevé of site AHL N with an average girth of 33 centimetres and being responsible for a Basal area of 25 m^2/ha. The low Basal area recorded in multiple burnt sites can partly be ascribed to the fact that few trees survived the fires and most pioneer species do not et exceed the critical diameter. Well-developed *Macaranga* forests have a Basal area that is two to five times as low as measurements taken in pristine Peatswamp forest of Central Kalimantan (Shepherd *et al.*, 1997) and in Berbak NP (Silvius *et al.*, 1984). Tree density however is 1,5 to two times higher in *Macaranga* forests. This indicates that tree density will drop in a next phase, when fewer but larger trees remain in the secondary forest after most pioneer species such as *Macaranga* have died. The results are presented in two separate graphs for both single fire locations and sites that burnt several times (annex 11). Sites have been sorted according to the TWINSPAN order and it is clear that here too this order represents an increase in Basal area.

The measurements of vegetation cover per height classes in relation to the environmental factors are analyzed by means of a PCA ordination. Correlation between basal area and abiotic factors, is less complicated and can be revealed by scatter plots (figure 5.10a,b and c). As most sites that burnt more than once, hardly have any values for Basal area, no significant relationship can be drawn from the data. However, Basal areas in single burnt sites are much higher, resulting in correlations with a higher level of accuracy. Figure 5.10a shows that there is correlation between flooding duration and Basal area, where sites that are hardly flooded throughout the year (flooding duration 1 and 2) have high basal areas and sites with prolonged flooding have smaller values (flooding duration 3-5; R^2 = 0,42). The correlation of basal area with peat depth is even stronger (R^2 = 0,56) and from figure 5.10b can be concluded that Basal area also significantly increases together with an increasing peat depth. This is in accordance with early Basal area measurements taken in Berbak's pristine forest. Average girth as well as Basal area were found to be higher in areas with deep peat than in areas with shallow peat. (Silvius *et al.*, 1984). In contrast maximum depth of flooding (figure 5.10c) is negatively correlated with maximum flooding depth, but the correlation is very weak (R^2 = 0,163). It should be noted however, that the correlations are based on a small set of measurements and consequently more data should be collected to reveal the exact link between basal areas and abiotic factors.

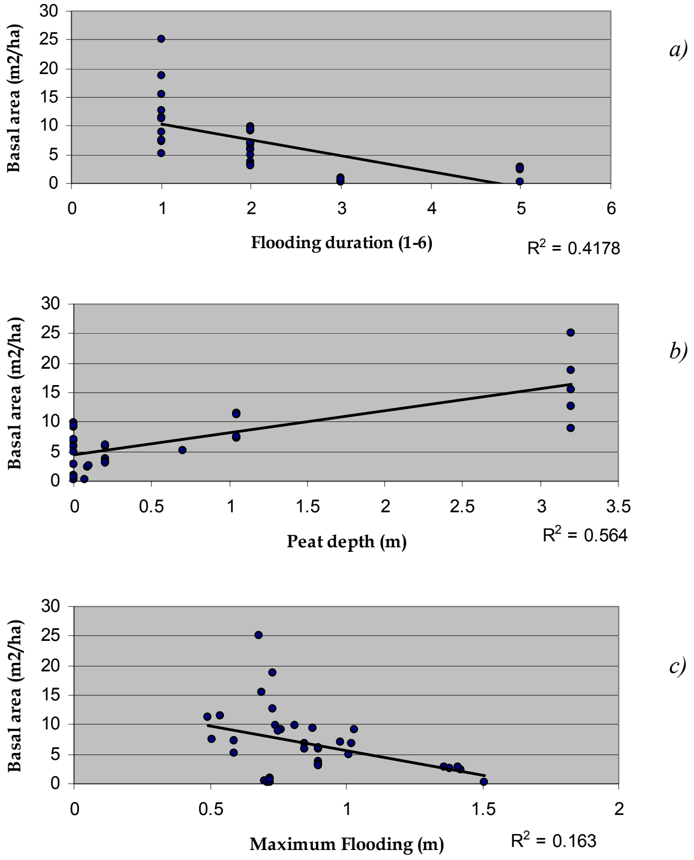


Figure 5.10 Correlation between Basal area and a) Flooding duration; b) Peat depth; c) Maximum depth of flooding

5.4.5. Principal Correspondence Analysis (PCA) in CANOCO

For the correspondence analysis in CANOCO, three input files have been used: the species file, the forest structure file and the environmental data file. To find relationships between abiotic factors and both species composition and forest structure, three analyses were made. In each case the same four environmental factors were selected: fire history (single/multiple burning), peat depth, maximum flooding depth and flooding duration. Soil structure and soil type were almost identical at all sites and consequently this factor was not included in the analyses. In addition the analyses were used for the further determination of vegetation types as they make a clustering based on species composition and forest structure respectively. In all cases, relevees that have the highest degree of similarity, are placed closely together.

Sites (Species) vs. Environmental factors

In the Bi-plot (figure 5.11) fire history (single vs. multiple) is the strongest determinant of the variation on the first ordinal axis, with a correlation coefficient of 0.85. Maximum depth of flooding depth and flooding duration are also quite strongly correlated with this axis. As these three environmental factors (vectors) are positioned close together, it is assumed that they have a similar effect on species composition. This is not surprising as high maximum flooding depth, long flooding duration and multiple fires are often interrelated. Peat depth is most correlated with the second ordinal axis (correlation coefficient = 0,53), but the length of the vector is smaller than all the others, indicating that the explained variance is rather low. Both axis together explain 55 % of all variance.

All sites that are positioned left in the graph were found to be characterized by high water levels and/or high flooding duration. However, because peat depth and occurrence of typical species strongly influence the ordination, the relevees of site AHL P are not positioned at the outermost position along the first ordinal axis (as one would expect, based on the flooding regime) but near to the vector concerning peat depth, slightly more to the centre of the plot. On the right side the more developed sites are situated, that have drier conditions and have a higher species diversity. Combining the information provided in the Bi-plot with the exact information acquired from the TWINSPAN table, it can be concluded that sites with shallow flooding, short flooding and deep peat that are single burnt, are best developed in terms of diversity and species composition. Sites with prolonged and deep flooding, situated on deep peat that face multiple fires are species poor and contain few peatswamp forest key species. The exact influence of peat depth is complex. In single burnt areas it seems that sites with a deep peat layer are better developed, although the extent of this correlation remains unclear. The sites with poorest development, in areas that burnt more than once, however are situated on deep peat deposits as well. This is probably caused by a strong relationship between peat depth and fire risk: sites that face multiple burning and deep flooding are invariably situated on a deep layer of peat. Consequently, the effect of a peat layer on regeneration differs from place to place. On the one hand, deep peat may increase fire susceptibility and is thus of negative influence on regeneration. On the other hand, if multiple burning does not occur, a peat layer seems to promote the regeneration process. This complicated relationship, may be the cause of the low variance explained by the peat depth in the PCA analyses. Seven clusters, containing sites that have a similar species composition, can be distinguished. The clustering observed from figure 5.11 is summarised in table 5.4.

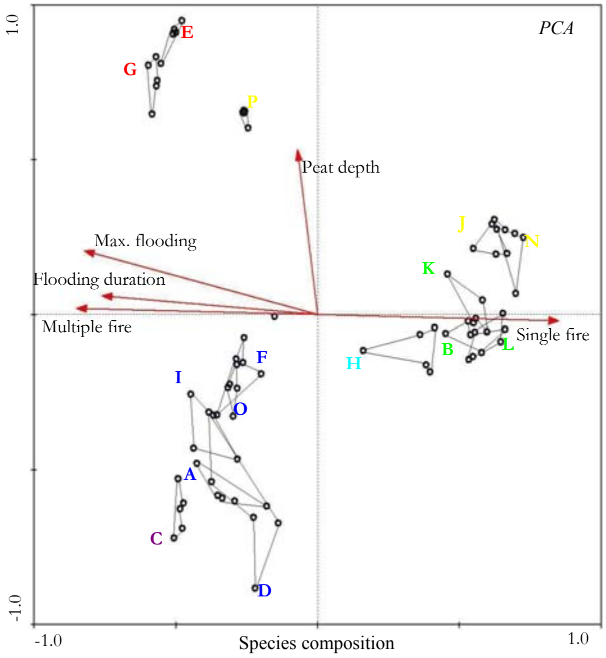


Figure 5.11 PCA Bi-plot: Relevees and environmental factors (species composition)

Species vs. Environmental factors

With the same data set a second Bi-plot was constructed that displays the correlation between the most common species (as identified during the present survey) and environmental factors (figure 5.12). The positioning of the environmental vectors is the same as in the previous analysis, and correlation coefficients are similar. In this case the first two ordinal axis explain 62,3 % of all variance.

The analysis shows a strong correlation of most species with fire history, as species are situated close along the vector. From the origin to the right hand side of the plot, species are found that are more related to well-developed regenerating forest. Among others *Nephrolepis bisserata, Nephrolepis cordifolia, Macaranga pruinosa, Gleichenia linearis* and *Alstonia pneumatophora* are situated most right, indicating a high abundance in areas that regenerate very good, due to shallow flooding depth and short flooding duration. This is in accordance with the TWINSPAN table (figure 5.9), that groups these relevees that contain these species mainly in the two most left clusters. On the other hand, the left side of figure 5.12 shows the species that are most commonly found in multiple burnt sites that are (heavily) flooded most of the year and have relatively high water tables. However, species that occur in the wettest sites (*Pandanus helicopus* and *Thoracostachyum bancanus*) are correlated to a thick peat layer as well and are therefore placed slightly more towards the centre and not in the extreme left of the plot. It's expected however, that in a more extensive study this correlation would not be found, as both species were observed to grow on clayey soils outside the relevees. It is more probable that the observed correlation is caused by the strong link between peat depth and other abiotic factors as described in previous section. *Scleria purpurascens, Hymenachne amplexicaulis, Barringtonia racemosa, Utricularia exolata, Pandanus helicopus* and *Blechnum indicum* are placed to the far left of the plot and are found most in multiple burnt areas with high and long flooding. These findings are in accordance with the contents of the TWINSPAN Two-way table as well, where the species mentioned above are most abundant in the clusters on the right hand side of the table..

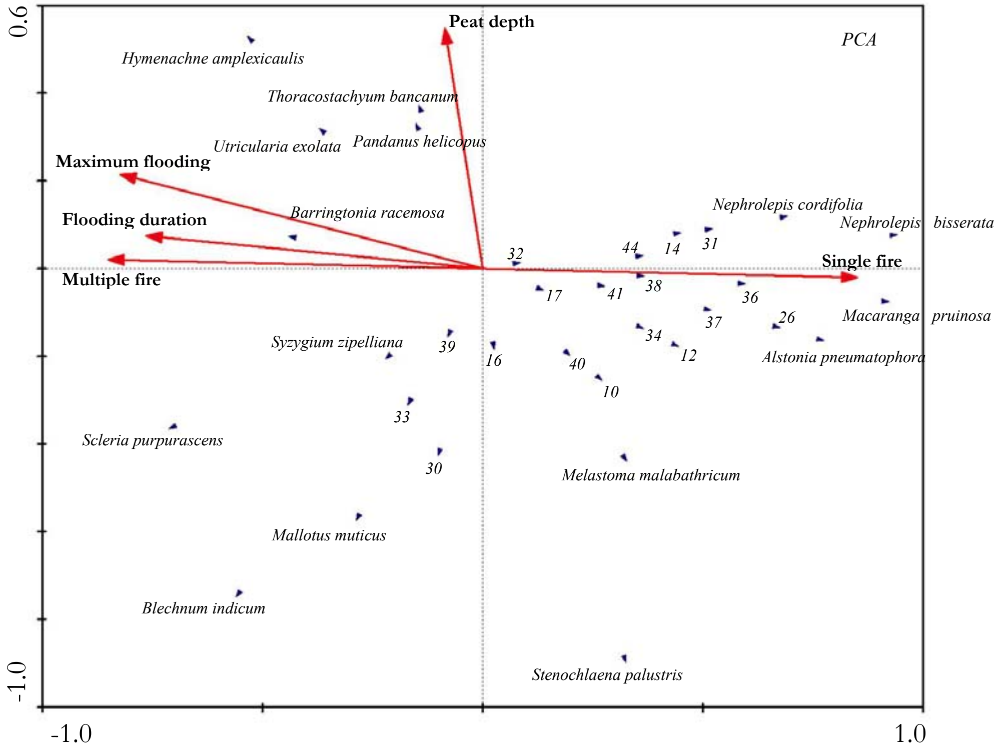


Figure 5.12 PCA Bi-plot: Common species and environmental factors (species composition); numbers refer to tabel 5.1.

Sites (Forest structure) vs Environmental factors

In the PCA analysis of forest structure only the cover of trees was included, as it is assumed that the pattern of regeneration is more clearly represented by the amount of trees, rather than by the cover of herbs. In the analysis, each relevé is clustered based on the percentage of cover that each of the five height classes accounts for. For this analysis again fire history is the strongest determinant of the variance with a correlation coefficient of 0,75 for the first ordinal axis. This axis already explains 84 % of the forest structure, whereas the second ordinal axis explains only 12%, which can also be deduced from the small peat depth vector.

