# Towards climate-responsible peatlands management

9

MITIGATION OF CLIMATE CHANGE IN AGRICULTURE SERIES

Food and Agriculture Organization of the United Nations

MITIGATION OF CLIMATE CHANGE IN AGRICULTURE SERIES 9

# Towards climate-responsible peatlands management

**Riccardo Biancalani and Armine Avagyan (Editors)**

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Cover photo: Peatland restoration
by application of *Sphagnum capitula*
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|---|---|
| **AFOLU** | Agriculture, Forestry and Other Land Use |
| **BUR** | Biennial Update Report |
| **$CO_2$-eq** | $CO_2$ equivalent |
| **DOC** | Dissolved organic carbon |
| **DOM** | Dissolved organic matter |
| **ESDB** | European Soil Database |
| **FAO** | Food and Agriculture Organization of the UN |
| **FPIC** | Free, prior and informed consent |
| **FTU** | Formazin Turbidity Unit |
| **GHG** | Greenhouse gas |
| **GWP** | Global Warming Potential |
| **IMCG** | International Mire Conservation Group |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IUSS** | International Union of Soil Sciences |
| **m a.s.l.** | metres above sea level |
| **MICCA** | Mitigation of Climate Change in Agriculture Programme |
| **MRV** | Monitoring, Reporting and Verification |
| **NAMA** | Nationally appropriate mitigation action |
| **NPP** | Net primary production |
| **PNTD** | Participatory negotiated territorial development |
| **POC** | Particulate organic carbon |
| **RSPO** | Round Table for Sustainable Palm Oil |
| **WRB** | World Reference Base for Soil Resources |

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# Executive summary

Peatlands are lands with a naturally accumulated peat layer at their surface. They are found all over the world and come in many forms, display many different characteristics and are used in many different ways. Even though peatlands extend over a relatively small portion of the earth's land surface, they hold a large pool of carbon. There is no universal definition of peatlands. For the purpose of assessing emissions, Intergovernmental Panel of Climate Change (IPCC) guidelines included the concept of peatland in the 'land with organic soil' category and identify organic soils as histosols. The IPCC guidelines also present emission factors for peatlands under different land uses.

In their natural state, peatlands support a large range of habitats and provide a home for unique biodiversity. Along with storing large quantities of carbon, peatlands also play an important role in the retention, purification and release of water and in the mitigation of droughts and floods. They provide a source for fish, non-timber forest products and other goods and services. Their special characteristics also make peatlands unique space for culture, leisure and education activities. Peat has also been extracted to generate energy and supply growing media to the horticulture industry. Many natural peatlands have been converted and drained to allow for conventional agriculture and forestry.

When drained, peatlands become net sources of greenhouse gas (GHG) emissions. Because of drainage, organic soils are currently the third-largest emitter of GHGs in the Agriculture, Forestry and Land Use (AFOLU) sector; they emit almost one gigatonne of $CO_2$ equivalent ($CO_2$-eq), which represents 10 percent of the total AFOLU emissions. High GHG emissions are particularly evident when oil palm and pulp wood production are carried out under deep drainage and high temperature on tropical peatlands.

Peatlands mapping is needed to estimate GHG emissions. However, mapping peatlands is not easy, as there is no generally accepted operational definition for peatlands and the use of remote sensing technologies is made difficult by the fragmented distribution pattern of peatlands and their differentiated land use. The challenge of mapping peatlands is heightened by the inherent environmental problems of conducting ground observations in many peatland areas. A global information system would be required to provide reliable data on peatlands and their management, and to support the identification of appropriate practices for the more responsible use of peatland resources.

Along with increasing GHG emissions, peatland drainage also leads to the lowering the height of the land surface, a process known as land subsidence. Peatland drainage also increases the discharge of carbon as dissolved organic carbon (DOC) and particulate organic carbon (POC) downstream, which reduces water quality in aquatic ecosystems. Over time, peatland drainage causes the vegetation cover to change and biodiversity to be lost. Fires become more frequent. There can be increases in salt water intrusion, droughts and soil erosion, all of which eventually reduce agricultural productivity. Many peatlands that have been drained for agriculture have been abandoned due to a combination of progressive soil degradation, decreasing productivity and increasing costs of drainage. As long as drainage continues, abandoned peatlands will continue to emit GHGs and the land will continue to subside.

To cope with the negative consequences of peatlands unsustainable management, the following steps are recommended:

- Conserve intact peatlands;
- Rewet drained peatlands;
- Apply climate-responsible peatlands management; and
- Implement adaptive management where rewetting is not possible.

The priority is to safeguard and preserve natural peatlands from degradation. Rewetting of already drained peatlands conserves biodiversity, regenerates vegetation, replenishes freshwater resources and reduces GHG emissions. During rewetting, the stabilisation of high water levels can be achieved through hydrological practices that include, enlarging water storage in the peatlands, decreasing water losses and increasing water supply.

Paludiculture (biomass cultivation in wet conditions) can be considered a responsible management option for peatland management. Paludiculture produces biomass from wet and rewetted peatlands under conditions that maintain the peat body, sustain ecosystem services and may facilitate carbon accumulation. Besides producing traditional agricultural commodities such as food, feed, fibre and fuel, paludiculture can also generate other raw materials for a variety of purposes, including industrial biochemistry.

Responsible management practices are also needed where peatlands are used as pastures. Raising the water table, regulating the number of grazing livestock, fencing pastures for rotational grazing and replanting or reseeding of forage species, all help to control soil erosion and reduce off-site water pollution.

In cases when rewetting of drained peatlands is not possible, adaptive management practices that reduce GHG emissions should be adopted. Adaptive management avoids over-drainage, soil tillage and the use of fertilizers. In forestry, a shift towards continuous forest cover and the avoidance of clear-cuts are also recommended. On croplands, permanent crops are the preferred agricultural option.

Cultivating fish in the rewetted peatlands to support local economies is a strategy that can potentially preserve existing carbon stores. However, further studies are required to evaluate the impact of aquaculture on the GHG balance and the livelihoods of local communities.

When considering peatland management, it is also essential to address social issues, such as local communities' access to and use of natural resources. The Participatory Negotiated Territorial Development approach offers a field-tested methodology that focuses on creating an environment of open dialogue, fair negotiation and social legitimacy from the local to the national level to introduce and implement climate-responsible strategies.

To access financing for responsible peatlands management practices and policies, international programmes and mechanisms such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) and Nationally Appropriate Mitigation Actions (NAMAs) can be considered.

# Definitions

**BOG:** a peatland that receives water and nutrients exclusively from atmospheric deposition and is isolated from laterally moving, more mineral-rich soil water.

**DISSOLVED ORGANIC CARBON (DOC):** the total carbon content of the dissolved organic matter (DOM) fraction.

**DISSOLVED ORGANIC MATTER (DOM):** an organic matter that passes through filter with a nominal pore-size cut-off of 0.22, 0.45 or 0.7 micrometre.

