FIRE AND PEAT FORESTS, WHAT ARE THE SOLUTIONS?

Herbert Diemont[1)], Paul Hillegers[1)], Hans Joosten[2)], Koen Kramer[1)], Henk Ritzema [1)], Jack Rieley [3)] & Henk Wösten [1)]
[1)]Alterra, Wageningen University & Research Centre,
[2)]Greifswald University,
[3)]Nottingham University

Summary

In this paper of fire and forest ecosystems are discussed in general. Special reference is given to peat forest bogs in SE Asia and the impact of drought and climate change. The conclusion is that fire in SE Asia forests has been always a factor to be reckoned with, including peat forests. But due to El Nino the extent of forest fires has intensified causing even lower water tables in peat forests and consequently an increased risk of fire in which always a human factor is involved. There is no technical possibility to raise water tables during a drought in non drained peat forest bogs so under these natural drought conditions exaggerated by El Nino there is only a possibility to diminish outbreak of fires through co-operation with local people and law enforcement by the government. Local actions including awareness actions, poverty reduction and water management to avoid unnecessary drainage are the ingredients for a strategy which could minimise the actual rate of fire outbreaks. These efforts protecting the carbon stored in the peat to emit to the atmosphere, could make simultaneously a significant and cheap contribution to prevent global climate change.

1. Introduction

Fire is incorporated in the long-term dynamics of many ecosystems. It releases the nutrients that are captured in the vegetation and litter and makes space, thus light, available for regeneration at the forest floor. Furthermore, it is well-known that for fire-adapted plant species, fire is required for the germination of seeds. Fire is thus essential for the sustainable maintenance of diversity of these ecosystems. However, frequency and spatial extent of fires are crucial factors in determining if fire contributes to long-term stability, or induces a shift to a degraded but stable grassland system or even to a peatland as under temperate conditions is possible.

The forest peat bogs in SE Asia mostly did not originate from a degraded forest as some of there European counterparts. Tropical domed bogs mostly succeed from tidal mangrove forests partly these peatlands are deposited on flat tertiary sediments inland.

Whatever there origin, all peatlands have in common that lowering the water table causes the fire risk. In Europe drainage was the main cause, whereas in the forest bogs of SE Asia the cause of the fire comes natural with climatic drought, which is exaggerated by EL Nino. In both cases man is involved as the direct agent setting fire to the system.

After a fire or repeated fire rehabilitation of these forests on peatland in terms of carbon sequestration and in species seems difficult to achieve. Moreover, the carbon lost from the peat by fire ads substantially to global warming by emitting substantial amounts of carbon dioxide to the atmosphere. For the human population in the areas with peat forests these cascading effects result in health problems and impose substantial economic losses to the economies in the region.

The paper will highlight actions taken at international level and actions that can be taken at the local level. At the international level awareness raising and funding is important, whereas on the local level co-operation with local people and government, law enforcement and poverty reduction go hand in hand.

An example of a concerted action on the local level towards rehabilitation and conservation of the peatlands of Central Kalimantan is briefly addressed. An international effort coupled to local ownership is urgently needed both for development and to minimise fire risks.

2. Peatlands and forest bogs

Peat swamps in the world as indicated by the presence of swampy land characteristic for histosols and gleysols on the FAO global soil map indicate that 900 Mha , i.e. 6 % of the global land surface may be fit to accumulate peat (Diemont et al 1997). Following the generally accepted definitions, surfaces by peat are estimated to cover 315 Mha, of which nearly 80% (248 Mha) is in the higher latitudes in West Siberia, Alaska and Canada. Most of the peat is in a pristine state. Peat in Europe comprises 19 million ha of which area 50 percent is converted. In some countries such as the Netherlands even all peatland was converted. In particularly in the wet tropics peat area comprises 47 Mha, mostly in Asia where peatland covers 36Mha; about 27 Mha is located in Indonesia (Succow & Joosten, 2001)

Two major types of peatland i.e. fen peats and bogs can be distinguished. Fen peats evolve anywhere in shallow open water, whereas rain water fed bogs evolve in climates with an excess of rainwater even direct on dry ground. Bogs in SE Asia are dome shaped (Figure 1 & 2).