The groups of sites that are mainly characterized by low tree cover and low tree height (and dense fern growth) are situated close together on the left side of the Bi-plot. Well developed *Macaranga* dominated sites are situated on the right side, with site AHL N separated from the other groups. This is not surprising as this is the most well-developed group in terms of forest structure. Site H and I are grouped totally different than was done by the first PCA analysis, as their poorly developed forest structure separates them from all the others sites. SM I is set apart, as the many *Licuala paludosa* palms that occur in the site and the high flooding regime greatly influence forest structure. It can be concluded that single burnt sites with the shallowest and shortest flooding, situated on a deep peat layer have the strongest rate of development with respect to forest structure. Single burnt sites with extreme flooding resemble multiple burnt sites. Poorest development of forest structure occurs in multiple fire sites with deep and long flooding and a deep peat layer. Peat depth influences the forest structure in two different ways in single and multiple burnt locations. A deep peat layer seems to promote tree development (see site N) but as a peat layer also increases fire susceptibility it also may negatively impact forest development. However it should be noted that the exact influence of peat depth remains unclear as there is a weak correlation between forest structure and peat depth. The clustering observed from figure 5.13 is summarised in table 5.4.

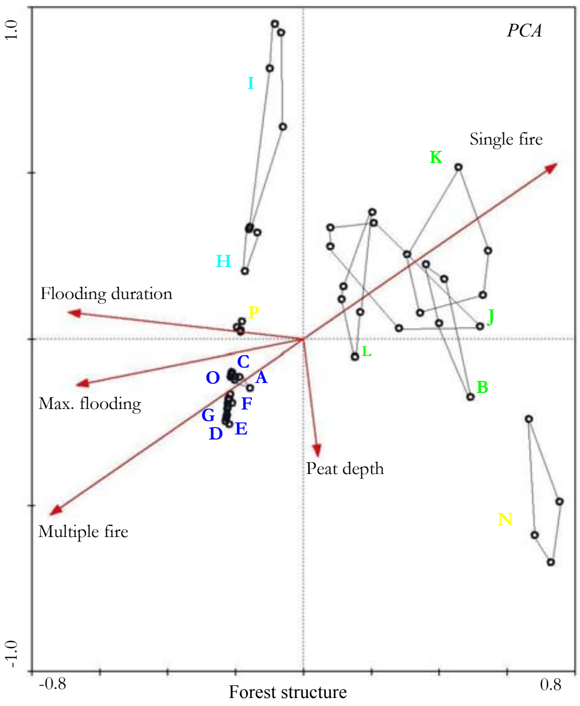


Figure 5.13 PCA Bi-plot: Relevees and environmental factors (forest structure).

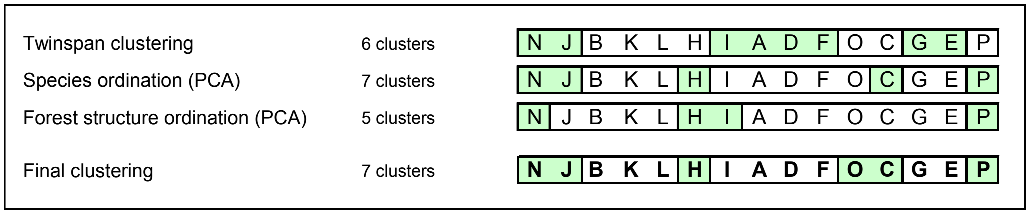
5.4.6. Determination of vegetation types based on species composition and forest structure

For the final determination of vegetation types, the TWINSPAN-clustering is used as a starting point. In addition the grouping of sites revealed by the Species ordination and Forest structure ordination is used to interpret and test the TWINSPAN division made earlier. Table 5.4 summarizes all groupings.

Site N and J are grouped together in the final clustering, as the TWINSPAN table and the species ordination indicate that they resemble most in diversity and species composition. The forest structure diagrams of these sites also show that they are best developed, containing *Macaranga* trees that cover the two uppermost height classes (annex 10). Site H was not included in the second cluster, that was recognized by TWINSPAN, as both the ordination of forest structure and species composition show that H is different from sites B, K and L. Although the site has similarities with the *Macaranga* dominated forest type, it is much more open and has a low basal area. Observations in the field show that site H is an important intermediate stage between early regeneration (fern dominated vegetation) and a well-developed *Macaranga* dominated forest type. Therefore this site is regarded as a single vegetation type.
Although site I is dominated by *Licuala paludosa* and consequently has a slightly different forest structure, sites A, I, D and F are grouped together in the next cluster as they are strongly similar in species composition. From here, forest structure does not play a role in clustering anymore as all remaining sites do not have much woody vegetation and are grouped together by the forest structure ordination. When comparing the abiotic characteristics and taking the field characteristics into account, locations O and C are clustered as they share most species; they have similar flooding conditions. The same counts for G and E, that have less favourable conditions to enable regeneration and are less diverse. Site P is unmistakably different from all other sites, as it turned into a lake habitat dominated by semi-aquatic species such as *Pandanus helicopus* and *Thoracostachyum bancanum*.

The divisions resulting from the analyses form the basis of the identification of vegetation types that are typical for fire-degraded areas in Berbak NP. To discern, understand and describe the vegetation types in more detail however, a much larger set of field data should be gathered. Several of the vegetation types described in the next section are based on a small number of relevees. When more data on species composition will be available in the future, however, characteristic species can be identified with a higher level of accuracy and a better characterization of the vegetation types can be developed. Furthermore, additional vegetation types that occur in fire-degraded areas may be discerned.

Table 5.4 Final clustering based on grouping by TWINSPAN and PCA ordination; letters represent location codes.



Twinspan clustering	6 clusters	N J	B K L H	I A D F	O C	G E	P	
Species ordination (PCA)	7 clusters	N J	B K L	H	I A D F O	C	G E	P
Forest structure ordination (PCA)	5 clusters	N	J B K L	H I	A D F O C G E	P		
Final clustering	7 clusters	**N J**	**B K L**	**H**	**I A D F**	**O C**	**G E**	**P**

5.4.7. Description of vegetation types

In order to clarify and understand the natural regeneration of peatswamp forest in Berbak NP. The seven clusters have been split in six different vegetation types (type 1-6) and two subtypes (type 3a and 3b). Each vegetation type comprises one or more locations visited during the fieldwork period. As a result the floral and abiotic description of each type, provided below, is a combination of the characteristics of all included relevees. The key factors for identification of an area belonging to a vegetation type are species composition, species diversity and forest structure and the description includes additional information on the general environmental conditions that occur in that type. Differentiating species and common companions are given to enable classification of a certain area as one of the vegetation types. Differentiating species are defined as species that commonly occur in a certain vegetation type and are virtually not present in any other type. These species are the strongest keys for distinction of a vegetation type. In addition, common companions are commonly present in relevees belonging to one type, but as they can occur in areas belonging to other types as well, they can only be used for type identification in combination with the presence of other species.

1. Pandanus and Thoracostachyum dominated lake-type

Fire history: >4 fires
Maximum flooding(2003): 152 cm
Flooding duration(1-6): 6

Nr. Species: <5
Basal area: 0-0,09 m^2/ha

Type 1. ***Pandanus*** **and** ***Thoracostachyum*** **dominated lake-type**
Type 1 is differentiated by *Pandanus helicopus*, that can occasionally reach a cover up to 50 percent. Soil is rapidly colonized by *Thoracostachyum bancanum*; the cover depends on fire history. The species stays largely submerged during much of the year. Species diversity is low (<5 per 0,1 ha). Total cover depends on fire history, but is usually low (15-25 percent). There is no establishment of seedlings; surviving tree species are occasionally present. Typical floodplain grasses (*Hymenachne amplexicaulis, Ottochloa nodosa*) are absent. Flooding is almost year round, and deep (150-200 cm) in the wet season. The underlying peat soil is only susceptible to fire in extremely dry years. Numerous fires have occurred in the past.

Diff.: Pandanus helicopus, Thoracostachyum bancanum
Comm. com.: Syzygium zipelliana

2. Hymenachne dominated seasonal lake-type

Fire history: >3 fires
Maximum flooding(2003): 128-178 cm
Flooding duration(1-6): 4

Nr. Species: 5-10
Basal area: 0-0,06 m^2/ha

Type 2. *Hymenachne* dominated seasonal lake-type

Type 2 is differentiated by the floodplain grass *Hymenachne amplexicaulis*, that covers at least 50 percent of the surface. The species floats on the water and cannot stay submerged for long. Other (semi)aquatic species that commonly occur are *Utricularia exolata* and *Scleria purpurascens. Ottochloa nodosa* occurs in areas that face relatively shallow flooding. The species does not mix with *Hymenachne*. Species diversity is low (5-10 per 0,1 ha). Total cover is generally high (70-100%). Ferns are virtually absent, although small numbers of *Lygodium microphyllum* occasionally colonize tree trunks. There is no establishment of seedlings, but small numbers of surviving trees (mainly *Barringtonia racemosa* and *Mallotus muticus*) are occasionally present. Flooding is deep, but not year round. Underlying peat soils strongly desiccate in the dry season, resulting in a high fire susceptibility. Some areas burn annually. Repetitive fires will lead to conversion into a *Pandanus* and *Thoracostachyum* dominated lake-type, provided that the area is situated on a relatively deep peat soil.

Diff.:	*Hymenachne amplexicaulis (>50%)*
Comm. Comp.:	*Scleria purpurascens, Utricularia exolata, Ottochloa nodosa, Barringtonia racemosa*

Type 3. **Fern and Sedge dominated early regeneration- type**
Type 3 is differentiated by the occurrence of high densities of *Blechnum indicum*. Furthermore the type is dominated by the fern *Stenochlaena palustris*, the sedge *Scleria purpurascens* and the tree *Mallotus muticus*, that often occurs as a survivor. All sites belonging to type 3 have these species in common. However they differ strongly in terms of overall species diversity and cover of individual species. Therefore the type has been subdivided into Sedge-dominated early regeneration– type (flooded) and a Fern-dominated early regeneration–type (less flooded)

3a. Sedge dominated early regeneration –type (flooded)

Fire history:	>2 fires
Maximum flooding(2003):	103-1,25cm
Flooding duration(1-6):	5

Nr. Species:	10-15
Basal area:	0-0,23 m^2/ha

Subtype 3a. **Sedge dominated early regeneration- type(flooded)**
Scleria purpurascens is dominant, reaching a cover that can exceed 60 percent. Fern cover remains high, but the wettest places are devoid of ferns. At these sites *Utricularia exolata* proliferates. Total diversity is low (< 15 per 0,1 ha) The pioneers *Alstonia pneumatophora* and *Macaranga pruinosa* cannot establish. Establishment of other seedlings is nearly absent and most trees are survivors. Flooding is moderately deep (100-150 cm) in the wet season and relatively long. The peat soil (if present) can dry out during a short period of the year and might become susceptible to fire during the driest years. Repetitive fires turn areas belonging to this type into an *Hymenachne* dominated seasonal lake- type, provided that a sufficiently deep peat layer is present.

Diff.: *Blechnum indicum*
Comm. Comp.: *Scleria purpurascens, Mallotus muticus, Syzygium zipelliana, Baringtonia racemosa, Utricularia exolata, Hymenachne amplexicaulis*

3b. Fern dominated early regeneration –type (less flooded)

Fire history: <3 fires
Maximum flooding(2003): 124-151cm
Flooding duration(1-6): 2-5

Nr. Species: 15-25
Basal area: 0-1.3 m^2/ha

Subtype 3b **Fern dominated early regeneration- type(less flooded)**
Fern cover is very high; up to 95 percent. *Scleria purpurascens* is present in the wettest areas (cover < 20%). *Melastoma malabathricum*, *Macaranga pruinosa*, and *Alstonia pneumatophora* are present in small numbers. Species diversity is higher than in subtype a (15-25 per 0,1 ha). Flooding is moderately deep (100-150 cm) in the wet season and relatively short. Fire susceptibility is quite low.

Diff.: *Blechnum indicum*
Comm. Comp.: *Mallotus muticus, Macaranga pruinosa, Alstonia pneumatophora, Scleria purpurascens, Barringtonia racemosa, Barringtonia macrostachya, Syzygium zipelliana, Pternandra galeata, Melastoma malabathricum*

4. Nephrolepis dominated tree establishment –type

Fire history: 1 fires
Maximum flooding(2003): 71-75 cm
Flooding duration(1-6): 3

Nr. Species: >25
Basal area: 0.3-1.0 m^2/ha

Type 4. ***Nephrolepis* dominated tree establishment- type**

Type 4 is differentiated by three woody species: *Teijsmanniodendron pteropodum, Poikilospermum suaveolens and Petunga microcarpa*[11]. Tree diversity is high with *Alstonia pneumatophora* and *Macaranga pruinosa* being common species. The *Macaranga* trees do not form a closed canopy yet. *Blechnum indicum* is replaced by *Nephrolepis bisserata*, a key species that is a strong indicator for areas with a high potential for natural regeneration as the species only grows under dry conditions. Species diversity is high (>25 per 0,1 ha) and the type contains both species of an earlier regeneration stage (type 3) as well as species of a more developed stage (type 5 and 6). Flooding is relatively shallow (<100 cm) in the wet season and flooding duration is relatively short.