**FEN:** A minerotrophic peatland that receives water and nutrients both from the atmosphere and from the groundwater.

**GLOBAL WARMING POTENTIAL (GWP):** An index, based on radiative properties of GHGs, measuring the radiative forcing following a pulse emission of a unit mass of a given greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in causing radiative forcing. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame.

**GREENHOUSE GASES (GHG):** greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Greenhouse gases discussed in this guidebook are carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$).

**MINEROTROPHIC PEATLAND:** a peatland that is nourished both from the atmosphere (e.g. rainwater, snow, airborne dust) and groundwater inputs.

**MIRE:** a peatland in a state of active peat formation and accumulation.

**OMBROTROPHIC PEATLAND:** a peatland that is nourished exclusively from atmospheric deposition (e.g. rainwater, snow, airborne dust) and is isolated from laterally moving, mineral-rich soil water.

**PALUDICULTURE PRACTICE:** biomass cultivation in wet conditions.

**PEAT:** a soil material that contains at least 30 percent (by dry mass) dead organic material.

**PEATLAND:** an area with a naturally accumulated peat layer at its surface.

**SUBSIDENCE:** lowering of the land surface.

# Introduction

Natural peatlands have stored carbon for thousands of years. The carbon is stored because the rate of plant production and peat accumulation generally exceeds the rate of organic matter decomposition. Aside from storing carbon, natural peatlands provide many ecosystem services for local communities. They conserve unique biodiversity and regulate the flow and storage of water over areas that often extend well beyond the peatland themselves. Many peatlands have been intensively managed and drained for use by agriculture and forestry. Drainage, however, converts peatlands from long-term carbon reservoirs into net sources of greenhouse gases (GHG) emissions. Peatland drainage also changes vegetation cover, erodes biodiversity, increases the frequency of fires, causes the land to subside, and can lead to greater salt water intrusion, more frequent droughts and damaging soil erosion. Due to the environmental threats that result from of unsustainable peatlands management, peat ecosystems have received increasing attention in scientific and policy fora addressing both climate and land use changes.

Currently, the scientific, technical and political debate is focused on three major aspects of peatlands:

- definition and mapping;
- assessment of GHG emissions resulting from peatland use; and
- peatland production potential, mainly for agriculture, forestry, fisheries and energy sectors.

The aim of this guidebook is to support the reduction of GHG emissions from managed peatlands and present guidance for responsible management practices that can maintain peatlands ecosystem services while sustaining and improving local livelihoods. This guidebook also provides an overview of the present knowledge on peatlands, including their geographic distribution, ecological characteristics and socio-economic importance.

This publication considers the environmental and pedological issues associated with peatland use and management before entering into the details of technical options for climate-responsible peatland use. This approach, which was already highlighted in previous MICCA papers, has been taken to ensure that real and potential environmental problems are well understood before peatland management decisions are made.

The guidebook is divided into three sections.

**Section 1** presents an overview of the characterization of different peatlands (Chapter 1) and provides recent global GHG emission estimates from drained organic soils (Chapter 2). This Section also describes types of peatlands (Chapter 3) and their extent (Chapter 4) in various latitudes. Chapter 5 reviews the different ways of peatlands have been utilized, and Chapter 6 looks at the environmental impacts and consequences of peatland use.

**Section 2** provides guidelines for improved management practices of peatlands. Chapter 7 and 8 focus on rewetting and paludiculture practices, respectively. Chapters 9, 10 and 11 demonstrate potential solutions for the restoration of degraded pastures, forestry sector and plantations in Southeast Asia. Chapter 12 looks at fisheries and aquaculture as potential options for diversifying incomes in local communities in rewetted and natural peatlands. The Section's last chapter highlights the importance of the engagement of all stakeholders and also offers guidance for promoting stakeholders involvement in the management processes (Chapter 13).

**Section 3** presents case studies of responsible management practices from all climatic regions: tropical, temperate and boreal. The case studies describe peatland management practices related to rewetting, paludiculture, degraded pasture restoration and forestry. Each case study considers the same set of factors, including management practices, environmental characteristics, socio-economic impact, cost-benefit assessment and the impact on ecosystem services and climate change. The use of a standard template for describing and assessing practices allows the studies to be compared easily.

Further case studies are presented on the MICCA website (www.fao.org/climatechange/micca/peat). A template for documenting case studies for those who wish to document their case study on the MICCA online platform is available in the annex.

This publication is targeted to anyone interested in more responsible and climate-friendly peatland management. It is particularly aimed at decision makers at the sub-national, district and local levels. These decision makers are the ones who can shape operational management choices and can make the difference between continued environmental degradation and increased progress toward sustainability.

Any feedback to this book is much welcome (micca@fao.org).

# SECTION 1
## Peatlands characterization and consequences of utilization

# 1. Peatland characterization

*Benjamin R. K. Runkle and  Lars Kutzbach*

Peatlands have diverse forms, characteristics and uses that reflect their geographical and ecological setting. Peatlands can generally be defined as having a naturally accumulated peat layer at their surface. However, as more specific sub-categorizations of peatlands often reflect local needs and geographical situations, it is difficult to create a universal system for characterizing peatlands. This chapter discusses definitions and distinguishing criteria of both peat and peatlands. It then details some of the unique ecological, chemical and hydrological characteristics that affect peatlands around the world.

## 1.1 Peat definition


Peat under a palm plantation, Indonesia.
Photo: Susanna Tol

'Peat' is defined as soil material that contains at least 30 percent (by dry mass) dead organic material (Joosten and Clarke, 2002). Others definitions include a requirement that this material contains a limited mineral content, which is determined by measuring the ash left after burning (e.g. less than 55 percent; Wüst *et al.*, 2003). Peat forms when inputs of dead plant organic matter to the soil exceed the mineralization and export of soil organic matter over a long period of time. These conditions generally require that water levels be near the soil surface. Under these conditions, soil water saturation and oxygen deficiency limit the decomposition of soil organic matter but still allow biomass production by locally adapted vegetation. Water saturated peat consists of more than 95 percent of water. The water content largely determines the peat's physical characteristics, such as bulk density, compressibility and hydraulic conductivity.

The physical and chemical properties of peat can be determined by using field, laboratory and modelling techniques. Due to the inherently unstable properties of peat, the use of each of these methods presents some difficulties. Consequently, different methods are often combined to deliver multiple estimates for the same parameters. One common semi-quantitative technique to assess the degree of peat humification is the Von Post scale. The Von Post scale considers:

- the colour and turbidity of the water squeezed from a peat sample;
- the proportion of peat extruded between fingers; and
- the type of plant residues visible in the sample.