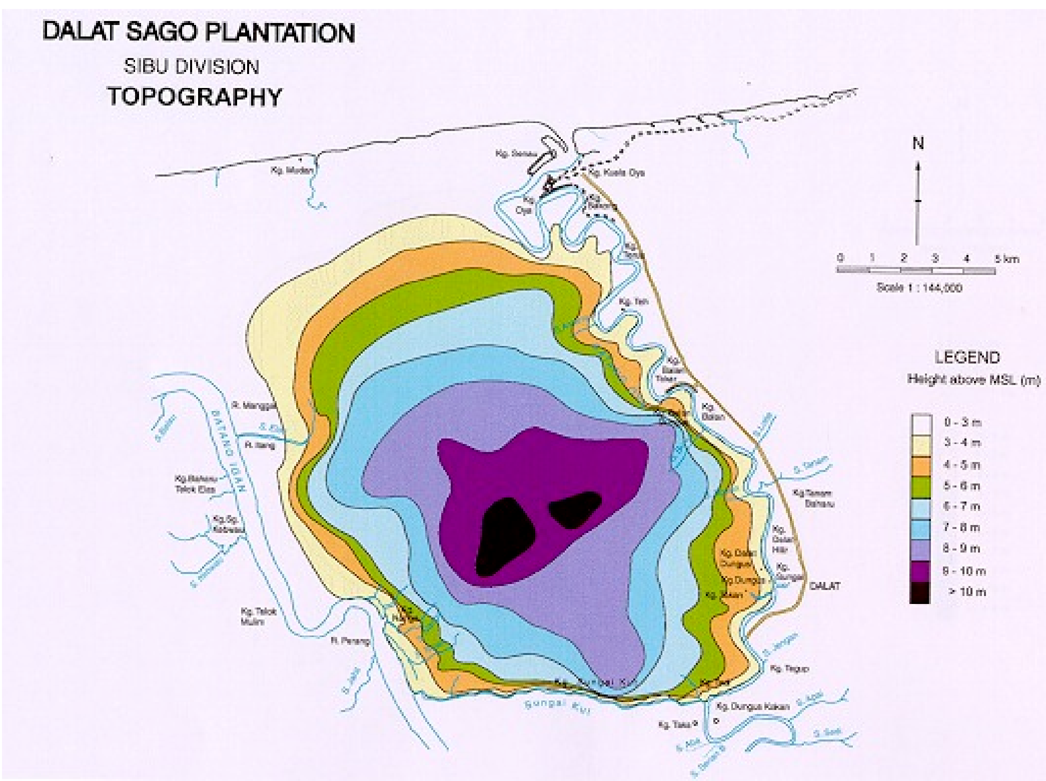


Figure 1 Topography of a domed bog (Melling 2000).

The youngest peat swamps are found close to the coast. The ground surface of the young swamps rises gently from the edges to form a convex shape (dome) with slopes of 1–2 m/km.

The highest point may be only 3–4 m above mean sea level. In the older, more developed swamps, the convexity at the edges is more pronounced. A rise of 6 m over the first 250 m has been recorded. The central bog planes are almost flat, with a rise of less than 0.5 m/km (Tie, 1991).

The basal mineral substrata of the peat swamps consist of sand or clay, in coastal areas mostly developed on former mangrove forests or tertiary deposits. The actual transition of a mangrove forest into a bog can be observed in the Matang mangrove area in Perak, Peninsular Malaysia. The topography of the subsoil usually drops gently from the riverbanks or the coast to the centre of the swamps. This is what gives the peat deposits their characteristic lens-shaped cross-section. Where old riverbeds or levees are buried under the peat, there are small rises and drops in the mineral substrata. Levelling of transects across various peat domes has shown that the mineral substrata usually lie within 1–2 m above or below mean sea level (Figure 2).

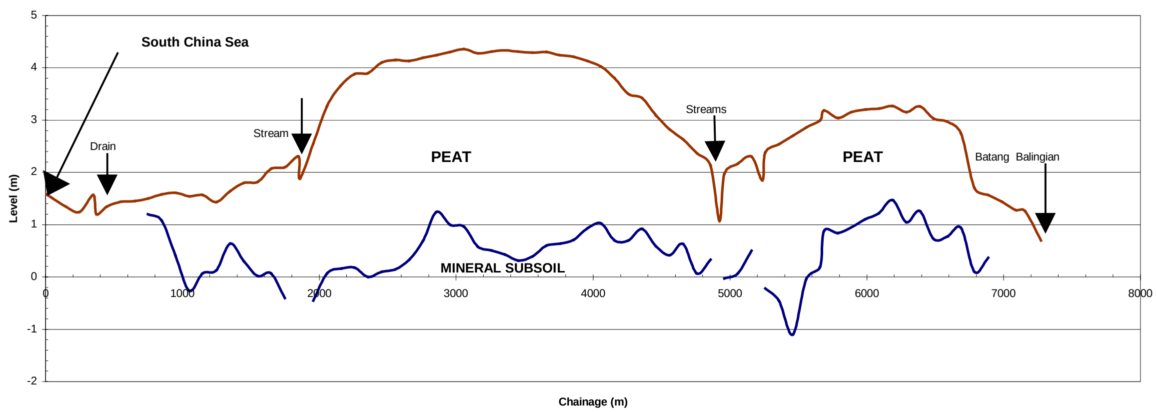


Figure 2 Cross-section through a peat dome (PS Konsultant 1998).

3. Fire and stability of ecosytems

Fire is not a problem but an essential factor for the stability of grasslands and shrub vegetation around the world controlling among others species regeneration, nutrient cycling, and in most cases an improvement of the palatability of the sward for grazing animals.

These grasslands and shrub lands (mostly derived from forests) comprise a wide variation of ecosystems including: alang–alang grasslands in SE Asia, savannahs in Africa, prairies in North America and the pusta in Central Europe, the maquis in the Mediterranean and heathlands in Atlantic parts of Europe, Australia and S. Africa .

Fire has changed the original forest systems to reach a new equilibrium in the absence of tree seeds and as a result of a shift in the carbon dynamics of the original forest system towards grassy and shrub systems. An example of a shift in terms of stability from forest to (in this case) a grassy heathland can be well demonstrated by using process based models. Figure 3 demonstrates that these grasslands become a complete new system (see the two discrete clouds in C) which implies that the system is not easy to reverse (Kramer et al. in press). These finding suggest that rehabilitation of the system is not easy to achieve, although in case of grazing animals (D) there is somewhat more chance.

It is not only carbon dynamics of a system, but also the hydrology which may shift to another stable situation after fire. In this case the forest does not shift to a grassland, but to a peatland. In Europe after deforestation paludification became a widespread phenomenon and these areas such as blanket bogs in Scotland and peat accumulating heathlands in Norway became peatland (Behre, 1988).

Figure 3. Effect of fire on carbon dynamics changing a forest into grassland (Kramer et al. in press).

Peat bogs in Europe are mainly formed by mosses (Sphagnum species), whereas the tropical bogs in SE Asia are forested bogs. Both systems may sequestrate carbon as high as 500 kg C/ha/year (Diemont et al., 1987). Sequestration near the edges of tropical may be very which is probably due to lower water tables near the fringes of the bog (Diemont et al., 1997). Although the carbon and peat sequestration in forest bogs in SE Asia are high , carbon sequestration is low in the climatic drier regions in East Europe, where Spaghnum bogs are invaded by trees. Although normally forest peats are only very slow carbon and peat accumulating systems (in Europe) there is an interesting exception. Alnus swamp forests in Europe do perform peat accumulating rates 3 to 5 times higher than those of slightly humified Sphagnum peats. This is probably due to high primary production and a high proportion of decomposition resistant lignin (Barthelmues 2000); lignin is also the main constituent of tropical peat deposits.