Diff.: *Teijsmanniodendron pteropodum, Poikilospermum suaveolens, Petunga microcarpa*
Comm. Comp.: *Nephrolpis bisserata, Alstonia pneumatophora, Macaranga pruinosa, Nephrolepis cordifolia, Barringtonia macrostachya, Pternandra galeata*

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[11] It should be noted that the description of this vegetation type is based on a small number of relevees and it is well possible that additional differentiating species will be recognized or that the present differentiating species prove to be not highly reliable.

5. Macaranga dominated early forest-type

Fire history: 1 fires
Maximum flooding(2003): 74-103 cm
Flooding duration(1-6): 2

Nr. Species: >25
Basal area: 2 9-9 8 m^2/ha

Type 5 ***Macaranga*** **dominated early forest- type**

Type 5 is differentiated by *Korthalsia flagellaria* and *Derris scandens* that both occur in low densities. *Macaranga pruinosa* (cover > 50%) forms a canopy at approximately 7-10 metre. This canopy differentiates this type from all others except the well-developed *Macaranga* forest-type. *Stenochlaena palustris* cover is relatively low (locally < 20%); *Pteridium aquilinum* and *Mikania cordata* differentiate the type from types 1-4. *Nephrolepis bisserata* separates this type from types 1-3. Species diversity is high (>25 per 0,1 ha). Basal area is up to 10 m^2 per ha. Understorey is shaded and has a thick litter layer, that is not completely covered by vegetation. Flooding depth is shallow (<100 cm in the wet season) and the flooding duration is short.

Dif.: *Korthalsia flagellaria, Derris scandens*
Comm. Comp.: *Macaranga pruinosa (>25%), Nephrolepis bisserata, Gleichenia linearis, Pternandra galeata, Calamus sp., Melastoma malabathricum, Barringtonia macrostycha*

6. Macaranga dominated, well-developed forest-type

Fire history: 1 fires
Maximum flooding(2003): 49-75cm
Flooding duration(1-6): 1

Nr. Species: >30
Basal area: 5.0-25 m^2/ha

Type 6 ***Macaranga* dominated well developed forest- type**

Type 6 is differentiated by *Smilax leucophylla and Forrestia mollisima*. *Uncaria* sp. reaches a cover from 5 up to 15 percent. The canopy formed by *Macaranga pruinosa* (at an height of 9-15 m) is different from all other types except type 5. *Stenochlaena* cover is low (<20%). *Pteridium aquilinum* and *Mikania cordata* differentiate this type from type 1-4. *Nephrolepis bisserata* differentiates it from types 1-3, which are the wetter areas. Basal area is very high, reaching a value of 10-20 m^2 per ha. Understorey is shaded and has a thick litter layer, that is not completely covered by vegetation. Flooding depth is shallow (<100 cm in the wet season), and the flooding duration is very short.

Diff.: *Simlax leucophylla, Forrestia mollisima*
Comm.comp.: *Macaranga pruinosa (>50%), Nephrolepis bisserata, Nephrolepis cordifolia, Alstonia pneumatophora, Uncaria sp. (>5%), Stenochlaena palustris, Macaranga amissia, Pteridium aquilinum, Mikania cordata, Gleichenia linearis*

5.5.Regeneration

Apart from the collection of data on species composition and structural measurements, numerous general observations were made at the research locations and during travelling along Air Hitam Laut, Simpang Melaka, Simpang Kubu and Air Hitam Dalam River. Many of those observations provided insight into the process of regeneration that has been occurring since the forest fires. Although many sites visited during the research period have a relatively similar fire history, and although it was not possible to study sites that have been recovering since more than seven years, a combination of the observations acquired at different sites gives a clear overview of long term regeneration in a burnt area. Next paragraph describes for both single and multiple burnt locations the pattern of succession as it is most likely to take place (figure 5.14).

5.5.1. Swamp forest regeneration: A hypothetical sequence of succession.

Regeneration in single burnt locations
Fires in swamp forest invariably cause considerable damage to flora and fauna, although the extent of disturbance depends on fire intensity that differs from site to site, depending on the depth of peat and the state and composition of the vegetation. In general, drained peat soils, with strongly degraded forest, suffer the most intense fires. Pristine forest, growing on clay or shallow peat is less susceptible to burning and, if it burns, often faces low fire intensity. Sites that have been affected most contain few survivors and suffer from intense flooding due to deterioration of the upper peat layer. Sites that have burnt less severely contain more surviving trees and face less inimical flooding conditions. The state of a site depends on numerous factors and can be anywhere between these two extremes. This means that the starting point for regeneration is differs among sites.

The first colonizers to occur on dry places are ferns, *Stenochlaena palustris* being the most common species, accompanied with *Blechnum indicum* in relatively wet and *Nephrolepis bisserata* in drier sites. *Lygodium microphyllum* is more scarce as a result of interspecific competition, but the species has a high ecological amplitude and can be found in both dry and wet environments. Under very deep flooding conditions, circumstances are not suitable anymore for ferns and instead the sedge *Scleria purpurascens* and the grass *Hymenachne amplexicaulis* act as colonizers (**B**). The only ferns to be found here grow on local elevations. It is expected that these sites by ferns as increasing accumulation of litter decreases flooding depth. As accumulation proceeds slowly, this process is expected to take many years, probably up to several decades. Soon after colonization by ferns, a number of other plants (e.g. *Flagellaria indica* and *Melastoma malabathricum)* move in. This species-poor vegetation type can persist for several years (**C**). The dense fern growth is a strong competitor for space and light and together with deep flooding it strongly inhibits establishment of seedlings.

The next stage of succession is dominated by the gradual emergence of seedlings. *Alstonia pneumatophora* is one of the first and most common species to appear (**D**). In sites that are only shortly and slightly flooded, *Alstonia* appears very soon, almost directly after establishment of the first ferns. In sites that are longer and more heavily flooded, it may take years for the species to appear. First flooding depth and duration need to be reduced by accumulation of dead and living packages of fern roots mixed with decomposed leaves. These packages, that can reach a height of more than 50 centimetres provide the seedlings with an elevated growth medium. Immediately after *Alstonia* emerges, *Macaranga* trees will establish as well (**E**). Again, the flooding depth is the main determining factor of this process. At places where flooding is shallow, *Macarang*a establishes soon and trees grow fast. Deeply flooded sites are colonized at a lower rate and it takes a long time before *Macaranga* dominates.

As soon as the stage of *Macaranga* dominance (**F**) is reached, the vegetation changes drastically. The stage is characterized by the formation of a closed canopy layer five to ten metres above the ground and the shadow caused by the trees negatively impacts by several of the early pioneers. As a result, *Stenochlaena* ferns slowly disappear, although they still compete for light with the *Macaranga* as they are able to climb several metres into the canopy. The same is the case for (non climbing) *Blechnum* and *Nephrolepis*. As the *Macaranga* trees grow larger, intraspecific competition decreases tree density (**G**). The weakest individuals die, and thus enable new tree species to settle. Meanwhile the ferns that were present in the pioneer stage further vanish from the area. Their place is taken over by shade preferring ferns and a large variety of woody climbers. In this species-rich stage, the site starts to attract animals that forage and find shelter in the *Macaranga* stands. Malayan Sunbears (*Helarctos malayanus)*, Malay Tapirs (*Tapirus indicus)* and Wild boars (*Sus scrofa)* venture from pristine forest far into the regenerating areas, as do a number of birds that search for fruits and insects. The open forest floor, partly covered by herbs and ferns is a perfect medium for species that cannot outcompete densely growing ferns, and are at the same time intolerant to the intense sunlight and high temperatures present in the earlier stages (**H**). These shade preferring species slowly grow taller and force their crown into the *Macaranga* canopy. Subsequent developments could not be observed in the field but it is known from literature that the short living *Macaranga* trees are poor competitors for light and space in comparison to longer lasting tree species. In the long term, *Macaranga* will die and *Alstonia* is one of the few large species that remain from the early pioneer stage. The species that developed in the *Macaranga* stand will form the new canopy and the number of species very slowly increases due to seed dispersal from nearby pristine forest areas. On the very long term the site will regain its pre-fire characteristics and can regarded as a peatswamp forest again.

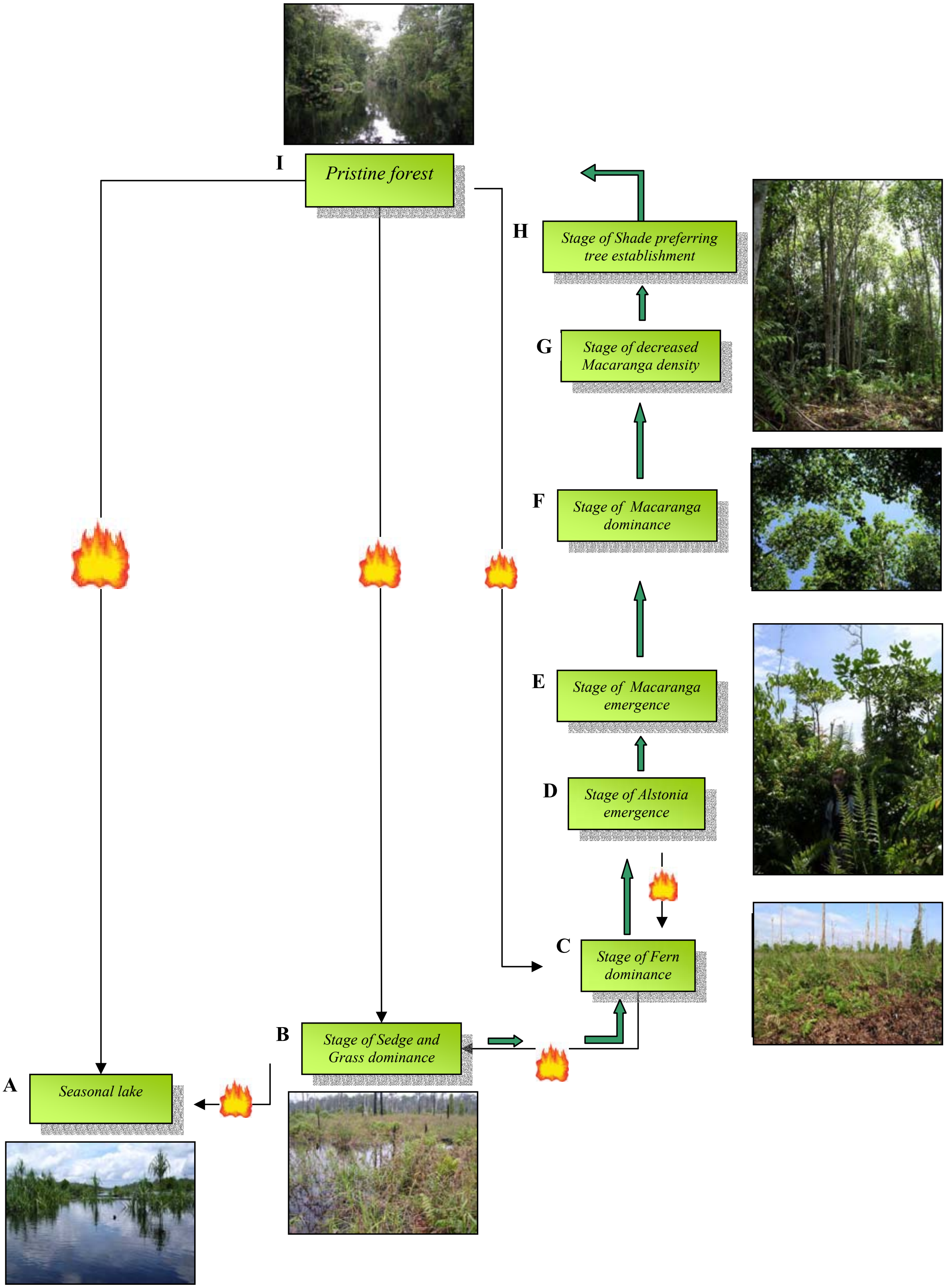

Fig 5.14 Schematization of hypothetical sequence of succession of fire degraded peatswamp forest.

Regeneration in multiple burnt locations

Repetitive burning is of great influence on succession and regeneration of a multiple burnt location differs from regeneration of a single burnt site in that:

1. A transition from one vegetation type into a higher stage of development is hindered. After each subsequent fire, succession has to start again.
2. Each fire causes changes in abiotic circumstances and thus the starting conditions for regeneration are repeatedly altered.