The Von Post value is a fair proxy to estimate both the state of decomposition and physical (hydraulic) parameters of the peat layer. Recent work using nuclear magnetic resonance techniques has confirmed the strong connection between peat chemistry and hydrology. Hydraulic conductivity depends on peat decomposition and the type of vegetation in the peat, both of which have a chemical signature (Grover and Baldock, 2013).

Relevant soil classification for peatland landscapes uses the terms 'histosols', 'organic' and 'peat', each of which is defined here. Soils formed from organic material are classified as 'histosols'. In the IPCC's Wetlands Supplement organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below:

1. Thickness of organic horizon greater than or equal to 10 centimetres. A horizon of less than 20 centimetres must have 12 percent or more organic carbon when mixed to a depth of 20 centimetres.

2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (about 35 percent organic matter).

3. Soils that are subject to periods of water saturation and have either:

   > at least 12 percent organic carbon by weight (about 20 percent organic matter) if the soil has no clay; or
   > at least 18 percent organic carbon by weight (about 30 percent organic matter) if the soil has 60 percent or more clay; or
   > an intermediate proportional amount of organic carbon for intermediate amounts of clay.

This definition largely follows definition of 'histosol' given in the World Reference Base (WRB) for Soil Resources published by FAO (FAO, 1998; IUSS Working Group WRB, 2006). However, the definition in the IPCC's Wetland Supplement excludes the depth requirement that is part of the WRB definition, which allows usage of country-specific definitions that may be more appropriate based on regional settings and characteristics (IPCC, 2013).

Soil profile at a boreal peatland.
Photo: University of Hamburg

According to the recent version of the WRB, for a soil to be classified as a histosol one of the following requirements should be fulfilled (IUSS Working Group WRB, 2007):

1. the cumulative thickness of its peat layers within 100 centimetres of the soil surface must be a minimum of 60 centimetres if 75 percent (by volume) or more of the peat consists of moss fibres, or a minimum of 40 centimetres if the peat consists of other organic material and starts within 40 centimetres of the soil surface; or

2. there must be a minimum of 10 centimetres thickness starting at the soil surface and immediately overlays ice, continuous rock, or fragmental materials, the interstices of which are filled with organic material.

The WRB has established following types of histosols based on the degree of decomposition of their peat (IUSS Working Group WRB, 2007):

- sapric peat, which consists of less than one-sixth recognizable plant matter after the soil is gently rubbed;

- fibric peat, which consists of more than two-thirds recognizable plant tissue after rubbing; and

- hemic peat, which falls between these categories.

## 1.2 Peatland definition

The IPCC has no formal definition of peatland, but it does include the concept of peatland in the 'land with organic soil' category (IPCC, 2013). The International Peat Society (IPS) and International Mire Conservation Group (IMCG) use the term 'peatland' to describe an area with a naturally accumulated peat layer at its surface. In their terminology, 'mire' is a peatland in a state of active peat formation and accumulation. Hence, all mires are peatlands but not all peatlands are mires (Joosten and Clarke, 2002). Moreover the term 'peatland' refers to an area with naturally accumulated peat at its surface and does not cover former peatlands with a mineral soil layer on the surface. Within these broad definitions there exists a vast, heterogeneous set of definitions for different types of landscapes. These definitions are not universally accepted. Regional definitions and translations into English vary substantially.

Classification schemes, or typologies, can take into account different distinguishing factors, including vegetation cover, land use, formation characteristics, hydrology and geochemistry. This typological diversity reflects in part regional differences in the historical uses and interests in peatlands. It also reflects the fact that peatlands are a biome found in all climate zones and so may have profoundly different vegetation, geochemical and hydrological characteristics. In some definitions, a minimum peat depth of 30 centimetres (based on historic plough depths) is required. Classification schemes generally consider the following factors:

- environmental information about seasonal and climate factors (e.g. temperature and rainfall);
- hydrological setting (bog or fen);
- nutrient conditions of the soil, including pH and salinity;
- the original source of peat material (e.g. moss, vascular plants, woody matter); and
- current vegetation cover and land use.

Often, the hydrological signifiers 'bog' and 'fen' have been used as a primary classification step. Bogs are ombrotrophic, i.e. they receive water only from precipitation, and are often raised above their surrounding landscape. Fens are minerotrophic and along with precipitation receive water that has been in contact with mineral substrates. These terms are often useful in providing additional information regarding nutrient and vegetation status. Precipitation water is generally nutrient-poor, and the vegetation that grows in such landscapes is unique and adapted to these conditions. However, there are many kinds of fens, some of which are nutrient-poor peatlands whose flow conditions or geological setting may limit mineral nutrient inputs. The topographic and hydrological setting is also used to describe peatlands as either terrestrializing (developed in open water), or paludifying (developed over a mineral soil).

Peatland definitions require additional clarification in the case of mire complexes, which are composed of different subunits. Along with their macrorelief (e.g. convex raised domed bogs and concave throughflow depression fens), most peatlands are characterized by some forms of microrelief. These surface structures include hummocks, ridges, hollows and pools, and occur in various patterns. Microtopography is critical for controlling hydrological processes, regulating subsurface biogeochemistry and maintaining ecological diversity. Often microtopographic features have a different water source than their surroundings. For instance, the raised hummocks in a fen behave like miniature bogs of one square metre or less. The microtopography of these and other peatlands may be also be characterized by the proportion of tree, shrub or moss cover, as this vegetation also determines the character of the developed peat material. The ecohydrological features of peatlands, including their microtopography, are often linked to their biodiversity (Couwenberg and Joosten, 2005).

Examples of country- or region-specific peatland definitions abound and often are used for local, regional and international policy making or ecological surveys. For example, a peatland typology of the former Soviet Union, provided in Masing *et al.* (2010), distinguishes eight major mire types within ten climatic zones. The Finnish typology includes classifications based on local topographic features that enable peatland development (Laitinen *et al.*, 2007). A hydro-geomorphological approach, based largely on the source of water and hydrologic setting, as well as nutrient status and presence of pools, is used in the state of Maine in the United States (Davis and Anderson, 2001). The Indonesian definition highlights the importance of peat depth. A plan to unify Indonesian peatland definitions for national purposes has recommended a definition with looser organic content limits (at least 12 percent) and stronger peat depth requirements (50 centimetres) than other systems (ICCC, 2012). In Indonesia, peatlands less than three metres deep and outside of forests can often be used for other purpose when they are in line with local development plans. To reflect regional and national differences, the IPCC's best practice guidance is to use for country-based definitions that are applied consistently over time and across national land areas (IPCC, 2013).

## 1.3 Ecological context

Pristine and near natural peatlands are complex ecosystems with ecological traits not found in other landscapes (Minayeva and Sirin, 2012). These traits include the self-regulating ecohydrological mechanisms of water retention produced through changes in the soil's hydrological transmissivity and natural restrictions on evapotranspiration. Two key features of peatlands are:

- their fragility, which makes their recovery time from disturbances, particularly draining, especially long; and
- their ability to store carbon (Peat soils may be 6–10 metres deep and store a globally significant amount of carbon).