Where the forest is able to resist fire, the forest may adapts to natural fire or even human induced fires. For instance most of the Pinus and Oak species in temperate forest ecosystems reflect a fire-history and these species depend even on fire for regeneration (Komare, 1983). In the tropical rain forest Macaranga is a pioneer also after fire and results from East Kalimantan (Slik et al., 2002) suggest that the forest tree species recover within a period of 15 years. In teak forests fire is essential to keep this valuable species dominant.

Exclusion of fire may enhance the flammability over years of forests and therefore exclusion of fire should not be recommended without having addressed the fire history of a forest as fire is in most forests part of the system and a prerequisite for its stability. Natural fires in wetlands and peatlands have been reported world wide (Brown 1990, Kangas 1990, Paijmans 1990, Kuhry 1994, Frost 1995, Zoltai et al. 1998). Fires affect wetlands in several ways, depending on their frequency and severity, the amount of organic matter and peat, and the soil moisture conditions. Fires may change the rate of litter mineralisation and actually add structural diversity and biodiversity (Brown, 1990), e.g. when lakes and pools originate from burned out holes in the peat. Some wetland species are adapted and even dependent on regular fires, such as the North American black spruce (Picea mariana) and pond pine (Pinus serotina), whose serotinal cones release their seeds after fire (Kangas, 1990). In peat forest in SE Asia Melaleuca trees replace the original peat forest, whereas in fen peat forest in a basin position or on floating mats a grassy (padang) vegetation replaces the forest (Endert 1927, Diemont & Pons, 1991). in the case of fire there is no longer peat/carbon accumulation possible and fire should be avoided.

4. Examples of peat fires

Peat fires in the wet tropics are a threat to health of millions of people and through the emission of carbon to the atmosphere a significant contribution to the greenhouse effect (Siegert et al. 2001, Rieley et al. Subm.). The impact of peat fires through a haze over thousands of kilometres is not a new phenomenon. An early record is from the UK in the seventeenth century (Law against moor-burning from King Jacob enacted in 1610 (Evelyn, 1661).

Anno vii. Jacobi Regis. An Act against burning of Ling, and Heath, and other Moor-burning in the Counties of Yorke, Durham, Northumberland, Cumberland, Westmerland, Lancaster, Darbie, Nottingham & Leicester, at unseasonable times of the year.

Whereas, many Inconveniencies are observed to happen in divers Counties of this Realm, by Moore-burnings, and by raising of fires in Moorish grounds and Mountaneous Countries, for burning of Ling, Heath, Hather, Furres, Gorsse, Turffe, Fearn, Whinnes, Broom, and the like, in the Spring time and Summer-Times: for as much as thereby happeneth yearly a great destruction of the Brood of Wild-fowle, and Moor-game, and by the multitude of grosse vapours, and Clouds arising from those great fires, the Aer is so distemper'd, and such unseasonable and unnatural storms are ingendred, as that the Corn, and the Fruites of the Earth are thereby in divers places blasted, and greatly hindered in their due course of ripening and reaping. As also, for that sometimes it hath happened, that by the violence of those fires driven with the Wind, great fields of Corn growing, have been consumed, and Meadows spoyl'd, to the great hurt and dammage of His Majesties Subjects: which Moor-burnings, neverthelesse, may be used, and practised at some other convenient times, without such eminent danger or prejudice.

Be it therefore Enacted by our Soveraign Lord the Kings most excellent Majesty, with the assent of the Lords Spiritual and Temporal, and of the Commons in this Parliament assembled, and by the Authority of the same: That from, and after the last day of July next ensuing the end of this present Session of Parliament, it shall not be lawful for any Person or Persons whatsoever in the Months of April, May, June, July, August, and September, nor in any of them, to raise, kindle, or begin; or to cause or practise to be raised, kindled, or begun any fires or Moor- burnings in the said Counties of York, Durham, Northumberland, Cumberland, Westmorland, Lancaster, Darby, Nottingham, and Leicester, or in any of them, for burning of Ling, Heath, Hather, Furs, Gorsse, Turffes, Fearne, Whinnes, Broome or the like; neither to assist, further, nourish or continue the same; And that all and every Person and Persons, which from and after the said last day of July, shall offend contrary to the true intent, and meaning of this Statute, the same offence being proved by confession of the Party, or by the Testimonies of two sufficient Witnesses upon Oath, before one or more Justices of the Peace of the same County, City, or Town Corporate, where the offence shall be committed; or the Person or Persons offending, apprehended, shall be by the said Justice, or Justices of the peace, for every such offence, committed to the Common Goale of the County, City or Town Corporate, where the Offence shall be committed, or the person or persons apprended, there to remain for the space of one Month without Bail or Main-prise.

And further, be it Enacted, by the Authority aforesaid, that all, and every person and persons, which shall be so convicted and imprisoned as aforesaid, shall not be enlarged from their said Imprisonment; but shall there remain after the said Month is expired, without Bail or Main- prise, until such time as every such Offender respectively shall pay, or cause to be paid to the Church-Wardens, or unto the Overseers of the poor of the Parish, or place, where the same Offence shall be committed, or the Offender or Offenders apprehended, or unto some of them, to the use of the poor of the said parish or place, where the same Offence shall be committed, to the Summe of Twenty Shillings, for every such Offence committed or done, contrary to this Act. This Act to continue until the end of the first Session of the next Parliament.