The starting point of regeneration in multiple burnt locations is similar to that of places that have burnt only once. Depending on the amount of flooding caused by a fire, colonization of sedges or ferns and further developments will take place in the same way as was described for single fires. If fires re-occur in a site, however, this pattern of regeneration is changed totally. Although it may take years before sites are burnt a second time, repetitive burning reverses the regeneration process. In sites that are covered by a peat layer, subsequent fires combust the peat and cause increased flooding. Locations that are only slightly flooded and are easily colonized by trees and ferns will become very wet after another fire. Consequently they will reach a stage from where they can only be colonized by sedges and grasses. If in the dry season more fires affect the area, flooding will increase even further and will finally be so intense that the regrowth of vegetation is virtually impossible. At this point a seasonal lake is formed (**A**), and in such locations fires will become less frequent as only exceptionally dry years the peat soil will dry out enough to become susceptible to fire. The seasonal character of these lake however, inhibits succession. Each year they almost dry out and thus prevent development of a real aquatic ecosystem.

In some locations the peat layer burns away after one or two fires as the peat is shallow and is situated on an elevated subsoil. Although fire susceptibility is highly reduced after disappearance of the peat, these sites sometimes still face repetitive fires. However, they differ from peaty areas in that subsequent fires do not increase flooding, and as a consequence these sites do not develop into seasonal lakes. They will instead develop a cycle of succession: the vegetation develops in one ore more years until it is burnt to the ground and has to redevelop again. Abiotic circumstances remain relatively constant after each fire. Multiple fires will finally wipe out most of the surviving trees although some species are very fire tolerant and can survive three or more fires. As a result of this valuable sources of seeds will disappear from the area.

The above description is supported by forest structure measurements. Although the study sites have relatively similar fire histories (i.e. burnt seven years ago or several times since 1997), abiotic circumstances are strongly different from place to place. Some sites have extreme environmental circumstances (multiple fire and deep and prolonged flooding) and have been barely regenerating since 1997. In other sites circumstances are less hazardous (single fire, shallow and short flooding) and regeneration is successful. This difference in rate of development enables to get insight in long term regeneration, the sites with poor circumstances representing an early stage and areas with favourable circumstance representing a late stage. This has been depicted in (figure 5.14), where the forest structure diagrams of six representative research locations have been ordered based on their abiotic circumstances. Sites with the poorest conditions (deep maximum flooding, long flooding duration and multiple fires) have been placed left in the figure. Sites that show more enhanced regeneration (low maximum flooding, short flooding duration and single fire) can be found on the right. The first structure diagram represents the ‘seasonal lake’ –stage. The area is barely vegetated and the tree cover solely consists of surviving trees, not by newly established species. The following three diagrams represent early stages of succession. Herbs and ferns are dominant and trees are scarce. In subsequent diagrams trees slowly become more common and herbs strongly decrease. Gradually a stage of succession dominated by trees is reached. Observations in the field make it easy to appoint a certain stage of succession to each structure diagram and the order generated in figure 5.15, based on environmental conditions supports the sequence of succession. The same ordering has been made with Basal area measurements (figure 5.16). It provides the same information as the structure diagrams; trees have barely developed in the early stage and only surviving trees contribute to Basal area. In more developed stages, trees play a more dominating role and Basal area increases.

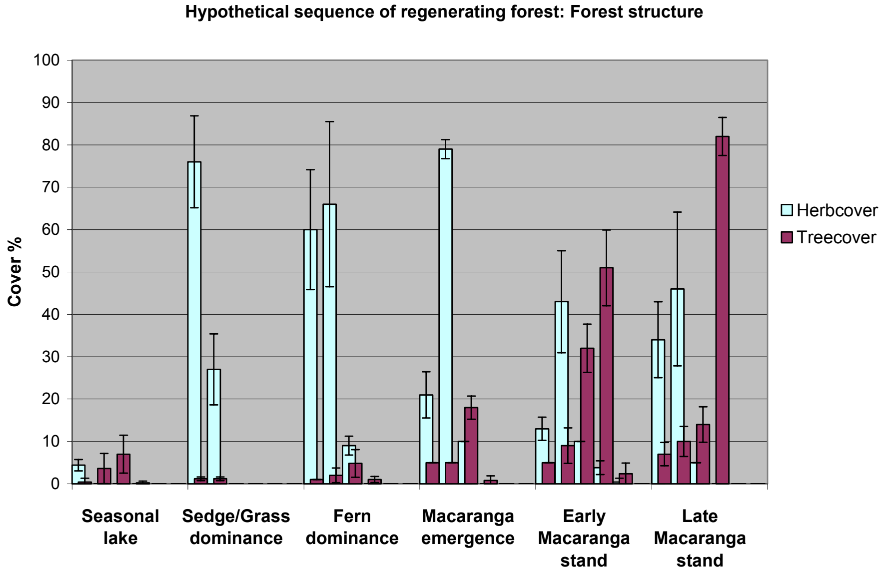

Figure 5.15 Forest structure as assumed to occur in the hypothetical sequence of succession; each set of bars represent a group of height classes (0-1m, 1-2m, 2-5m, 5-10m, 10-20m).

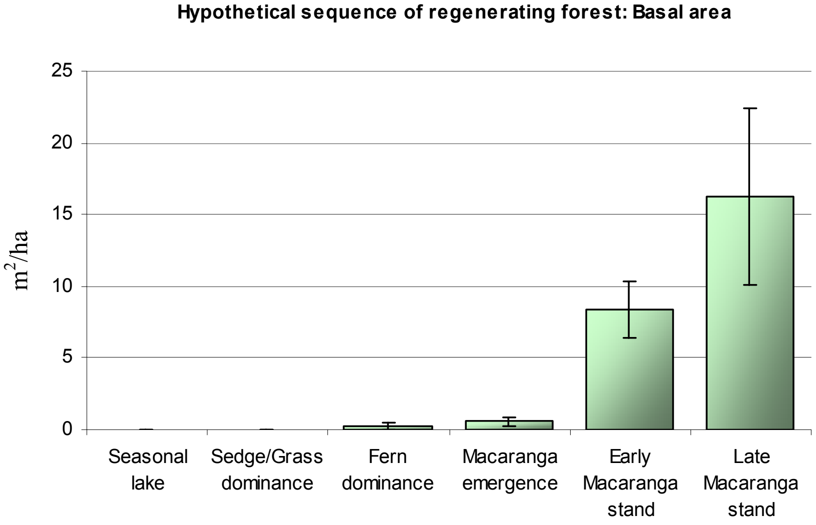

Figure 5.16 Basal areas as assumed to occur in the hypothetical sequence of succession.

5.5.2. Stimulators to successful regeneration

Apart from the abiotic circumstances that optimize the regeneration process (see paragraph 5.4), there are several other factors that promote regeneration or protect against reoccurrence of fires. One of them is fern "package" formation. At many sites *Stenochlaena palustris* and *Blechnum indicum* are dominant species that cover almost the entire surface with their strangling stems (*Stenochlaena*) and dense leaves (*Blechnum*). Until now these ferns were seen as predominantly harmful, significantly hampering the establishment and growth of seedlings (Giesen, 2004). Although this is definitely true in the short term, observations in the field indicate that fern dominance might be beneficial for regeneration in the longer term. After establishing, each *Blechnum indicum* plant forms separate clump of dead and living roots that grows bigger with increasing age. Often the *Blechnum* ferns are accompanied by *Stenochlaena* whose roots fill the space between the *Blechnum* clumps. Together the species form a deep layer of dead and living roots and partially decomposed leaves. Within seven years this layer can reach a height of 40 to 80 centimetres, depending on the productivity of the system. This uplift of ground surface causes a significant decrease in flooding and enables plants that can not survive deep and long flooding (such as most tree seedlings), to establish. Over the years the fern package will become compressed and then begins to decompose. This improves opportunities for plant establishment. Field observations indicate that at least two species have capacities to germinate directly on fern packages. *Pternandra galeata* was found once to grow on a 60 cm high fern package (figure 5.17 and 5.18). *Alstonia pneumatophora* was more commonly encountered, growing on fern packages of different sizes and even on floating *Hanguana malayana* mats, indicating the species' adaptability to a wide range of abiotic circumstances. It is expected that there are many more species (e.g. *Macaranga pruinosa, Barringtonia macrostachya, Ficus* sp.) that can establish on fern packages, but this is not yet confirmed by field observations.

Figure 5.17 Fernpackage formation is observed to promote growth of Alstonia and Pternandra seedlings (tree about 2.5 m tall).

Figure 5.18 Establishment of Pternandra galeata on fern package.

In a regenerating forest, protection against future fires is of high importance. Observations from site SM I indicate that *Licuala paludosa* palms are influential in this. Directly surrounding SM I, three huge, 50 metre high *Alstonia* trees were found. The trees were densely surrounded by *Licuala* palms and didn't show any sign of fire damage. The survival of such high trees in the centre of a burnt area is exceptional. Similar trees were only observed at the edges of burnt areas that only suffered from light fire damage. Therefore the survival of the *Alstonia* trees is hypothesized to be caused by the presence of the *Licuala* palms. The palms which are highly resistant to fire themselves, are expected to act as fire intensity mitigators, reducing the effect of fires and providing some of the nearby trees with an opportunity to survive. It is difficult to assess how these palms mitigate fire intensity, but it might well be possible that they create a cool and moist microclimate which decreases fire susceptibility of plants and underlying peat soil. In addition. the palms that form a dense canopy several metres above the ground, might prevent further spreading of fire from the ground into the crowns. The presence of numerous resprouters between the *Licuala* palms and the persistence of peat pockets at places with the most dense palm cover support this theory. Behind site SM I, further from the river, the cover of *Licuala* is greatly reduced. Surviving trees are barely present and flooding is about 15 centimetres deeper. It is possible that the fires were so intense here that even the fire resistant *Licuala* palms burnt, together with the accompanying vegetation. It is more probable however, that these sites have never been dominated by *Licual*a and consequently contain few surviving trees. This is supported by the observation of Silvius *et al.* (1984) that *Licuala paludosa* often grows in close clusters together at elevated levees and gives way to other species quite abruptly further inland. Observations in the field strongly suggest that this was the case near the research site as well: at a fixed distance along the river, *Licuala* was dominant; further inland the species was almost absent. Table 5.5 summarizes the observations that support the theory.

Table 5.5 Observations supporting Licuala- fire mitigation theory.

1. Survival of huge *Alstonia* trees.
2. Presence of resprouters surrounded by *Licuala* palms.
3. Presence of peat pockets at places of highest *Licuala* density.
4. Low tree survival rate at bordering sites lacking *Licuala*.

The influence of surviving trees on the regeneration process is unclear. It is not automatically true that sites with a high number of survivors have a better rate of development. Other factors are more influential. However, survivors may act as seed sources and thus they are expected to facilitate recolonization, especially of species that cannot easily disperse their seeds via wind or water. For palms (*Licuala paludosa* and *Pholidocarpus sumatrana*) this is clearly visible, as numerous seedlings were often found directly surrounding the mother plant. Many of the birds and mammals that occur in burnt areas, stick to clusters of surviving trees. The tree groups also act as stepping stones for animals that roam throughout the area and as many of these animals play a significant role in the dispersal of seeds, surviving trees may facilitate this mode of colonization. This can be illustrated by the occurrence of figs. Nine species of Fig (*Ficus sp.*) have been identified in burnt areas in different stages of regeneration. Their fruits are valuable food sources for many mammals and birds. In the field it was observed that pigeons (*Treron* and *Ducula*) often forage on *Ficus* in both pristine and burnt forest and as they fly from forest patch to forest patch in an area degraded by fire, they are a probable mode of dispersal for these trees.

5.5.3. Inhibitors to successful regeneration

Although the extent of regeneration is largely influenced by abiotic conditions (see paragraph 5.3) there are a number of other factors that may negatively impact the rate of development. Competition with ferns seems to be most influential. Ferns have several characteristics that make them strong competitors; They produce large amounts of spores that are easily dispersed by wind. Many pioneer fern species have a high ecological amplitude and high growth rates, and can, in contrast to many other species of ferns often recover quickly from flooding damage. These characteristics make that ferns can rapidly colonize fire-degraded areas, reaching a cover of almost 100 percent. As a result establishment of other species is very difficult. *Blechnum indicum* is the strongest competitor at the wettest sites. At drier sites this role is taken over by *Nephrolepis bisserata* and *Stenochlaena palustris.* The latter not only poses a threat to very young seedlings; as the fern can climb up to a height of five metre, the species competes for light and space with higher trees as well. If trees manage to establish between the ferns, initially their growth rate is significantly reduced. This is obvious in *Alstonia*, where seedlings were observed to remain hidden between the ferns for a long time. As soon as they escaped from the ferns their growth rate was boosted. These negative impacts are mainly present in the short term. In the longer term excessive fern growth may positively influence regeneration.