Mires are of great importance for regional biodiversity because they provide habitats for specialized and endangered plant and animal species. In many regions, land use conversion and landscape degradation have made near natural peatlands rare. These peatlands often represent 'island ecosystems' within the surrounding environment.

The unique characteristics of peatland ecosystems also account for their biodiversity. Peatland conditions often include acidic soil water conditions, high waterlogging, low oxygen content and low nutrient conditions, particularly in solely rainfed ecosystems mires (bogs). These conditions lead to specialized adaptation strategies. For plants, these strategies include the development of aerenchyma[1] to bring oxygen to the root layer, the use of insects as a nutrient source, the secretion of toxic chemicals and symbiosis with soil microbiota (Minayeva and Sirin, 2012). The marginal areas of peatlands, particularly raised bogs, are often important transition areas where waters from the nutrient-poor bog and surrounding mineral forest soils mix (Howie and Tromp-van Meerveld, 2011). These wet areas, in and around peatlands, are locations of ecological connectivity, linking terrestrial areas to aquatic systems.

The major ecological functions of peatlands are crucial for providing ecosystem services. These services include storing freshwater, providing wildlife refuges and sequestering carbon over long periods of time. This carbon is often essentially 'locked up' and removed from the near-term global carbon cycle due to the slow (or negligible) decomposition processes within peatlands (see Box 1.1 for further details). Because of their biodiversity, peatlands can deliver ecosystem services that contribute to the provision of important products, such as crops, berries, timber and fibre, livestock and purified water (Kimmel and Mander, 2010). Harvesting these resources and draining peatlands for other uses can change the landscape in ways that reduce peat at rates much faster than it can be created. The slow rate of peatland growth and development, associated with waterlogged and anaerobic subsurface conditions, requires active management over much longer time horizons to restore these landscapes when they are destroyed or degraded. This final point reflects the fragility of peatlands and indicates that short-term interventions like draining, harvesting, or construction can cause significant damage to landscape functioning.

[1] i.e. spaces or air channels in the leaves, stems and roots of some plants.

## Box 1.1 GHG emissions and waterborne carbon loss from peatlands

*Armine Avagyan*

Natural peatlands function as long-term carbon reservoirs because the rate of plant production generally exceeds the rate of organic matter decomposition (Frolking *et al.*, 2011; Yu *et al.*, 2011).

There are several pathways for the uptake and release of carbon from peatlands. Carbon uptake results from:

- sequestration of carbon from the atmosphere through photosynthesis;
- inputs of dissolved organic and inorganic carbon with rainwater; and
- the intake of inorganic carbon from the weathering of underlying strata and lateral inflows of organic and inorganic carbon from other sites.

Separation of the DOC fraction.
Photo: Armine Avagyan

Carbon release follows lateral and vertical pathways. Vertical pathways include respiration of $CO_2$ and methane ($CH_4$) through the decomposition of organic matter. Carbon is transported laterally from peatland to streams in the form of particulate organic matter (POC), dissolved organic carbon (DOC), or dissolved inorganic carbon (DIC). Generally, in peatlands DOC is the main component of the lateral carbon fluxes (e.g. Roulet *et al.* 2007). To differentiate DOC from POC a filter with a specified pore cutoff size (usually 0.45 micrometres) is used.

Drainage changes peatlands from long-term carbon reservoirs to net sources of GHG emissions. Peatland drainage leads to increased peat oxidization and consequent high $CO_2$ emissions. Drained peatlands also release more DOC (e.g. Moore *et al.*, 2013) than undrained peatlands, whereas $CH_4$ emissions from drained peat soils are virtually absent. However, drainage ditches typically represent hot spots for $CH_4$ emissions and must be accounted for when quantifying GHG emissions on the landscape scale. Drainage also causes an increase in nitrous oxide ($N_2O$) emissions. The application of fertilizers contributes to increasing the overall negative balance of GHG emissions from drained peatlands. Thus, any management practices that lower the water table lead to losses of carbon and nitrogen from peatlands.

## 1.4 Characteristics of peatland geochemistry

The development and stability of peatlands are determined by their hydrological setting and the soil's high water content. It is difficult to establish a simple mire classification system that can accommodate both the flow characteristics and the chemistry of peatland waters. Bog peatlands are generally nutrient-poor and fen peatlands are typically richer in nutrients. However, these different terms relate only to the source of water and do not explicitly define a peatland's chemical, nutrient or ecological status. Indeed, there are many fens with low levels of nutrients in areas where the substrate material is mineral-poor and groundwater flow is limited. This limited throughflow is often the direct result of the slow hydraulic conductivity of the peat itself.

The diversity of peatlands can be seen in nearly all peat water chemistry parameters, including pH, nutrient content, base richness and salinity. Peatland diversity is also reflected by integrated parameters, such as vegetation (Wheeler and Proctor, 2000). Peatlands are also characterized by special redox[2] conditions, which directly control the availability of nutrients, the presence of toxic metal species and GHG production (Shotyk, 1988). Additionally, differences in physical characteristics contribute to peatland diversity (e.g. depth of the water table, the temporal stability of water supply and the stability of snow cover in winter). These features are often indicted by differences in microsites or microstructural characteristics (Økland *et al.*, 2001).

[2] redox (reduction-oxidation) reactions: include all chemical reactions which involve transfer of electrons between two chemical species

Water chemistry can reveal the connectedness of the peatland to groundwater or nearby mineral systems. For example, the presence of calcium and bicarbonate can be used as an indicator of the inflow of deep groundwater. Together with pH, base cations (like calcium, magnesium, sodium and potassium) are often used to categorize peatlands into bogs, poor fens, moderately rich fens and rich fens (as reviewed in Bourbonniere, 2009). Nutrient gradients that recognize the elements that limit plant growth are also used to characterize and distinguish different peatland types (Bridgham *et al.*, 1996).

The export of DOC from peatlands is a key part of the carbon cycle and has important implications for downstream water chemistry. Drainage, which mobilizes old carbon from deeper depths in the peat profile, is expect to increase DOC export and lead to higher concentrations of $CO_2$ in the atmosphere. Understanding how DOM reacts to land use and climate changes can improve predictions about the solubility and transport of metals and organic pollutants, which are closely linked to DOM dynamics (Kalbitz and Wennrich, 1998).