The problem of haze became widespread in the nineteenth century in Europe (see Map). The technique of buckwheat fire cultivation was brought from the Netherlands to North-western Germany around 1700. The culture expanded rapidly in Germany during the 18th and 19th century as large expanses of mires, considered ”idle areas”, were available. Numerous people, mostly without any means of subsistence, were settled as colonists in the wild mires. Buckwheat fire cultivation was the only means of exploiting the extensive uninhabited peat lands without transport ways, fertiliser, and financial resources.

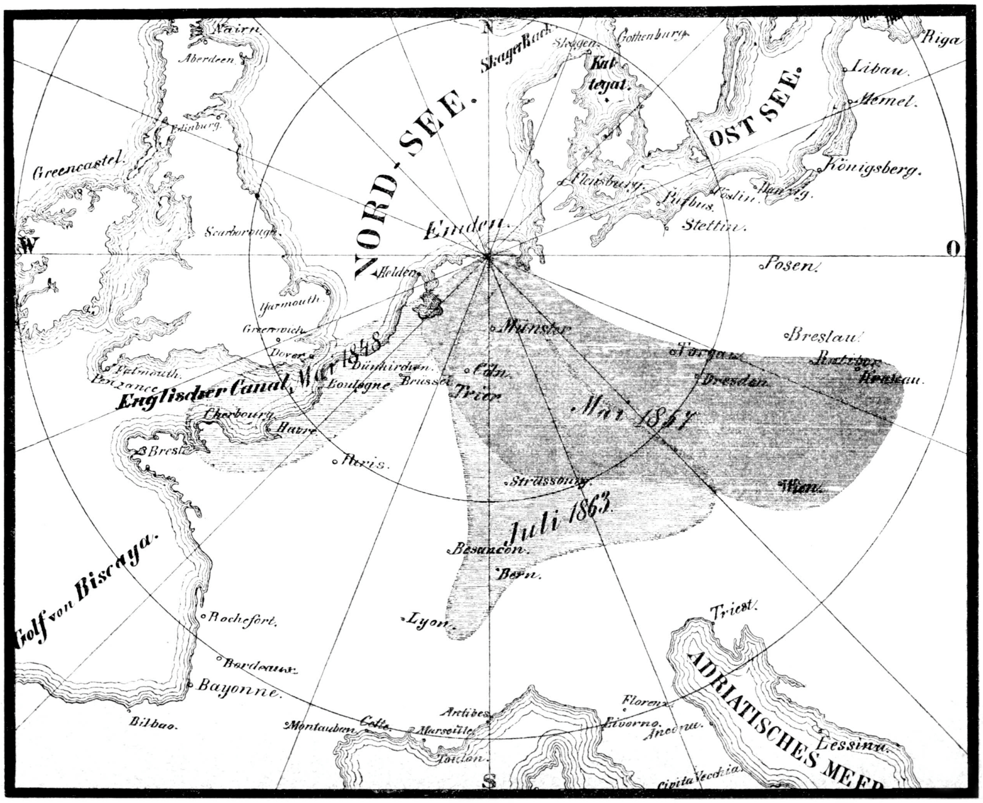
Map of the distribution of moor haze stemming from buckwheat fire cultivation in North-western Germany in the years 1848, 1857 and 1863 (after Prestel, 1903).

KARTE

darstellend die

Verbreitung des Moorrauches 1848, 1857, 1863.

Von Dr. M. A. F. Prestel.



Beilage der „Oesterr. Moorzeitschrift", III. Jahrg., 12. Heft.

Around 1870, buckwheat fire cultivation may have covered an area in North-western Germany and the adjoining Netherlands of around 100.000 ha annually .The crop was initially received with enthusiasm. But it was also a "lottery crop". The harvest was lost every third year because of the frequent night frosts in the peat lands in summer or because of too much rain. Other disadvantages gradually became clear. The drainage ditches had to be deepened continuously because of vanishing peat layers. Deep fires could "burn the peat land to death": the surface changed in a dusty, pulverised mass, that could not be wetted anymore and that was easily captured by the wind. The extensive drainage of the raised bogs caused inundation in the surrounding areas on mineral soil. Many negative environmental effects were observed. An annually burned area of 50,000 acres caused atmospheric emissions. The haze spread over large areas and even reached Hungary and the South of France (see Map).

Drought and fire have always been a part of the natural environment in Borneo in the last several thousand years (Wirawan 1993, Brookfield et al. 1995, Goldammer 1997). Von Gaffron, exploring the Kotawaringan district in Central Kalimantan for coal and gold, described almost 600,000 ha of swamp forest burning for months during the drought of 1846 (Pijnappel, 1860).

Braak (1915) mentions extensive haze in 1902 and fires during the drought of 1914. Accounts on fire in East Kalimantan is given by Endert(1927). An account of the present damage which is unprecedented is well documented for instance by Siegert et al. (2001).

5. Water and Fire

The fire risk in European peatlands was induced by drainage of the peat. In European bogs the water table is normally in a range of 10 cm above and below the water table, but the fluctuation in water table under natural conditions is higher as in temperate Sphagnum bogs. The fluctuation of the water level in a peat swamp depends mainly on rainfall because evaporation and (groundwater) outflow are fairly constant. During the wet season, the rainfall always exceeds the combination of evaporation and groundwater run-off. Thus, in this period, the water level is always above the soil's surface (Figure 4).

These wet conditions are favourable for peat accumulation. During the drier months of the year, when dry spells can last for weeks, the water level in the swamp can drop below the soil surface. Observations in different swamps have shown that the drop of the water table is not the same throughout the whole swamp. Between the dry and wet seasons, the water table in a peat swamp can fluctuate up to 0.58 m near the edge of a peat dome (Tie, 1991). In the centre, the seasonal fluctuation is slightly smaller (0.45 m). The relatively steep periphery has a deeper water table than the flat centre. On hot and non-rainy days, the daily drop can reach 10–15 mm/d (Ong and Yogeswaran, 1991).