Exceptional flooding seems to negatively impact regeneration as well. At several locations in the core zone (mainly around the Simpang-T junction) large numbers of small trees and shrubs that died during the exceptional December 2003 flood were found. The plants, mainly *Melastoma malabathricum* but also *Barringtonia racemosa* were several years old. This indicates that the water regime in normal years is suitable for establishment of these species, but that exceptionally deep and prolonged floods, occurring once every few years, can significantly slow down the regeneration process.

The impact of logging and felling practices on regeneration is unclear. Although trees in a regenerating forest normally do not have a commercial value (most trees are young and most species don't provide high quality timber), they were observed to be used by locals for construction of camps. Sometimes newly established trees were used for this purpose, but more often surviving trees were cut. It is difficult to assess the effect of these activities. Until now logging in burnt areas seems to be small scale and insignificant, but as the vegetation regenerates further, it may well be possible that logging practices increase.

5.6. Conditions of the Park

5.6.1. Illegal activities

This paragraph summarizes illegal activities that were observed during the survey. It provides additional information to the comprehensive description of illegal activities compiled by Giesen (2004, situation 1985-2004) and Silvius *et al*. (1984, situation before 1984). The information can be used by the park's officials to optimize adequate law enforcement and to obtain an up to date view of Berbak's conditions. A complete list of illegal activities noticed in the park is provided in annex 12.

Logging
Observations indicate that logging is most intense in the ***western side*** of the park. This is in accordance with information derived from satellite imagenary and assessment by others (Giesen, 2004). The 26 illegal camps situated along Air Hitam Laut as far downstream as Simpang-T, that were observed in October 2003 (Giesen, 2004) were still present, but the majority of the camps was not inhabited during the present study. This might be an indication that most logging activities take place in the dry season, when accessibility to the forest is much higher. However, it is also possible that the loggers take their refuge in elevated areas further from the river, where flooding is less excessive. At least on one occasion chainsaws were heard. Transport of timber out of the forest was much more commonly observed. During all visits from the western side, lorries loaded with poached timber were encountered on Pt. PDIW's railway system (figure 5.19). This wood was observed to be loaded on lorries at the railway's crossing with the Air Hitam Laut River. Keteks were used to transport the wood out of the park towards the railway. Although illegal transports along the railway seem to be daily practice, locals stressed that the loggers try to arrange communal transport out of the park, maybe to prevent to be arrested by rangers. At the time of visit (April 2004) these transports took place on Tuesdays in groups of 15 to 20 people. From Pt. PDIW's main camp, the wood is further transported by pompong. Some of the timber is directly delivered to local sawmills. Other loads are transported further over the Batanghari River or transferred to trucks for further transport in the direction of Jambi city. At the time of the visit, Pt. PDIW was constructing a second railway next to the existing rail. This poses an increased threat to the park as it further simplifies illegal transport of timber. The forest along Air Hitam Dalam in the **north-west** of the park has a long history of illegal logging and is severely degraded, mainly in forest stretches along lower reaches of the river. Long logging trails were found everywhere but the only recent tracks were situated upstream at the point where the river reaches the size of a narrow ditch. These tracks were several months old. During the visits no illegal loggers were encountered, but observations of large rafts of timber in October 2003 (Giesen 2004) indicate that the construction of a low bridge crossing Air Hitam Dalam's rivermouth and a re-establishment of a ranger post, under the CIDA project in august 2003 to prevent illegal wood transport, did not completely eradicate the practices. However, given the extent of logging in the past, current observations indicate that the intensity of logging may have decreased during the past months.

Figure 5.19 Frequently loads of illegal timber, poached in Berbak NP, are transported along Pt. PDIW's railroad.

The CIDA project's support greatly enhanced law enforcement by the Park's staff and the rangers proudly announced that they often confiscate illegal logs during patrols at Batanghari River. They stated that, after construction of the bridge in August 2003, no illegal wood has been transported out of the park along the Air Hitam Dalam River, but this in contradiction with observations by Giesen (2004). During a conversation with one of the rangers in the night of 2 April 2004, a group of men was observed to load confiscated wood into a Pompong. When the ranger was asked what the men were doing, he answered as follows: " This is confiscated wood and the loggers pay a small tax to get back their timber. That tax is used for development." When asked what was meant with development, the ranger answered: " The money is used for construction of the ranger post and building of the bridge."
This statement seems very suspicious. It is highly unlikely that the money is used for development of the ranger post as the CIDA-project recently invested in renovation of the parks facilities. If it is indeed used for development, however, this gives a weak base to law enforcement as the rangers then act at the fringe of -or outside- the law. One day later a group of men were constructing new rafts of old logs that were confiscated by the rangers several months earlier. They probably supported the rangers with a 'tax' too.

Logging in the **eastern** side along the lower reaches of the Air Hitam Laut is less intense than in other regions. Most logging practices in the area do not seem to be commercial or highly organized. However, some observations indicate that the area is stronger affected than previously assumed. During a short walk through pristine forest South of the Rumah biru rangerpost, the remains of 15 large *Shorea* trees were found. Only one unaffected individual was found, the rest of the trees were logged and large amounts of timber were left unused in the forest. Although these were not visible from the river, many logging trails that lead for several hundreds of metres into the forest were constructed. In one occasion fishermen were observed to load small logs on three Pompongs. Although these men probably collected the wood for construction of fisheries equipment and clearly did not have commercial incentives, the amount they collected was large and the effect on the forest might be considerable if these activities occur regularly.

Finding evidence of logging in the ***Burnt core zone*** is difficult. Excessive flooding or very dense fern cover make it hard to search for the remains of logged trees and consequently these were found in only one occasion. This was close to AHL N, approximately 100 metre away from the river. Several old logs, floating between *Hanguana malayana* in he east of the core zone provide additional in situ evidence. A striking characteristic already mentioned by Giesen (2004), is the small diameter of the remaining dead trees. This may be an indication of intense logging activities before the outbreak of fires. Small-scale logging of surviving trees for construction of fishing camps occurs as well. On 22 March, people from Desa Air Hitam Laut, Nipah Panjang and Palembang were logging trees for the construction of their camp. They were sent away by rangers accompanying the fieldtrip.

Poaching

Poaching of ***birds*** in Berbak occurs on a small scale but is widespread. Although it is unlikely that there are poachers that specialize in bird catching, most local fishermen will catch birds if they have the opportunity. They told that the birds that are caught most are: Blue-crowned Hanging Parrot *(Loriculus galgulus*), Oriental Magpie Robin *(Copsychus saularis),* White-rumped Shama *(Copsychus malabaricus)* and Hill Myna *(Gracula religiosa)* (figure 5.21). Mostly they are taken from the nest, raised by hand and kept as a pet or sold to local villagers. Occasionally, locals catch owls or even Oriental darters *(Anhinga melanogaster)* the latter as food or pets (Noor and Van Eijk, *in prep*.). The fishermen's statements are supported by an observation of a young Magpie robin being taken out of the forest and a large bamboo construction in a dead tree build to rob a Hill Myna's nest (figure 5.20).

Bornean terrapin *(Orlitia borneensis)* is one of the ***reptiles*** that was observed to be caught by a fisherman along Simpang Melaka. He told that the species is common in Berbak's rivers and that it is are caught regularly. These large turtles are of considerable value on the Chinese market and consequently they are highly wanted among fishermen. Occasionally, small False gharials *(Tomistoma schlegelii)* are trapped, but according to the fisherman they are released and not sold to traders. Outside the park in Desa Air Hitam Laut, villagers caught three Reticulated Pythons (*Python reticulatus*) and kept the snakes for several weeks as a curiosity. They were considering to sell the skins in Nipah Panjang.

Figure 5.20 Construction for plundering of Hill Myna's nest.

Figure 5.21 Hill Myna's are very popular in the cage-bird industry.

Fishing

Fishing activities are abundant throughout the park and although they are considered to be far less harmful than logging, there are a number of negative impacts. First of all the pressure on fish populations, may be of negative influence on other species that are dependant on fish (e.g. Crocodilians, turtles and certain bird species). Accidentally these species are being caught by baited hooks (Silvius *et al*., 1984; Giesen 1991). In addition the presence of fishermen brings along a range of other activities that harm the park; poaching of reptiles and birds and collection of construction materials for their camps are the most important ones. Fishermen are expected to play a significant role in the outbreak of wildfires. They are careless with fire and many of 2003's small fires seem to have originated in fishermen's camps. A story told by an old woman, who lives along Simpang Melaka illustrates this. In February 2004 the woman and her son had ongoing problems with a five metre tall Reticulated Python, that entered their camp and used it as a resting place. During the last encounter they managed to chase away the snake that fled into the surrounding *Pandanus* vegetation.

With a can of petrol, that was poured onto the *Pandanus,* the bushes were set to fire. Undoubtedly the Python managed to escape but the *Pandanus* fringe was damaged and if this fire would have occurred in the dry season the fire could have easily turned into a wildfire, threatening a large part of the park. Locals stated that fishermen possibly initiate fires more regularly. Many fishermen believe that the floodplains created by the fires have strongly benefited fish populations and several persons suggested that some of their colleagues sometimes create fires to increase the size of the floodplains.

5.6.2. Animal observations

Birds

In total 107 bird species were observed in and around Berbak National park, spread over four different habitat types (See annex 13 for a species list). Not every type was monitored to an equal extent. Observations at sea were highly incomplete and no inventory was made of the coastal fringe. The richness of birds on the coastal mudflats was largely missed, as transport over sea was too far from the coast. Only on a few occasions distant groups (over thousand individuals) of large unidentified waders could be observed. Observations in pristine forest were incomplete, as the were almost entirely confined to river bank vegetation and to birds crossing the river in flight. Furthermore, the time spent in pristine forest was much less than that in burnt areas and the conditions for observation differed highly between burnt areas (easy due to low vegetation) and pristine forest (hard due to high and dense vegetation). Despite these difficulties however, it remains possible to note some remarkable differences in diversity and species composition between fire degrade areas and pristine forest.

Although much more time was spent in burnt areas, the number of species observed in fire-degraded areas (58 species) was much lower that that in pristine forest (71 species). This indicate that the fires caused a great loss in bird diversity. It is difficult to assess which species suffered most from fire degradation, as the distribution and abundance of birds in Berbak's pristine forest are insufficiently known. It is probable however, that species that are dependant on large fruiting trees (e.g. Hornbills) faced the strongest decline as high trees are virtually absent in burnt areas, whereas insect-eaters are expected to be less negatively affected by the fires as the large variety of insects that occurs in burnt areas may provide a good food source. Several species were very common in burnt areas and some of them, taking the different observation conditions and the different time spent in each habitat type into account, can be regarded to have a preference for (i.e. be more numerous in) fire-degraded areas. These are summarized below.

Oriental Darter *(Anhinga melanogaster)*

Oriental Darters were observed almost daily, both in burnt areas and in pristine forest. Numbers were largest in he burnt core zone, where Darters were commonly observed to roost in dead trees. The floodplains were used as fishing grounds. One of the roosts in the western part of the core zone near Simpang Raket, contained ten individuals at the time of discovery. Several weeks later the number of birds present on the roost rose to 89 individuals and by that time the birds established a colony in three clusters of dead Mallotus muticus trees, consisting of 24 newly established nests. Approximately one month later (part of) the colony was revisited and it proved that most nests were unsuccessful (Noor and Van Eijk, in prep). Disturbance by fishermen, who stated that they reguraly poach eggs and nestlings, is the most probable cause of this failure. This is the second breeding record of Oriental Darter on Sumatra and the first for Berbak National Park.

Herons *(Ardeidae)*

Most herons observed (except *Striated heron, Butorides striatus*) have a strong preference for open fire-degraded areas. Floodplains in the west of the core zone and temporal lakes along Air Hitam Laut's upper reaches are favored most. Sometimes dryer fern dominated sites are visited. These areas contain a rich variety of reptiles, amphibians, insects and fish, which form a highly suitable food source. Herons were less commonly observed in pristine forest, although Purple herons *(Ardea purpurea)* were observed to roost in pristine forest during the night. They were regularly observed to fly towards their roosts from burnt areas and farmland that surrounds the park.

Grey-headed fish eagle *(Ichthyophaga ichthyaetus)*
Grey-headed fish eagles were regularly observed, soaring over burnt areas, single or in pairs. They were rarely seen over pristine forest. The large floodplains that are rich in fish probably provide the species with an easy food source. Although the species was not observed to breed in these areas, it is expected that they do so, as pairs were regularly observed to display and on one occasion a bird was seen that perched in a suspicious way in a cluster of surviving trees along the Simpang-T River.

Black-tighed-falconet *(Microhierax fringillarius)*
Black-tighed-falconets were much more common in fire-degraded areas than in pristine forest. The were often found to hawk on grasshoppers and dragonflies, both species that are abundant in burnt areas.

Long-tailed parakeet *(Psittacula longicauda)*
Long-tailed parakeets are common throughout Berbak National Park and they were often observed passing in small noisy flocks. Surprisingly densities were highest over burnt areas, where the birds were observed to feed on surviving trees and to breed in cavities in dead standing trees.