## 1.5 Characteristics of peatland hydrology

The hydrological functioning of peatlands varies depending on the season, the position in the watershed and the state of drainage or degradation (Acreman and Holden, 2013). The large surface, flat topography and water-holding capacity generally allows low lying peatlands to play a buffering role in regional hydrology. Peatlands and other wetland types, including marshes and floodplain wetlands, are often seen as 'sponges', delaying flood peaks and reducing their amplitude. During dry periods, these wetlands may provide a source of water to the regional stream network. Less well known is the potential for wetlands to enhance flooding. Though more common in headwater and upland rainfed wetlands, this effect can happen in any peatland with a high water table already at holding capacity before a storm. In this case, peatlands can be a source of overland flow.

Peatland hydrology, as well as much of its ecology, has been described according to a system with two distinct layers: the 'acrotelm' and the 'catotelm' (Ingram, 1982; Clymo, 1984; Holden and Burt, 2003; Morris *et al.*, 2011). In this system, the catotelm is the permanently saturated lower portion of the peat profile that underlies the acrotelm, a high-hydraulic conductivity 'active' layer. The catotelm is nearly always anoxic with slow biogeochemical kinetics, while the acrotelm is aerobic (i.e. oxygen-containing) during periods when the water table is deep (and possibly year-round depending on site conditions). More recent conceptual modeling has found it beneficial to view to peatland biogeochemistry and hydrological interactions in terms of 'hot spots'. This conceptual model proposes greater degrees of lateral and vertical variation than a simple boundary layer between catotelm and acrotelm. Hot spots may occur at interfaces between different microtopographic units and may be responsible for the bulk of a site's $CH_4$ emissions or aquatic biogeochemical processing.

Drained or agricultural peatlands have different hydrological functions, which are often governed by changes in the peat's physical properties (e.g. compaction) or by management history. Generally, the drainage of these peatlands lowers the depth of the water table and allows greater infiltration of precipitation. For flood management, however, this storage effect can be partially or totally counteracted by the increased rate of drainage from tiled, channelized or otherwise managed systems. The varying proportion of vegetation cover in all peatlands, particularly in agricultural settings, plays a role in controlling the speed of overland flow. Variations in vegetation add another component to the variability of the peatlands hydrological function.

Drainage also has critical, nearly irreversible, effects on peat structure and on the ecological services provided by peatlands (Oleszczuk *et al.*, 2008). The substantial drop in the water table that is required for agricultural production (ranging from 0.4 metres for grasslands to 1.2 metres for crop production) leads to a decline in soil moisture content and the contraction of peat volume, which is further compounded by oxidation. This consolidation increases the specific density of the upper peat layers and causes the soil surface to subside. These shifts in peat properties decrease its structural porosity and hydraulic conductivity, which makes it difficult to carry out continued draingage in peatland landscape (Pfadenhauer and Klötzli, 1996; Kechavarzi *et al.*, 2010).

# 2. Contribution of drained organic soils to GHG emissions

*Riccardo Biancalani, Mirella Salvatore and Francesco N. Tubiello*

Organic soils constitute a major terrestrial carbon pool. They hold about 20–25 percent of global soil carbon stock but occupy only 3 percent of world's ice-free land surface (IPCC, 2014). Most of the world's organic soils are located in temperate and boreal areas. Tropical organic soils cover only about 13 percent of the total area of organic soils (Figure 3.1a). However, as the layers of organic matter are much thicker in tropical areas, tropical organic soils store a quarter of the total volume of organic soils (Page *et al.*, 2011b).

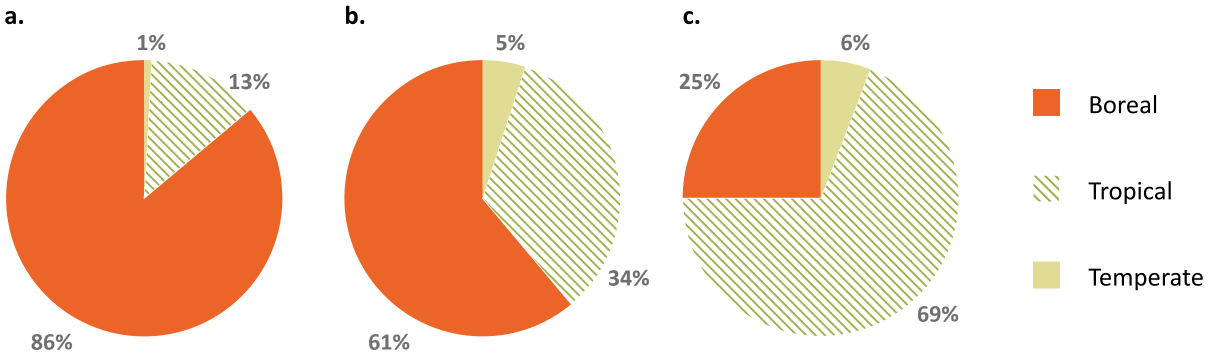



**Figure 2.1** Global information on organic soils per climatic zone.
a: distribution of organic soils; b: distribution of drained organic soils; and c: GHG emissions[3] from drained organic soils.

Drainage of organic soils for crop cultivation, grazing, forestry or other purposes converts organic soils into a net source of $CO_2$ and other GHG emissions. Recent data indicate that the extent of organc soils drainage over the last three decades has been much greater in tropical areas. Today tropical areas account for 34 percent of all drained organic soils, which is almost three times greater than their share of total organic soils (Figure 2.1b). According to FAO, about 26 million hectares of organic soils are utilized today for agriculture: 18 million hectares for cropland and 8 million hectares for pastures (Figure 2.2).

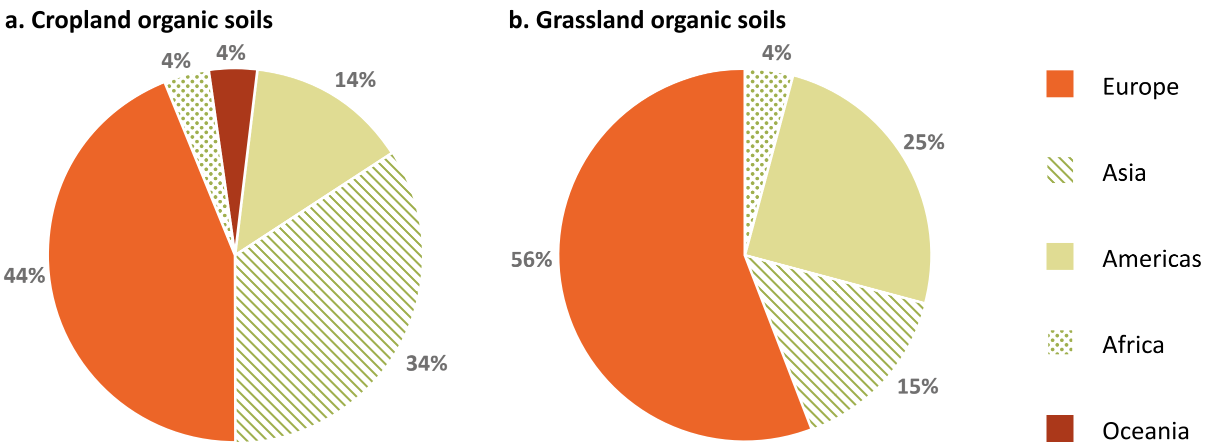



**Figure 2.2** Distribution of drained organic soils under a: cropland and b: grassland, by continent (FAO, 2014a).

[3] The estimates are based on the IPCC Guidelines 2006 (Tier 1 approach: $CO_2$ and $N_2O$) and on the geo-referenced data of the Harmonized World Soil Database.