Under natural, non drained conditions, there are three types of outflow from the peat body of a swamp: surface run-off or depression flow; sub-surface flow or interflow; deep groundwater flow. Because of the predominantly high water levels in a peat swamp, surface flow will account for about 66% of the natural outflow, interflow for about 22% and groundwater flow for the remaining 11% (SWRS 1990).

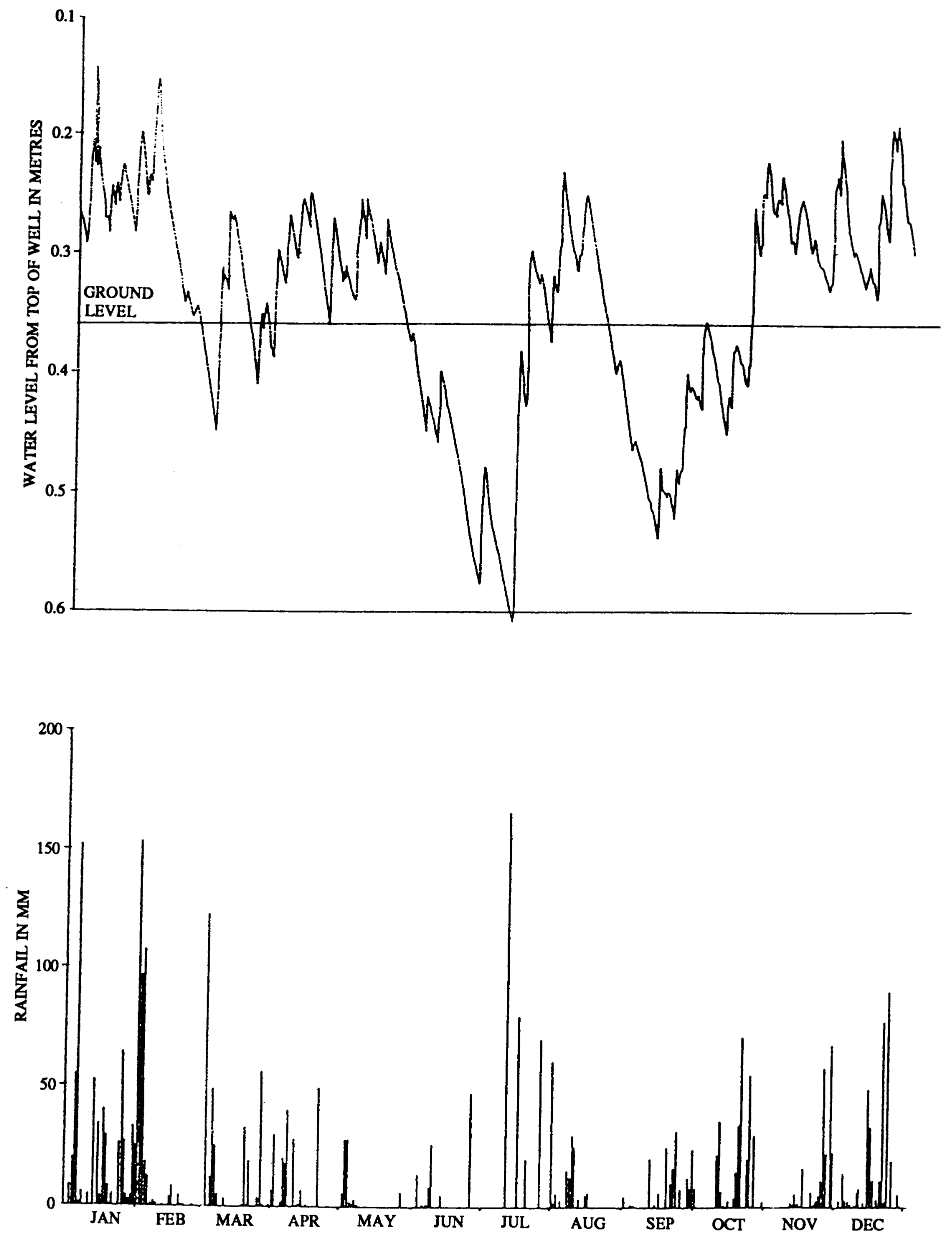
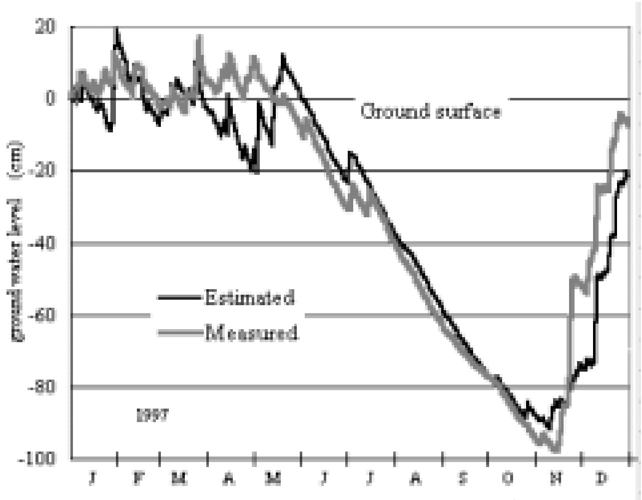


Figure 4 Water level and rainfall for Penibong in 1991 (Ong and Yogeswaran, 1991).



Measured water table levels in Central Kalimantan (Takahashi 2002; see opposite Figure 5) follow the estimated evapotranspiration rates in the dry season. The lowest level was below 80 cm, reflecting the most serious drought of the 20 century. It should also be noted that the capillary rise of soil water in a tropical peat is minimal due to its very course pores (Wösten & Ritzema, 2002). As a result peat surfaces can become very dry in the dry season. The conclusion is that under natural conditions (without drainage) the risk of a fire is higher in tropical bogs as compared with undrained Sphagnum bogs in temperate areas. The claim that logging in itself increases the risk of a fire in a peatswamp (Siegert et al 2002) may be right for reason that fires are not spontaneous, but water tables can be low enough to become a risk.