Blue-tailed bee-eater *(Merops philipinus)*
As Blue-tailed bee-eaters have a strong preference for large flying insects it is not surprising that the species was most commonly encountered in fire-degraded areas. The birds were often observed to hunt between the dead standing trees or to perch on these trees and they were often recorded in close proximity of rivers.

Dollarbird *(Eurystomos orientalis)*
Although Dollarbirds occur in small numbers throughout Berbak National Park, their density is highest in burnt areas. This is probably the species that has benefited most from the forest fires. At least 54 birds were counted on a single afternoon during transport on the Air Hitam Laut River in the western part of the core zone. Densities were similar in burnt areas elsewhere in the park.

White-breasted wood swallow *(Artamus leucorhynchus)*
This species was encountered solely in fire-degraded areas. Single birds were regularly observed to fourage on insects or to rest in trees.

Besides the species mentioned above, that are clearly more common in fire-degraded areas, a number of species observed during this survey are mentioned by MacKinnon and Phillips (2001) to prefer degraded, shrubby or open areas. They are listed in table 5.6.

Table 5.6 Bird species observed, that are mentioned in literature to prefer degraded, shrubby or open areas.

Species	*Scientific name*	*Local name*
White-breasted waterhen	*Amaurornis phoenicurus*	*Kareo padi*
Spotted dove	*Streptopelia bitorquata*	*Dederuk jawa*
Buffy fish-owl	*Ketupa ketupu*	*Beluk ketupa*
Savanna nightjar	*Caprimulgus pulchellus*	*Cabak gunung*
Common goldenback	*Dinopium javanense*	*Pelatuk besi*
Sunda woodpecker	*Picoides moluccensis*	*Caladi tilik*
Striped tit-babbler	*Macronous flavicollis*	*Ciung-air Jawa*
Magpie robin	*Copsychus saularis*	*Kucica kampong*
Ashy tailorbird	*Orthotomus ruficeps*	*Cinenen kelabu*
Bar-winged prinia	*Prinia familiaris*	*Perenjak Jawa*
White-breasted wood swallow	*Artamus leucorhynchus*	*Kekep babi*

Mammals

Thirteen mammal species were recorded during the survey (see annex 14). Six of them were noted within burnt areas. This is a surprising number as the conditions in the burnt zones do not seem to be highly suitable for most mammals. Some species (e.g. Long tailed macaque and Silvered leaf monkey) have a strong preference for patches of surviving trees. The two monkey species observed clearly reached these patches by themselves after the 1997 fires and settled here probably because these sites are largely free from predators, contain sufficient food and have plenty of water (river) nearby. Other species are expected to occur in these surviving patches, because they simply have no choice. It is unlikely that the squirrels observed in a small patch of surviving forest in the centre of the core zone travelled for kilometres through *Stenochlaena palustris* vegetation to reach this site. Probably they survived the fires together with the surviving trees and remained there since, captured in a sea of ferns. Other species seem to be less dependent on clusters of surviving trees and wander through the burnt areas when searching for food. This is the case for the Malayan Sun bear (*Helarctos malayanus*) whose tracks were observed in a well developed *Macaranga* stand in the burnt core zone (site AHL K). This species has a broad choice of diet and regularly feeds on bees, ants and termites in secondary forest (Payne *et al.*, 1985). These insects (mainly termites in dead wood and ants associated with *Macaranga* and rattan) are abundant in fire-degraded areas and may attract the animals from far. The scratches caused by tree climbing were very fresh and during the visit a large animal that might have been a bear was heard between the dense vegetation. Other scratches were several weeks old indicating that the bears can stay for weeks in this habitat or at least visit it regularly. The same is true for the Wild boar (*Sus scrofa*), another omnivore, whose gamepaths were found at site SM B. These paths were clearly used over a long period of time and were situated in well-developed regenerating *Macaranga* forest, that provide a wide diversity of food. A well developed Malay Tapir (*Tapirus indicus*) trail was found far away from pristine forest in a poorly recovering site dominated by *Stenochlaena palustris* and *Melastoma malabathricum* (Site AHL M). In the dry season, this track is possibly used by animals that come from far to drink in the Air Hitam Laut River. Fresh droppings on the track however, indicate that the tapirs also used the track in the wet season and it is well possible that the species ventures into degraded areas to feed on young tees and herbs. This is in accordance with literature that states that tapirs often favour plants that are typical of regenerating forest (Medway, 1975). Interviews with local fishermen indicate that in the dry season many more mammals roam into burnt areas in the search for water. The fishermen told that they observed Sumatran tiger (*Panthera tigris sumatrae*), Mouse deer (*Tragulus sp.*), Sambar (*Cervus unicolor*) and Malay tapir (*Tapirus indicus*) over the years.

Reptiles and Amphibians

Ten out of 14 species of reptiles and amphibians were observed within fire-degraded areas (annex 15) and although it is difficult to draw conclusions on differences in species diversity between pristine forest and burnt areas, it was found that these animals are far more numerous in burnt locations. This is most probably caused by the abundance of insects that form a food source for amphibians and small reptiles, which are in turn consumed by larger reptiles (snakes). The wettest (*Hymenachne* and *Scleria* dominated) areas are inhabited by *Rana erythraea*. *Stenochlaena* dominated sites are commonly inhabited by *Mabuya fasciata*, a species that prefers sunny open patches in the vegetation. Snakes were observed almost daily both in the floodplains where they probably forage on frogs and toads and in dryer location where Skinks are a good source of food. During the trips on the Air Hitam Laut and the Simpang Melaka numerous crocodiles were encountered, mainly *Tomistoma schlegelii* but also *Crocodilus porosus*, a species that is mentioned by Silvus *et al.* (1984) to have become increasingly rare due to encroachment of coastal areas. These sightings combined with information derived from fishermen, indicate that Berbak is still a very important area for crocodile survival. Table 5.7 summarizes all sightings of crocodiles. Locals regularly encounter Gavials, mainly around sunset. At night crocodiles often damage fishermen's traps to obtain the fish inside, and occasionally small gavials are caught in these traps. Close to Simpang Raket, locals often observe a mysterious white Gavial, undoubtedly it concerns an albinistic or leucistic individual.

Table 5.7 Observations of Crocodilians in Berbak NP 2004.

Species	**Date**	**Remarks**
Tomistoma schlegelii	5-3	One large individual spotlighted in burnt core zone half way between Simpang Raket and Simpang-T.
„ „	15-3	Two animals submerging approximately 3 km downstream of Rumah biru rangerpost
„ „	21-3	One small individual basking on a fallen log on Simpang Melaka River close to the confluence with Air Hitam Laut.
„ „	21-3	One 50 cm long individual spotlighted 1km upstream of Rumah biru rangerpost
„ „	8-4	One individual submerging in pristine forest downstream of Kem Panjang (Air Hitam Laut)
Crocodillus porosus	2-4	Two large (3m) individuals basking on the riverbank downstream of Rumah biru rangerpost.
Tomistoma/Crocodilus	21-3	Two eyeshines upstream of Rumah biru rangerpost.

Invertebrates

Invertebrates were not studied in detail during the survey, but as they are thought to be an important food source for reptiles, amphibians and birds, the most important groups that occur in fire-degraded areas are noted below. Grasshoppers (*Acrididae*) were abundant in grass and fern dominated sites. Black-thighed falconets were often observed to hawk on them. They also preyed upon dragonflies (*Anisoptera*) that are numerous in a wide range of habitats. Ants (*Formicidae*) are very common (and hazardous) within fern-dominated vegetation and many species are associated with *Syzygium*, *Calamus* and *Macaranga.* Together with termites (*Isoptera*) that have colonized the numerous dead logs, they are a food source for woodpeckers and other insectivorous birds. True bugs (*Heteroptera*) are locally common in *Stenochlaena* dominated vegetation where they occur in close clumps hidden between the ferns. In other sites they were absent. Walking sticks (*Phasmidae*) and praying mantids (*Mantodea*) are largely restricted to well-developed *Macaranga* vegetation, although individuals were occasionally seen in more degraded sites.

6. Discussion and conclusion

6.1. Conclusions

Berbak NP

- Extreme human impacts strongly degraded the western part and the core zone of Berbak National Park. These are the direct cause of the 1997/1998 – fire outbreak. Radar images indicate that pre-fire disturbance in the east of the core zone was more intense than previously assumed. In addition, they indicate that areas degraded by logging activities and which burnt during the 1997/98 fire, face increasingly extreme flooding conditions from 1992 onwards. This possible change in hydrology is expected to have significantly increased fire susceptibility.

- Approximately 17,000 ha of forest in Berbak's central zone (about ten percent of the park) has been destroyed by the 1997/98 forest fires. 40-50 Percent of the fire-degraded areas faces repetitive burning. The western part of the core zone and surroundings of rivers are most sensitive to repetitive fires as deep peat deposits and extreme soil desiccation in the dry season increase fire susceptibility. The floodplains west of Simpang-T burn almost annually. Repetitively burnt sites at Air Hitam Laut's upper reaches turned into (temporal) lake ecosystems and consequently became less susceptible to fire.

- 107 **Bird species** were recorded in and around the park. The fires clearly have had a strong negative impact on bird diversity, but there are a number of species that benefit from fire degradation. The following species can be regarded as being more numerous in burnt areas: Oriental Darter (second breeding record for Sumatra, first of Berbak NP), Herons, Grey-headed fish eagle, Black-tighed Falconet, Long-tailed Parakeet, Blue-tailed Bee-eater and Dollarbird. In addation 11 species were observed that are known from literature (Mackinnon & Phillips, 2001) to prefer degraded, shrubby or open areas.
  13 **Mammals** were noted in and around Berbak. Seven species were recorded in fire-degraded areas. Squirrels and monkeys strongly favour clusters of surviving trees. Wild Boar (*Sus scrofa*), Tapirs (*Tapirus indicus*) and Sun Bears (*Helarctos malayanus*) roam into burnt areas and prefer well developed *Macaranga* stands that provide food and shelter.
  14 **Reptiles** were noted within the park. Densities are highest in burnt areas. The frog *Rana erythraea* is very common in *Hymenachne* dominated floodplains. Fern dominated habitats have been colonized by the skink *Mabuya multifasciata*. Both species form a food source for snakes, that are very common throughout burnt areas. Crocodiles still commonly occur in Berbak's rivers. *Tomistoma schlegelii* was most regularly seen, whereas *Crocodillus porosus* was observed twice.

- **Illegal logging** takes place all year round in all parts of the park, although accessibly is greatly reduced in the wet season. The park's west side still faces extensive commercial logging. Pt. PDIW's railway is extensively used for transport of poached timber out of the park. Logging activities in the north-western zone (along Air Hitam Dalam) seems to have strongly decreased since CIDA's investments in the parks facilities. The eastern side is strongly degraded by past logging activities. Almost all large *Shorea* trees have been logged. However at present, timber poaching seems to be not highly commercial here.
  Poaching of birds and reptiles is widespread and forms an extra source of income for many locals. Birds are sold locally as cage birds. White-rumped Shama *(Copsychus malabaricus)*, Oriental Magpie Robin *(Copsychus saularis)*, Blue-crowned Hanging Parrot *(Loriculus galgulus*) and Hill Myna (*Gracula religiosa*) are most commonly caught. Turtles (mainly *Orlitia borneensis*) are caught by fishermen for the Chinese market.

Fishing activities are widespread and although they are not seen as the park's primarily threat, they bring along a range of problems. Logging activities (for camp construction) and (small scale) poaching contribute to the general disturbance. In addition, fishermen cause a significant proportion of fire outbreaks in burnt areas, which leads to further degradation.