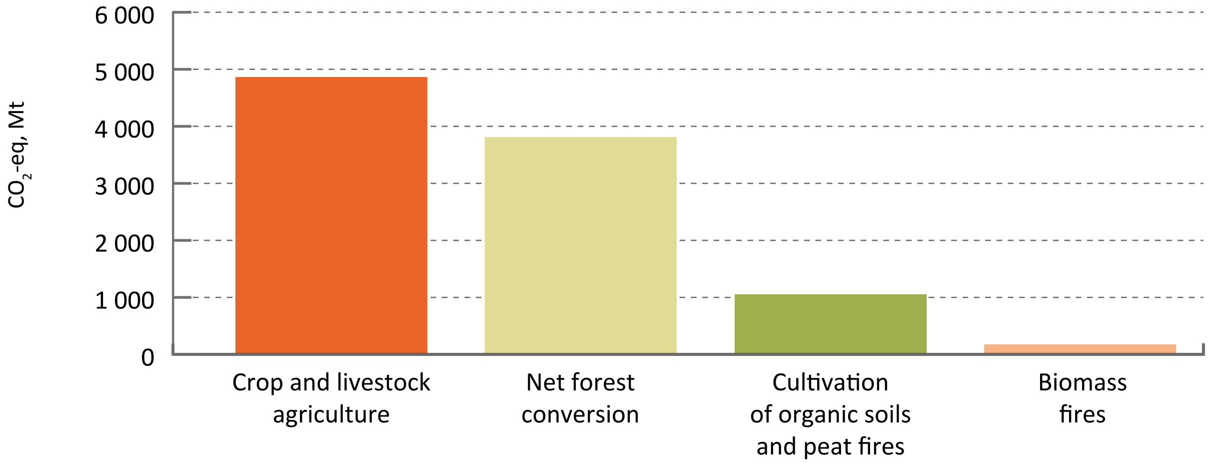



**Figure 2.3** Global average annual GHG emissions from AFOLU (FAO, 2014a).

Because of drainage, organic soils are currently the third-largest emitter of GHGs in the AFOLU sector, after crop and livestock agriculture[4] and deforestation (Figure 2.3). More specifically, according to the IPCC's Fifth Assessment Report, drained organic soils are responsible for about 1 gigatonne of $CO_2$ emissions (including emissions from both oxidation and fires) annually, which represents 10 percent of all AFOLU emissions (IPCC, 2014).

### Geographic distribution of emissions

Due to climatic factors, rates of carbon loss from drained organic soils are much higher in tropical areas than in boreal areas. Consequently, the distribution of emissions from drained organic soils does not closely match their geographic extent. Drained tropical organic soils account for almost 70 percent of total emissions (Figure 2.1c). Because of drainage patterns and climatic factors, the geographic distribution of GHG emissions from drained organic soils is significantly skewed towards Southeast Asia (Figure 2.4 and Figure 2.5).

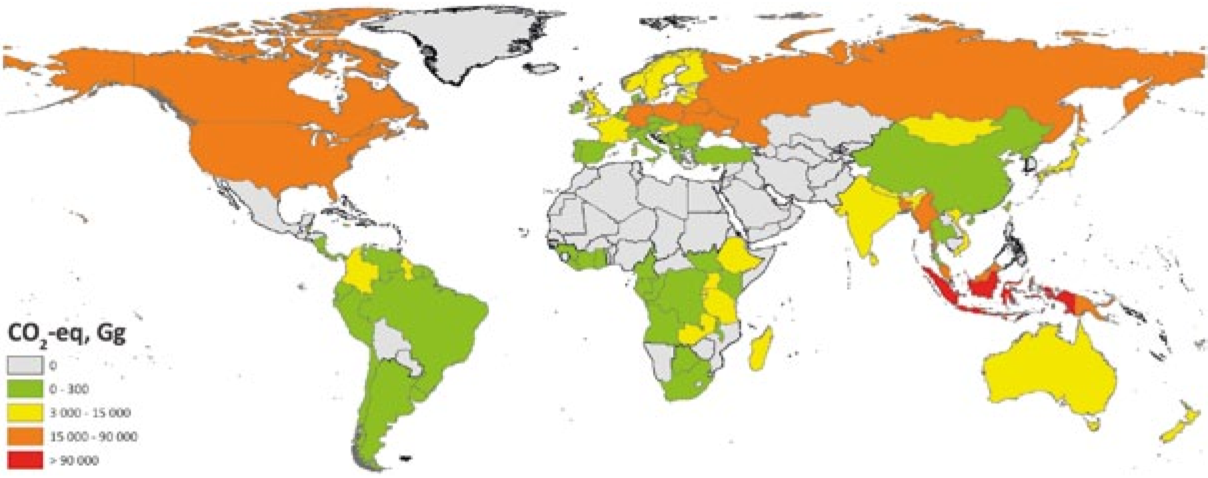



**Figure 2.4** Global distribution of GHG emissions from drained organic soils (FAO, 2014b).

[4] Crop and livestock agriculture includes: enteric fermentation, manure management, manure left on pasture, manure applied to soils, rice cultivation, synthetic fertilizers, burning savanna and burning crop residues.