A low water table also affects the carbon sequestration capacity of a peat. Although it is not known what is the critical water table in a peat forest for peat accumulation to take place there is information from drained peatland. Figure 6 indicates that especially in the tropics (high temperature) there is still a considerable rate of oxidation of peat with a mean water table of 20 cm (Wösten & Ritzema, 2001). Extrapolation of this figure would suggest that even at a level minus 20 cm no peat accumulation will occur. It could be indeed possible that peat accumulation comes mostly from the roots and trees fallen down. There is a need for more information on both ground water levels in pristine peat forests and on peat sequestration.

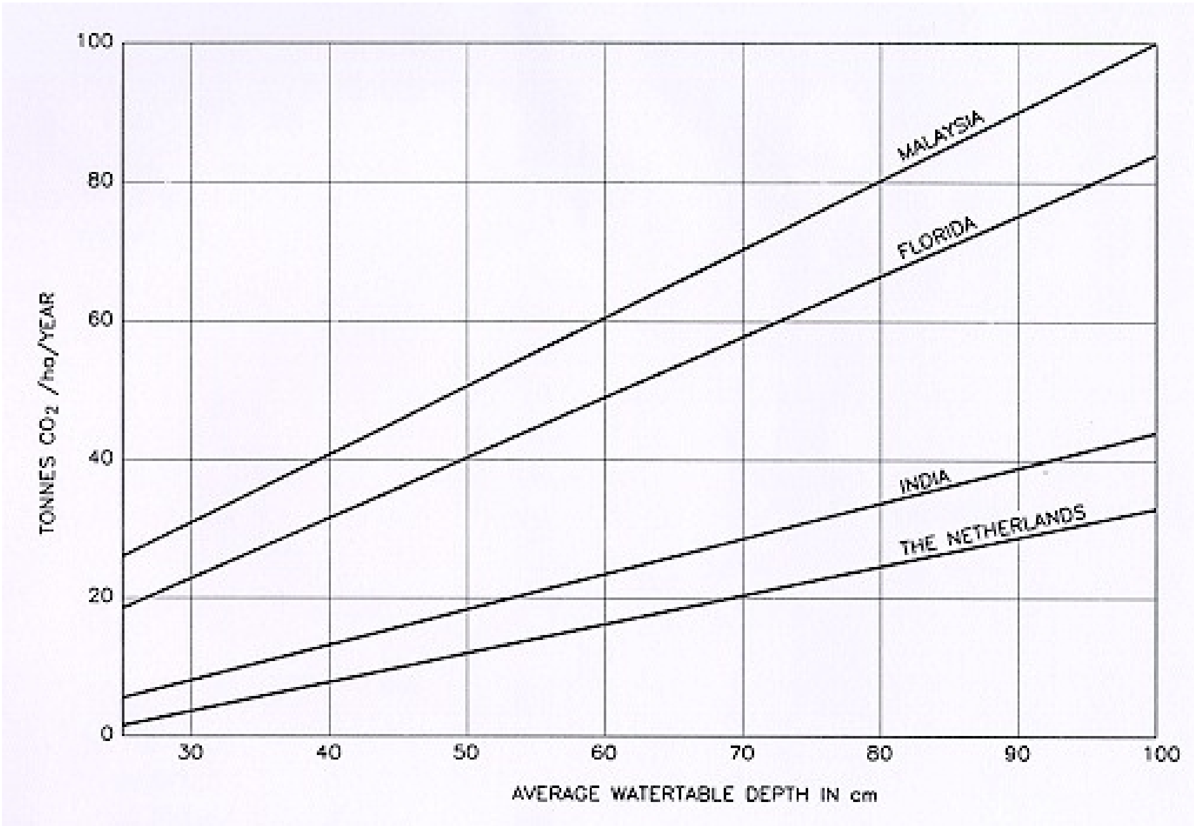


Figure 6. CO_2 emission rates as a function of water table depths in peat soils for different areas

If peat domes are used for agriculture controlled burning is often used deliberately e.g. in oil palm plantations. Under these conditions, controlled drainage is a prerequisite and carbon sequestration if any) is reversed to carbon oxidation. During periods with rainfall excess maximum drainage capacity is needed to avoid waterlogged conditions. During prolonged dry spells, when evapotranspiration exceeds rainfall, drainage has to be restricted to avoid an excessive drop of the water level. Controlled drainage can be achieved by using a network of shallow drains in combination with fixed or adjustable weirs (Ritzema et al., 2001).

6. How to avoid peat fires?

From the foregoing it can be concluded that there is no easy way out if it comes to fires in non drained peat forests, as it cannot be prevented that water tables lower during dry periods causing a high fire risk if people are around. If drought periods increase in future the question is not how to solve but how to minimise forest fire risks in SE Asia.

International actions

As stipulated in the fore going paragraphs forest and other vegetation fires have always existed. These fires attracted almost never more than national - in a very few cases regional - concern until recently. The first internationally recognised global forest fire disaster was in 1982-1983. In

Indonesia forest fires burned down millions of ha of natural forest, secondary forest and other vegetation types and had serious impacts on human health and on the economies of Indonesia and other countries in the region. More great forest fires followed in 1987, in 1991 and in 1994, with shorter periods in between. Environment and people suffered in the archipelago and on the neighbouring Asian mainland. Disastrous fires in other parts of the world took place and received more and more international attention. Closely related with the outbreaks of the fires is the climate phenomenon of El Niño, the process of heating up of the surface water in the Pacific Ocean in the southern hemisphere which has its influence on the climate all over the world. It changes normal dry wet seasons into dry weather periods around and south of the equator and brings more rains than normal in northern regions of the world. This El Niño phenomenon was particular strong in the fall of 1997 and in the beginning of 1998. Most frightening is that the El Niño Southern Oscillation (ENSO) is becoming shorter and shorter, increasing the frequency of large scale wildfire disasters. Disastrous very large scale fires blazed throughout the world during the second half of 1997 and the first months in 1998, in particular in Indonesia, Brazil, Canada and Eastern Russia. But also in numerous other countries in South and Central America and in Europe, fires caused more than in other years environmental degradation and human suffer. The Indonesian fires reached their highest violence in March and April of 1998. On the islands of Sumatra and Borneo millions ha of grasslands, degraded and logged-over forests and to lesser extend primary forest burned, including large areas of peat swamp forests.