Peatswamp forest regeneration

- Six years after the devastating fires of 1997/98, large areas are prone to repetitive burning, leaving heavily degraded and flooded ecosystems behind, unable to regenerate naturally. On the other hand, vast areas of Berbak that are subject to single burning already are in an advanced stage of regeneration. Here *Macaranga* has proliferated very well, forming in a closed canopy of trees, exceeding ten metres. As many non-pioneer species are present in the subcanopy, a relatively diverse and valuable secondary forest could be formed in the future. In addition there are large areas that are mainly covered with ferns and their rate of regeneration depends on hydrological conditions.
- 117 Plant species have been identified in Berbak's fire-degraded areas during the 2004 survey. Extended with findings during a rapid survey executed in 2003 in Berbak and west of its borders (Giesen, 2004), this results in a joint list of 148 species. 46 of these species can be regarded as common: 20 Trees, eight climbers, seven ferns, five palms, two shrubs, two sedges one grass and one aquatic herb.
- The following species are associated with areas that burnt only once, with a shallow and short flooding: *Nephrolepis bisserata, Nephrolepis cordifolia, Macaranga pruinosa, Gleichenia linearis* and *Alstonia pneumatophora.*
- The following species are associated with multiple burnt areas with relatively deep and long flooding:*Scleria purpurascens, Hymenachne amplexicaulis, Barringtonia racemosa, Utricularia exolata, Pandanus helicopus* and *Blechnum indicum.*
- Single burnt sites, with shallow and short flooding, are best developed in terms of **species composition and diversity**. These areas contain an higher diversity in tree and palm species that are typical for a pristine peatswamp forest, than sites that face deep and prolonged flooding.
- Single burnt sites with shallow and short flooding have been developing best with regard to **forest structure** and contain the most and the highest trees. Those site have a considerable Basal area, which can be as high as 25 m^2/ha. This is in contrast with sites that are subjected to deep and prolonged flooding, which have a poor rate of structural development. These areas are virtually devoid of trees.
- The influence of peat depth on regeneration is complex. In single burnt areas, sites with a deep peat layer are better developed in terms of species composition, diversity and forest structure (although correlation is relatively weak), than sites with a shallow peat layer. In multiple burnt sites the effect of peat on regeneration is negative as remaining peat can increase fire susceptibility and the occurrence of repetitive fires and severe flooding.
- Basal area in areas that burnt only once is positively correlated with peat depth (R^2 =0,56) and negatively correlated with flooding duration (R^2 =0,417). There is a very weak correlation with maximum flooding depth (R^2=0,163).
- Exceptionally deep floods, occurring once every few years, negatively impact the regeneration process as they can kill or severely damage a number of species.
- Twenty-six species of palms, trees and climbers have been observed to survive fires, seven as resprouter, twelve as aboveground survivor and seven species were found to have both modes of survival. Viability among resprouters is generally high. Many individuals form flowers and fruits. The condition of survivors is variable. Some completely recovered from their damage, others will not survive in the long term. Eight out of 26 tree species have strong surviving capacities and may be of interest for restoration programmemes: *Licuala paludosa, Pholidocarpus sumatranus, Eleaocarpus littoralis, Mallotus muticus, Dialium maingayi, Barringtonia macrostachya, Barringtonia racemosa* and *Pternandra galeata.*
- Long term regeneration of fire-degraded peatswamp forest proceeds along a fixed range of succesional stages. The rate and direction of development is determined by flooding regime and

reoccurrence of fires. Depending on the intensity of burning, fires turn peatswamp forests into temporal lakes, sedge and grass dominated floodplains or fern dominated areas. **Seasonal lakes** cannot regenerate to forest on the short term and stay largely devoid of trees for a long time. **Sedge and grass dominated areas** will turn slowly into the **stage of fern dominance** as accumulation of dead organic material slightly decreases flooding depth and duration, and improves conditions for fern establishment. From the stage of fern dominance, regeneration gradually proceeds towards the **stage of *Alstonia* emergence** and the **stage of *Macaranga* emergence** and next the vegetation slowly develops into the **stage of *Macaranga* dominance** followed by the **stage of decreased *Macaranga* density** caused by intraspecific competition. The *Macaranga* trees strongly change the areas abiotic circumstances and the vegetation turns into the **stage of shade preferring tree establishment**. From this stage, in the very long term, a 'natural forest' will redevelop as more and more original species disperse into the area. Multiple fires reverse the regeneration process: subsequent fires will cause increased flooding in peaty areas. These sites turn eventually into seasonal lakes. In areas lacking peat deposits, repeated fires will be less influential on abiotic conditions; the starting condition of regeneration will the same equal and the process will develop into a 'sequence of succession'.

- An essential role in the transition between fern dominated plains and the emergence of *Macaranga* and *Alstonia* is the formation of 40-80 cm high packages of fern roots and leaves. This natural process significantly decreases flooding depth and duration in many burnt areas. Several species, that do not grow under extreme flooding conditions, are able to establish in this elevated growth medium. Consequently, excessive fern growth, although harmful on the short term, is beneficial on the long term.
- *Licuala paludosa* mitigates fire intensity and protects other species against burning. These fire-resistant palms are thought to inhibit the spreading of ground fire into the tree canopy and are expected to decrease fire susceptibility of vegetation and peat deposits.

Peatswamp forest rehabilitation

- Twenty tree species and two palms, commonly encountered in regenerating peatswamp forest, may be of interest for reforestation programmems. The following species have most potential*:* *Alstonia pneumatophora, Macaranga pruinosa, Barringtonia macrostachya, Barringtonia racemosa, Syzygium zipelliana, Pandanus helicopus* and *Licuala paludosa.*
- *Nephrolepis bisserata, Blechnum idicum, Hymenachne amplexicaulis, Pandanus helicopus, Thoracostachyum bancanum, Scleria purpurascens* and *Ficus sp*. are important key species for determination of an area's flooding regime and identification of vegetation types. They are suitable for assessment of an area's potential for reforestation.
- Based on floristic composition and forest structure, six vegetation types have been distinguished. Each representing a certain stage of development.

Type 1:	*Pandanus* and *Thoracostachyum* dominated lake-type
Type 2:	*Hymenachne* dominated seasonal lake-type
Type 3:	Sedge and Fern dominated early regeneration- type
Subtype 3a:	Sedge dominated early regeneration- type (flooded)
Subtype 3b:	Fern dominated early regeneration- type (less flooded)
Type 4:	*Nephrolepis* dominated tree establishment- type
Type 5:	*Macaranga* dominated early forest- type
Type 6:	*Macaranga* dominated well developed forest- type

- The numerous animal observations and the remarkable development of some fire-degraded forest areas indicate that burnt peatswamp forests should not automatically be considered as lost. Despite the enormous loss of biodiversity, these areas are still of considerable value to conservation. Even the strongly degraded lake areas and floodplains that are unlikely to regenerate to forest on the short term, have conservation value. They do not harbour the original peatswamp forest values, but a new value determined by many lake associated species that settle into these systems and these area add to overall diversity of habitats.

6.2. Discussion

Many ecological aspects of peatswamp forest regeneration were highlighted during this survey and the information acquired can be directly used as a base line for rehabilitation programmes. Information on species occurrence and abundance, regeneration processes, influence of abiotic factors, vegetation types and indicator species can all be implemented during replanting trials that should further increase insight in and success of peatswamp forest rehabilitation. However it is of importance to realize that the information presented in this report should be finetuned with additional information and still a lot of gaps in knowledge need to be filled. Especially knowledge regarding the exact link between abiotic factors and species composition and forest structure needs to be refined. The links revealed in this paper are based on six weeks of fieldwork and they will certainly be further clarified if additional data are collected. Assessment of indicator species and common companions, based on a larger data set would also result in a more extensive description of vegetation types and recognition of additional (sub) types.

On several occasions extreme circumstances in the field forced the research methodology to be slightly changed and this has had a negative influence on the survey's final result. The most influential change that had to be made, was the choice of a fixed relevé size of 100 x 10 metre. In some well-developed sites the minimal area was larger and it would have been better if data were collected along a larger relevé (e.g. 200 x 10 metre). As this would have certainly resulted in a more comprehensive description of vegetation types and increased insight in the exact links between abiotic factors and floral composition. This however proved to be too time consuming and not realistic within the time available. Despite this, the variance in species composition and structure among sites are relatively large, the choice of a fixed transect length still enables statistical analyses. Inaccessibility of burnt areas forced selection of research locations closer to rivers than initially planned. As a result, it was impossible to check the conditions (and search for additional vegetation types) throughout all regions of burnt areas. More research time and manpower could have easily tackled these problems.

Patterns of regeneration are dependant on a large number of abiotic variables and it should be noted that there are many more factors that influence the process of regeneration than those highlighted in the present survey. This should be taken into account during implementing replanting trials. Fire intensity may be very important. This factor proved to be very difficult to measure in the field although flooding depth and duration give to some extent an indication of fire intensity. Pre-fire logging disturbance may be an other factor that influences the regeneration. During the site selection procedure, sites were selected in the centre of the park and not along the western border, where extreme disturbance occurs. However, the Satellite and Radar images indicate that logging in the centre of the core zone was widespread as well. Therefore it is inevitable that sites that were selected, faced a certain extend of disturbance before the 1997 fire outbreak. One site (AHL M) was later found to be situated in an area that was severely degraded before 1997 through clear-felling. This site has been ecluded from the statistical analysis. Other abiotic factors that might impact regeneration are acidity, nutrient availability, soil structure, but also seed dispersal and inter- and intraspecific competition.

As was already stated before, there are still some gaps in knowledge. Future research should therefore aim particularly at:

1. An inventory of the stage of regeneration (identification of vegetation types) in all burnt areas of Berbak NP. This would provide information on the conditions of burnt areas as a whole and a large scale mapping of the distribution of each vegetation type or succesional stage will clarify which areas are most suitable for rehabilitation. At the same time an overview will be created of the extent of rehabilitation needed and the funds that have to be allocated. These large-scale inventories can be made during field trips, but given the difficult accessibility an airplane equipped with a radar or an aerial photographic device would be a better option.
2. Large-scale inventory of trees that occur as survivors in fire-degraded areas and assessment of the exact role they play in the regeneration process.

3. Identification of additional species that can colonize fern packages.
4. Identification of additional vegetation types and further description of vegetation types determined during the present survey.
5. Acquisition of additional information on the exact relationship between flooding depth, flooding duration, peat depth, fire history and composition and structure of vegetation.
6. The link with peat depth, as there seems to be a complex relationship between peat depth and the re-occurrence of fires and regeneration.
7. Assessment of the influence of other abiotic factors on species composition and vegetation structure.
8. Assessment of the link between colour patterns in radar images and the extent of regeneration as has been observed in the field.

In addition it is recommended that the survey described in this report will be repeated within five to ten years (between 2009 and 2014). This will further clarify long-term patterns of regeneration and in addition descriptions of the regeneration process presented in this paper, can then be further tested and extended with new information. Such a survey will provide an opportunity to assess the general conditions of the burnt areas (further degradation, recovery, improved abiotic conditions). This information can be used as a basis for the park's management. It is recommended that the methodology of such a future survey adhere as much as possible to the one applied in this research and surveys should be made in exactly the same location. This will enable comparison of survey results. Ideally four people should be involved as collection and processing of data is very time consuming.

7. Implementation of results and recommendations

7.1. Implementation of results in reforestation schemes

The results presented in the previous chapters could form the basis for future rehabilitation trials in Berbak NP. Their implementation is described in this chapter and is summarized in the Decision Support System in annex 16, that provides a schematized step–by–step approach for decision making. Information on the links between abiotic factors and the rate of vegetation development and general observations on long term regeneration, fern package formation and inhibitors and promoters of regeneration, is largely transferable to other peatswamp forests in Southeast Asia. Information on species that are expected to be suitable candidates for rehabilitation trials in Berbak cannot automatically be applied to other areas, as species composition depends on a lot of other factors and differs strongly among geographical regions.

7.1.1. Site selection

One of the major steps in rehabilitation programmes is selection of appropriate sites, as the success of replanting trials is largely dependant on abiotic conditions that differ among areas. In addition, limited availability of funds requires a careful selection of sites that have most potential for recovery. Until now, lack of understanding of the influence of an area's site characteristics on success of replanting caused the failure of many reforestation schemes. Replanting trials in Berbak largely failed because they were situated in sites with extreme flooding conditions, that killed nearly all the seedlings that were planted.

The identification of a vegetation type proved to be the most suitable way to determine an area's suitability for rehabilitation. The species composition and the vegetational structure indicate for each type to what extend natural regeneration has proceeded. This information can be applied to assess the potential success of replanting activities, that is the **suitability** of a location. Sites that completely lack newly established trees can be regarded as not highly suitable for reforestation. Areas with a strong rate of development are expected to be easily replanted and sites with a rate in between these extremes could in some occasions be considered as suitable for replanting, depending on the exact circumstances and the possibilities for improvement of conditions for tree establishment (e.g. mound construction). In addition, for each vegetation type a **priority** ranking can be made, based on other constraints. Some sites with very beneficial circumstances for reforestation have such a strong rate of natural development that planting of additional tree species does not have a high priority. On the other hand, sites that have very poor conditions for reforestation might have a high conservation value and therefore still have a high priority for reforestation. The suitability rating combined with a priority rating should lead the decision making process.This is the most crucial step during a replanting trial, as the final success of the trials is largely dependant on a sound selection of replanting sites. This will result in an advice on replanting efforts that are thought to have the highest yields.

The quality of each vegetation type for rehabilitation is summarized below. This listing should act as a guideline and can be extended with specific additional priorities as identified by the rehabilitation specialist.

Type 1: *Pandanus* and *Thoracostachyum* dominated lake-type
This type does not naturally regenerate on the short term and should not be the target for replanting programmes as excessive flooding conditions negatively influence the performance of most terrestrial plant species.

Type 2: *Hymenachne* dominated seasonal lake-type
This type does not naturally regenerate on the short term and should not be the target for replanting programmes as excessive flooding conditions and repetitive fires negatively influence the performance of most plant species. Most replanting trials in Berbak NP have been undertaken in this type because of easy access in the dry season. They largely failed, despite mound construction.