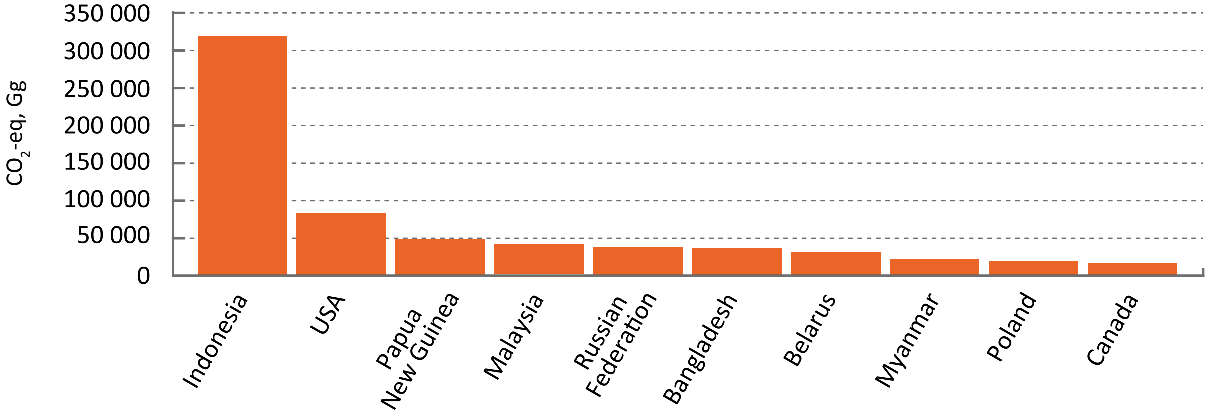



**Figure 2.5** Top ten annual GHG emissions from drained organic soils, by country (FAO, 2014b).

# 3. Overview of types of peatlands

*Harri Vasander*

Peatlands share some common characteristics; one of the most salient is that they contain large amounts of organic matter. There are, however, several different types of peatlands that reflect the particular circumstances of their formation and composition. Boreal and temperate peatlands are very different from tropical peatlands. Similarly, high-altitude peatlands differ significantly from those found at low altitudes. This chapter will describe the primary differences among the main groups of peatlands.

## 3.1 Tropical peatlands

Tropical peat swamp forest Indonesia.
Photo: Wim Giesen

Tropical peatlands are found in mainland East Asia, Southeast Asia, the Caribbean and Central America, South America, and Central and Southern Africa. In contrast to younger temperate/subarctic peatlands, a 27 000 years old, 10-metre-thick peat deposit from the Sebangau river catchment in Central Kalimantan, Indonesia shows that tropical peatlands were involved in the global carbon cycle prior to the last glacial maximum (26 500–19 000 years ago) (Page *et al.*, 2004). Not all tropical peatlands, however, are this old. Rieley *et al.* (2008) have compiled data on the origin and development of Southeast Asian peatlands and demonstrated that tropical peatlands are complex systems that have developed in stages rather than through a continuous progression. Factors influencing the rate of peat accumulation include vegetation type, hydrological setting, climate and environmental changes. Over their long lifetime, the peatlands in Southeast Asia have acted as both carbon sources and sinks. Over thousands of years, however, the accumulated peat represents net carbon storage. The three main phases in the initial development of tropical peatlands in Southeast Asia have mainly been due to sea level changes (Anshari *et al.*, 2004; Page *et al.*, 2004; Sieffermann *et al.*, 1988; Wüst and Bustin, 1999).

The highest proportion of tropical peatland is found in Southeast Asia, where lowland peatlands cover an area of 0.248 million square kilometres. This represents 56 percent of the total tropical peatland area and 6 percent of the global area (Page *et al.*, 2011b). Both the surface vegetation and especially the underlying deep peat constitute a highly concentrated easily available carbon pool of global significance. Indonesia has the most peatland in Southeast Asia, with tropical peat covering over 0.20 million square kilometres, mainly in Kalimantan, Sumatra and Papua (Page *et al.*, 2011b). Recent findings show that there are diverse ombtrotrophic peatlands also in Amazonia (Lähteenoja and Page, 2011; Lähteenoja *et al.*, 2009, 2012). According to peat chemical analysis, 40 percent of Amazonian peatlands were shown to be ombrotrophic and 60 percent minerotrophic (Lähteenoja *et al.*, 2009; Lähteenoja and Page, 2011). Because minerotrophic peat swamp forests have already been mostly lost in Southeast Asia, the diversity of Amazonian peatland ecosystem types may be higher than that found in Southeast Asia. Unfortunately, little is known about African tropical peatlands. The best recent estimate for the extent of tropical lowland peatlands in Africa is 95 900 square kilometres. In Southern and Eastern Africa, many low lying peatlands have been converted to agriculture and the remaining natural peatlands are severely threatened by conversion and degradation (Wetlands International, 2013).

Tropical peat deposits are formed and maintained by continuous large litter inputs from evergreen trees into seasonally water-saturated peat. Carbon input rates are able to balance out the losses caused by decomposition. As the peat in tropical peat swamp forests is largely composed of trees, the speed of water flow on the surface layer is usually faster in these peatlands than in boreal and temperate peatlands that are composed of mosses and sedges. Since most of the tropical peatlands are situated at low altitudes in coastal and subcoastal locations where human population growth is high, they are likely to be developed at a faster rate than peatlands in temperate and boreal zones (Rieley *et al.*, 2008).

## 3.2 Boreal and temperate peatlands

The development of northern peatlands began 16 500 years ago. They expanded during the Holocene period (the past 12 000 years after the latest glaciations) on land that became exposed when glaciers retreated (Macdonald *et al.*, 2006). The world's largest peatlands are located in boreal and subarctic regions in western Siberia in the Russian Federation, central Canada, northwest Europe and Alaska in the United States.


Types of peatlands in temperate and boreal zones peatland.
a: Temperate peatland (blanket bog) in Ireland (photo: Anna Laine); b: Fertile boreal peatland in northern Finland (photo: Hannu Nousiainen) c: Boreal fen with different kind of sedge (photo: Markku Saarinen).

In boreal and temperate regions, the accumulation of peat is due to waterlogged conditions and peat-forming plants, such as:

- peat mosses (genus *Sphagnum*);
- other mosses, especially 'brown' mosses (family Amblystegiaceae);
- sedges (genus *Carex*); and
- dwarf shrubs and trees.

The net primary production (NPP) and peat accumulation rates in different kinds of peatlands vary widely. The 'efficiency' of peatlands (i.e. the ratio between peat accumulation and NPP) varies between 1 and 20 percent (Tolonen *et al.*, 1992; Francez and Vasander, 1995; Moore *et al.*, 2002; Feng, 2002). The peat accumulation rate is linked to the peatland's geographical location, age and type.

Mire complexes can be divided into groups based on their nutrient status and the vegetation in the central areas. The different types of mire complexes in temperate to arctic zones, with their typical peat characteristics, are presented in relation to their climatic conditions in Figure 3.1, with a special focus on Europe in Figure 3.2.

In temperate regions where precipitation is less than evapotranspiration, generally only alluvial mires occur. Concentric and eccentric bogs and bog forests are found in temperate to boreal regions where precipitation is approximately equal to evapotranspiration. In boreal to subarctic regions where precipitation exceeds evapotranspiration, aapa mires (patterned fens) are formed. In northern arctic areas where the annual mean temperature is below $0^{o}C$, palsa mires with discontinuous permafrost and polygon mires with permanent permafrost are found (Figure 3.1).