Fire disaster response

Especially because of the haze caused by the fires and its effects on human health and on the regional and national economies the forest fires became a hot item on the international, regional and national agendas. National and international intergovernmental organisations, as well as NGO's, are very concerned and have launched many activities to mitigate the impacts of the fire. UN organisations are responding according to their mandates. For the United Nations the Office of the Co-ordination of Humanitarian Affairs (OCHA) and the United Nations Environment Programme (UNEP) are responsible for the disaster response. Their task is to monitor closely fire disaster situations and stay in close contact with the national authorities through the Joint UNEP/OCHA Environment Unit (Joint Unit). In 1997 and 1998 they have sent disaster assessment and co-ordination missions to Indonesia and Brazil. The Executive Director of UNEP was requested by the UN Secretary General to co-ordinate the UN system's response to the forest fires. FAO, WHO, WMO, UNESCO, UNDP, ICRAF and CIFOR mobilised their own capabilities. The haze pollution problems caused by the fires in Indonesia became major issue on the agenda of frequent meetings of the ASEAN ministers of environment. Many governments contributed money or made in kind donations. Unilateral organisations, international NGO's, bilateral assistance agencies and National Governments launched a variety of aid and support programmes. A strategic plan for immediate, mid-term and long term actions was developed after the 1997/98 fires. The plan concentrates primarily on Indonesia and South East Asia, while offering opportunities for expansion at the global level. It consists of a series of activities addressing the need for immediate response to fire emergencies, an early warning system, and public awareness.

I. FIRE STRATEGY FOR SOUTH EAST ASIA

A. Immediate response to the fire emergency in South East Asia

1. Expert meeting to develop a short-term action plan to combat fires in Indonesia
2. Implementation of a short-term action plan to combat fires in Indonesia

B. Early Warning System for South East Asia

1. Workshop on the design of an early warning system for South East Asia
2. Establishment of an early warning system for South East Asia

II. GLOBAL FIRE STRATEGY FOR THE 21ST CENTURY

A. Global action plan to address fire emergencies

1. International Conference on fire fighting and conservation
2. Implementation of a global action plan to address fire emergencies

B. Global Fire Watch

1. Expert workshop to design a Global Fire Watch
2. Establishment and maintenance of the Global Fire Watch

C. Public Awareness

1. Expert meeting on raising public awareness on fire risks
2. Implementation of the medium term action plan

Major problems

Experiences of earlier emergency responses and the great variety of current actions taken by the numerous organisations involved, show that there are some problems to be resolved with regard to medium- and long-term strategies and action plans for fire prevention, preparedness and restoration of damage and losses, linked to short-term emergency response. Major problems to work on are:

- Early warning system. Development of an efficient early warning system based on a strong information, monitoring and assessment capability.
- Co-ordination of UN organisations with regard to medium- and long-term activities. Given the multiple actions by concerned UN organisations, it is essential that a co-ordinated, comprehensive approach is taken. Responsibilities should be clearly delineated, roles of organisations defined, and overlaps identified and allowed for.

Partnership. Creating and strengthening global, regional, national, provincial and local alliances to prevent and combat environmental disasters arising from land, brush and forest fires. This calls for a closer co-operation between government organisations, NGO’s and the private sector.

Local actions

The most important action to be taken on the grass root level is in particular in poor areas is to get a local commitment, which must be balanced by international funding in order to replace income of people from peat forest, people who are trapped in a “system of impoverishment“ and get part if not all of their income from forest resources which should be protected from fire, for biodiversity reasons and to avoid carbon emission. In peatland set aside for agriculture, water management should be in place in order to minimise carbon emission and decrease fire risks.

At present the EU project “STRAPEAT” and teams from WWF, CIDA, CARE are present in Central Kalimantan present in one of the most extensive peatland areas the province of Central Kalimantan with 4 to 4 million ha of peatland including the former Mega Rice Project area and the Sebangau watershed with a large population of Orangutan. The commitment of the local people to conserve the forest and to rehabilitate the peatland in the former Mega Rice project as well as the role of the international community towards sustainable use of peatlands in Central Kalimantan will be briefly discussed during the presentation.

References

Barthelmes, A. 2000. Paläoökologische Untersuchungen zur Entstehung von bruchwaldtorfen. Diplomarbeit Greifswald University, Germany.

Behre, K.E. 1988. The role of man in European vegetation history. In: Huntley, B. & Webb,T. (eds) Vegetation history. Kluwer Academic Press 803 pp.

Braak, C. (1915) De sterke nevel in de oostmoesson van 1914. *Natuurkundig Tijdschrift voor Nederlandsch Indie* 74: 131 - 140.

Brookfield, H., Potter, L. & Byron, Y. 1995. In Place of the Forest. Environmental and Socio-economic Transformation in Borneo and the Eastern Malay Peninsula. United Nations University Press, Tokyo - New York – Paris.

Brown, S. 1990. Structure and dynamics of basin forested wetlands in North America. In Forested wetlands (eds A.E. Lugo, M. Brinson & S. Brown). Ecosystems of the World 15, pp. 171 - 199, Elsevier, Amsterdam.