Subtype 3a: Sedge dominated early regeneration- type (flooded)
This type does not naturally regenerate on the short term and should not be the primary target for replanting programmes as establishment of seedlings is dissicult and fire risk remains high. However, reforestation of these areas seems to be not impossible as mound construction can solve part of the problems.

Subtype 3b: Fern dominated early regeneration- type (less flooded)
This type shows early signs of regeneration and tree establishment and it is recommended that this process is assisted by means of rehabilitation programmes.

Type 4: *Nephrolepis* dominated tree establishment- type
This type shows clear signs of regeneration and it is recommended that this process is assisted by means of rehabilitation programmes.

Type 5: *Macaranga* dominated early forest- type
This type shows strong signs of natural regeneration and therefore these sites do not have the highest priority for rehabilitation programmes. However, enrichment planting might significantly improve diversity, increase regeneration speed and improve quality of the secondary forest. Efforts are expected to be very successful and the construction of mounds seems to be unnecessary.

Type 6: *Macaranga* dominated well developed forest- type
This type shows very strong signs of natural regeneration and therefore these sites do not have the highest priority for rehabilitation programmes. However, enrichment planting might significantly improve diversity, increase regeneration speed and improves quality of the secondary forest. Efforts are expected to be very successful and the construction of mounds seems to be unnecessary.

In addition to the physical constraints there may be several other constraints that influence decision making. For a detailed description of possible constraints see also Giesen (2004).

Available funds
The availability of funds is very important during site selection. In case of limited funds it is important to adhere strongly to the guidelines mentioned above, as these provide the highest chances of success. In case of sufficient resources it may be worthwhile to invest in small-scale replanting trials in areas with advanced regeneration (to increase the forest's diversity) or areas with extreme conditions (to increase experience with rehabilitation in a wide range of habitats).

Logistical aspects
Transport of human resources and materials towards the replanting sites may be complex, time consuming and expensive. Accessibility of the replanting sites is an important factor as well. This should be taken into account during site selection.

Legal aspects
As Berbak is a National Park, there are numerous regulations that prohibit human activities, including reforestation, particularly in the center of the park. Therefore possible legislational aspects should be taken into account, before the actual replanting activities.

Social aspects
Success of replanting trials will be dependant on the enthusiasm and willingness of local communities to participate.

Identification of the different vegetation types is simple. An identification key based on a small number of easily recognizable indicator species is provided in the DSS (annex 16). The complete descriptions of the different vegetation types can be used to verify the identification that resulted from the identification key. Vegetation type identification can also take place based solely on the vegetation type description, provided that some knowledge on Berbak's vegetation is available. The CD-rom accompanying this report can assist with both species identification and the verifying of vegetation types. It contains images of a large number of species observed as well as images of research locations representing the vegetation types. It should be noted, however, that vegetation types can occur close together in some areas. For example sometimes closed *Macaranga* stands and open fern vegetation can form mosaics on a relatively small scale.

The species that enable the identification of vegetation type into a number of consecutive steps are regarded as key species. Sometimes they are differentiating species, in other cases they are identified as common companions as they subdivide at a higher level. The key species have been selected based on the TWINSPAN Two-way table and dendrogram as presented in figure 5.9 and 5.8 as well as the PCA ordination, described in paragraph 5.4.

The key species have the following characteristics:

Nephrolepis bisserata and ***Blechnum indicum***. Both ferns are very clear indicators of flooding conditions and can be used for identification of vegetation types and the assessment of a site's potential for rehabilitation. *Blechnum* grows under wet conditions and can endure relatively deep (> 100 cm in the wet season) and prolonged flooding. The species is abruptly replaced by *Nephrolepis* if the maximum flooding depth drops with a few centimetres and flooding duration decreases. The species do not grow together in the same place. In general, it was found that areas covered with *Nephrolepis* are easily colonized by seedlings. Sites that contain this species are therefore of great interest to rehabilitation programmes. In *Blechnum*-dominated sites this is not automatically true and additional information should be obtained to assess suitability for regeneration programmes. Because of these characteristics both ferns are important key species for rehabilitation specialists. However, identification can be difficult. The appearance is relatively similar although the lobes of *Blechnum*-leaves are finer, and strongly pointed in an upward direction. Positioning of the spores is the best characteristic; In *Blechnum* the spores are situated in a band along the main central nerve. In contrast, the spores in *Nephrolepis* are situated in numerous dots that are positioned in two rows at the fringes of the leaf (figure 7.1 and 7.2).

Hymenachne amplexicaulis is a typical species of temporal floodplains that face very deep flooding in the wet season (>150 cm). As long as flooding duration is not too long, the species can survive. It is absent from dry locations, probably because it cannot compete with ferns. Sites characterised by *Hymenachne* are not suitable for rehabilitation.

Pandanus helicopus only occurs where flooding is deep and almost year round. These areas turn into lakes and do not regenerate naturally in the short term. As a consequence areas containing *Pandanus* are unsuitable for replanting. *Thoracostachyum bancanum* has the same characteristics and was occasionally encountered in areas with a shorter flooding duration.

Figure 7.1 Positioning of spores on Blechnum indicum.

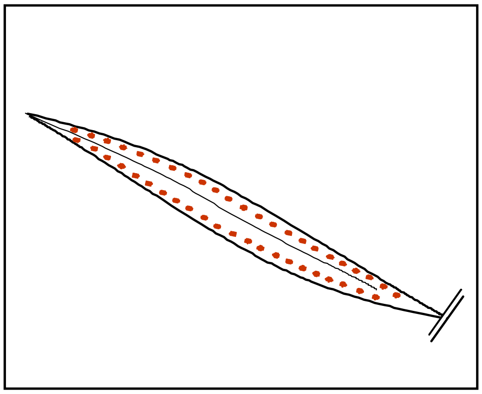

Figure 7.2 Positioning of spores on Nephrolepis bisserata.

7.1.2. Selection of species

After selection of a suitable site for rehabilitation based on physical, social, legal, logistical and financial constraints, a set of plant species suitable for rehabilitation should be composed. The 20 tree species and 2 palms that were commonly encountered in burnt area's of Berbak NP are all candidates. Many of them only grow under specific environmental conditions and consequently a species' natural distribution should be taken into account when selecting appropriate species. Table 5.2 indicates under which circumstances a species naturally grows. This table can be used for the selection of species, extended with the rehabilitation specialist's insights with regard to applicability of additional species in fire-degraded areas. Several species are of interest to replanting in particular. As they occur in a wide range of circumstances, have a high growth rate and strong tolerance to harsh conditions and are strongly fire resistant:

Alstonia pneumatophora is a species that occurs in a wide range of habitats. It can grow in dry places, but also easily colonizes fern packages in wetter areas and even occurs on floating beds of *Hanguana malayana*. The species grows fast and is able to compete with other pioneers. Ferns may temporarily inhibit growth but as soon as the tree escapes from the ferns its growth rate is boosted. ***Macaranga pruinosa*** has similar characteristics, although the species seems to be less tolerant to flooding. It has the highest growth rate of all trees observed. Although *Macaranga* trees have a short life span and are not highly attractive to animals, they perform an essential task in peatswamp forest regeneration. So far *Macaranga* is the only species found in Berbak that is able to form a closed canopy within several years after burning. The shade caused by the crowns decreases density of ferns and this is necessary for establishment of long living trees that cannot compete with dense ferns and have in their young stages a preference for shade. These species will later outcompete the *Macaranga* trees and form the future canopy. This step of fern decrease and shade forming is regarded as one of the most important events in the regenerating process of peatswamp forests and consequently *Macaranga* can be seen as one of the most promising species for rehabilitation of the drier sites. This replanting of *Macaranga* will not only sort effect on the short term (formation of a closed canopy) but will also be effective on the long term (strongly improved natural regeneration).
Pternandra galeata is a promising candidate for areas with medium deep and medium long flooding conditions, as the species was observed to be fire resistant and commonly flowering. ***Barringtonia macrostachya*** is commonly encountered at relatively dry locations. The species' natural abundance combined with it's competitive capacities makes it suitable for restoration. The species mentioned above are absent from locations with deep and long flooding. Here ***Mallotus muticus, Barringtonia racemosa*** and ***Syzygium zipelliana*** are the best candidates for restoration. *Syzygium* occurs in a wide range of habitats. *Barringtonia* and *Mallotus are* strongly restricted to clayey soils close to the river. The species should only be replanted at places were they are known to occur naturally. Despite their

restricted range, *Barringtonia* and *Mallotus* are expected to be valuable species for rehabilitation in areas with harsh conditions, as they can survive deep flooding and are strongly fire resistant. Areas that have turned into lakes are virtually impossible to rehabilitate. The only species that might be suitable for replanting is ***Pandanus helicopus***, provided that the area involved experiences year round flooding. *Pandanus* is known to be an important species for long-term regeneration, as it can form thick root packages that can ultimately be colonized by trees (personal comm. Giesen 2004). Two fire resistant palm species, ***Pholidocarpus sumatranus*** and ***Licuala paludosa*** are of interest to reforestation programmes. Especially *Licuala* seems to be suitable as the species is expected to protect other species against fire degradation. However the palms have a rather restricted natural distribution and should only be planted at locations where they occur naturally.

The Decision Support System summarizes this information and indicates which species are most promising for rehabilitation of areas that are characterized by a specific vegetation type. Although not all types should be a primary target of replanting programmes, the DSS mentions specific species for each type.

The major goal in rehabilitation should be to speed up the natural regeneration process and to assist the natural system in doing so. It is recommended that the species that naturally occur in fire-degraded areas are considered as target species for reforestation, as many of them strongly promote the long-term natural regeneration process. In areas that are not extremely flooded, *Alstonia pneumatophora* and *Macaranga pruinosa* are without doubt the most promising species. Especially *Macaranga* is of high importance for natural re-establishment of trees as the species forms a closed canopy and has a short life span and thus enables naturally invading species to establish. The enormous importance of stimulation of the natural regeneration process, has been underestimated in many replanting trials. In these trials tree species that occur in well developed forest and do not naturally recolonize fire-degraded areas, have often been targeted. Many of these trials failed, as the species that were selected proved unable to survive the harsh circumstances, but also when the trials are successful the recreated forest is expected to remain species-poor as new establishment of naturally invading plant species is largely hampered by the long living species that have been replanted. However, these species can be replanted in low densities in addition to the target species, provided that they occur in the direct surroundings of the burnt areas and have characteristics that make them suitable for survival in fire-degraded areas. Such a combination of a large number of naturally occurring pioneers with some additional species is expected to sort optimal effect, both on the long term (natural re-establishment of species) and on the short term (diversity of species that do not naturally settle). It is not recommended to select species that do not occur in Berbak NP or to obtain different races from elsewhere, as they might not be optimally adapted to the extreme abiotic circumstances. The disappearance of the upper peat layer in many fire-degraded areas seems to be not very influential on establishment of species and does not justify a choice of species from elsewhere that naturally occur on clayey soils as most species occurring in Berbak's fire-degraded areas have a good performance on both peat and clayey soils.

This survey identifies the optimal conditions for rehabilitation and species that can be applied. Measures that optimize survival of replanted seedlings should, however, be identified during future replanting trials.

7.2. Recommendations for rehabilitation programmes

- Replanting sites should be situated at least 200-300 metre from the river. There are very few fire-degraded areas that are situated closer than 200 metre to the river and have abiotic conditions that are suitable for rehabilitation.

- Replanting sites should be situated at least 200 metre from fishermen's camps. Many small-scale fires originate from these camps and they destroy the direct surroundings.

- The occurrence of exceptional floods (once every few years) should be taken into account during rehabilitation (e.g. by adjustment of mound height). These floods can kill a large number of recently planted seedlings.

- Before site selection, an assessment of future fire risk should be made, based on the most actual information. The map provided in figure 5.5 can be used as a starting point. The larger part of the western side of the core zone (west of Air Hitam Laut) faces a high fire risk (and extreme flooding conditions) and is not regarded as suitable for rehabilitation trials.

- If funds are limited, reforestation should be performed in separate interspaced clusters. The clusters may promote regeneration of surrounding areas through seed dispersal and act as stepping stones for animal species that venture through burnt areas. These separate clusters also help to spread the risk of fire destruction.

- Remaining dead standing trees should not be removed from the replanting area. They are of considerable value for birds that feed on them and use them for nesting.

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9. Annexes

Annex 1	*HotSpots that occurred in 2001, 2002 and 2003 in and near Berbak NP*
Annex 2	*Itinerary of the fieldwork period 30 January –29 April 2004*
Annex 3	*Relevé data sheet (example)*
Annex 4	*Herbarium note book (example)*
Annex 5	*Site descriptions (16 sites)*
Annex 6	*Species list Burnt peatswamp forest, Berbak NP (117 species)*
Annex 7	*Complete species list Burnt peatswamp forest, Berbak NP (148 species)*
Annex 8	*Common species of Burnt peatswamp forest, Berbak NP(46 species)*
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Annex 16	*Decision Support System for restoration of burnt peatswamp forest*
Annex 17	*Cd-rom: photographic overview*