Diemont W.H. & Pons, L.J. 1992. A preliminary note on peat formation and gleying in the Mahakam inland floodplain, East Kalimantan, Indonesia. In B.Y. Aminuddin & S.L. Tan (eds). Tropical Peat: Proceedings of the International Symposium on Tropical Peatlands 6-10 May 1991, Kuching, Sarawak, Malaysia.

Diemont, W.H., G.J. Nabuurs, J.O Rieley & H.D. Rijksen. 1997. Climate change and management of tropical peatlands as a carbon reservoir. In : tropical peatlands. J.O. Rieley & S.E. Page (eds): 363-368. Samara Publ. Lim. Cardigan.

Driessen, P.M. 1978. Peat soils. Soils and Rice, pp. 763-779. IRRI, Los Banos Philippines.

Endert, F.H. 1927. Floristisch verslag van de Midden Oost Borneo expeditie 1925. Indisch Comite voor Wetenschappelijke Onderzoekingen: pp.200-312.

Evelyn, J. 1661. Fumifugium or The Inconveniencie of the Aer and Smoak of London dissipated. Together With some Remedies humbly Proposed By J.E.Esq; To His Sacred Majestie, And To the PARLIAMENT now Assembled. W. Godbid, London. www.geocities.com/Paris/LeftBank/1914/fumifug.html

Frost, C.C. 1995. Pre-settlement fire regimes in south eastern marshes, peatlands and swamps. In Fire in wetlands: a management perspective (eds. S.I. Cerulean & R.T. Engstrom), pp. 39 – 60, Tall Timbers Research Station, Tallahassee.

Goldammer, J.G. 1997. The Role of Fire on Greenhouse Gas and Aerosol Emissions and Land Use and Cover Change in Southeast Asia: Ecological Background and Research Needs. International Conference on Science and Technology for the Assessment of Global Environmental Change and its Impacts on the Indonesian Maritime Continent, Jakarta, Indonesia, 10-12 November 1997.

Kangas, P.C. 1990. Long-term development of forested wetlands. In Forested wetlands (eds. A.E. Lugo, M. Brinson & S. Brown), pp. 25 - 51, Ecosystems of the World 15, Elsevier, Amsterdam.

Komarek, E.V. 1983. Fire as an anthropogenic factor in vegetation ecology. In W. Holzner, M.J.A. Werger & I. Ikusima (eds.) Man's impact on vegetation. dr. W. Junk Publishers 370pp.

Kramer, K., I.T.M. Jorritsma & T.A. Groen. Effects of the interactions between ungulates on forest dynamics at different spatial scales using the model FORSPACE. Submitted

Kuhry, P. 1994. The role of fire in the development of Sphagnum-dominated peatlands in western boreal Canada. Journal of Ecology 82: 899 - 910.
.
Melling, L. 2000. Dalat and Mukah sago plantation peat soil study. Final Report. Soil Branch, Department of Agriculture Sarawak.

Ong, B.Y. and Yogeswaran, M. 1991. Peatland as a resource for water supply in Sarawak. Proceedings of the International Symposium on Tropical Peatland. Kuching, Sarawak.

Paijmans, K. 1990. Wooded swamps in New Guinea. In Forested wetlands (eds A.E. Lugo, M. Brinson & S. Brown), pp. 335 - 355, Ecosystems of the World 15, Elsevier, Amsterdam.

Pijnappel, J. 1860. Beschrijving van het Westelijke Gedeelte van de Zuider-en Oosterafdeeling van Borneo (De Afdeeling Sampit en de Zuidkust). Bijdragen tot de Taal-, Land- en Volkenkunde 3: 243-346.

PS Konsultant 1998. Detailed Design and Construction Supervision of Flood Protection and Drainage Facilities for Balingian RGC Agricultural Development Project, Sibu Division, Sarawak (Inception Report), Department of Irrigation and Drainage, Kuching. pp. 24.

Ritzema, H.P., Tom K.F. Chong and Tie Yiu Liong. 2001. Water Management Guidelines for Agricultural Development in Peatland. Proceedings Workshop on Water Management for sustainable Agricultural Development of Peatland, 28-29 March 2001, Kuching, Sarawak, Malaysia.

Sarawak Water Resources Council,1997. Sarawak Water Resources Study Projects - Final Report submitted by PS Konsultant, Montgomery Watson, Australia, The Centre for Water Research (CWR).

Siegert, F., G. Ruecker, A. Hinrichs & A.A. Hoffmann. 2001. Increased damage from fires in logged forests during droughts caused by El Nino. Nature vol 414: 437-440.

Slik, J.W. ,F.R.W. Verburg & P.J.A. Kessler. 2002. Effects of fire and selective logging on the tree species composition of lowland diterocarp forest in East Kalimantan, Indonesia. Biodiversity and Conservation: 85-98.

Succow, M. & H. Joosten. 2001. Landschaftökolgische Moorkunde. E. Schweizerbert'sche Verlagsbuchhandlung, Stuttgart. 662 pp.

Takahashi, H., S. Shimada, B.F. Ibie, Usup, A , Yudha & S.H. Limin. 2002. Annual changes of water balance and a drought index in a tropical peat swamp forest of Central Kalimantan, Indonesia. International Peat Journal. In press.

Tie, Y.L. and Esterle, J.S. 1991. Formation of lowland peat domes in Sarawak, Malaysia. Proceedings of the International Symposium on Tropical Peatland. Kuching, Sarawak.

Wirawan, N. 1993. The hazard of fire. In: South-East Asia's environmental future - the search for sustainability (ed. H. Brookfield & Y. Byron). United Nations University Press, Tokyo – New York – Paris.

Wösten, J.H.M. & H.P. Ritzema. 2002. Land and water management options for peatland development in Sarawak. International Peatland Journal. In press.

Zoltai, S.C., Morrissey, L.A., Livingston, G.P. & De Groot, W.J. 1998. Effects of fires on carbon cycling in North American boreal peatlands. Environmental Reviews 6: 13 - 24.