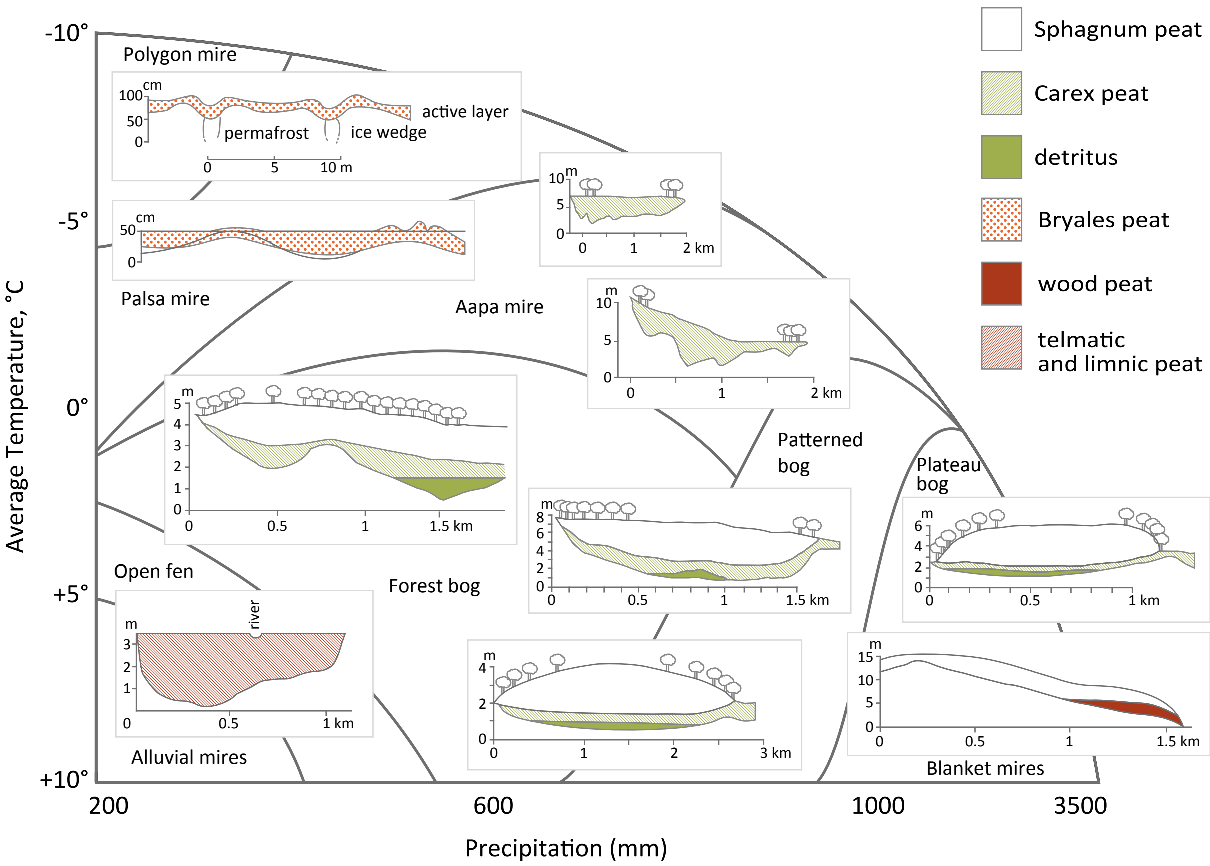



**Figure 3.1** Relationship between climate (temperature and precipitation) and major peatland complexes of the temperate to arctic zones. The figure follows Eurola *et al.* (1984) and Vitt (2006) and is originally based on patterns presented by Damman (1977), Botch and Masing (1983), Sjörs (1983), Ruuhijärvi (1983), Zoltai and Pollett (1983), and Vitt *et al.* (2003).

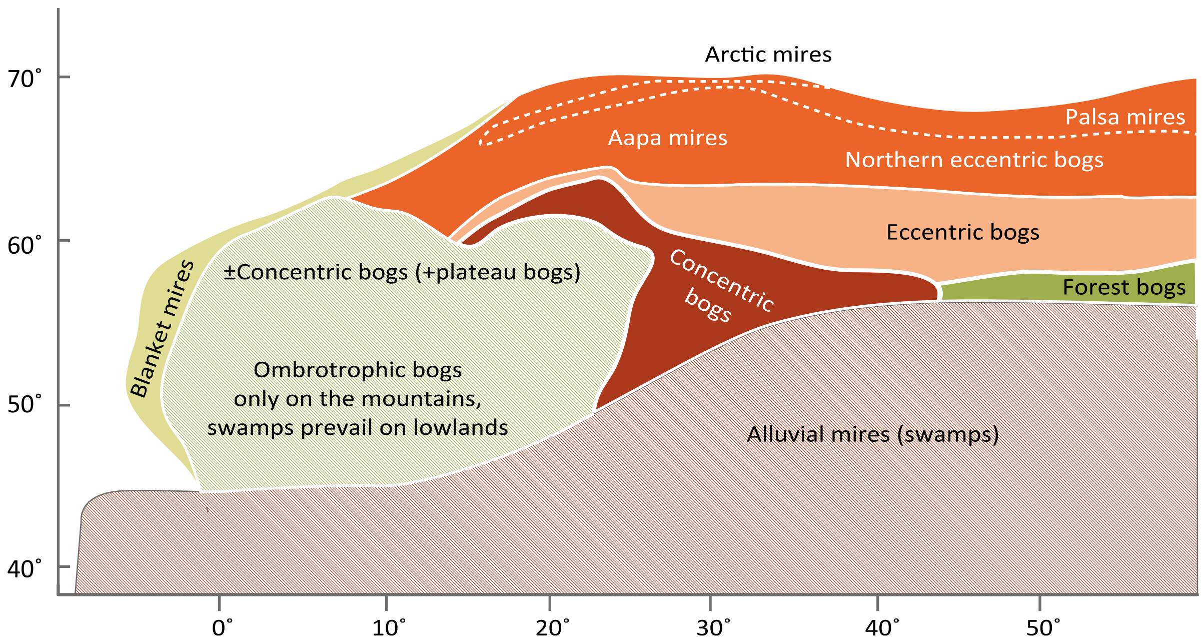



**Figure 3.2** The mire regions of Europe. The schematic map, excludes shelf-seas, bays, enclosed seas, etc. The x and y axes present geographic coordinates. Modified after Eurola *et al.* (1984).

## Box 3.1 Mire formation

*Harri Vasander*

There are three main ways that mire is formed (Figure 3.3).

1) Water bodies may be overgrown either from the top (A in Figure 3.3) or from the bottom (B in Figure 3.3). In practice, these phenomena often occur simultaneously. In the former, a peat moss layer together with rhizomatous herbs (e.g., *Calla palustris, Menyanthes trifoliata*) spreads across the surface of the lake as a floating raft, eventually covering the entire water body in vegetation. Following the continued formation of peat, the space between the lake bottom and vegetation raft gradually becomes filled with peat. Overgrowing starts from the top especially in nutrient-poor and deep lakes, as opposed to the bottom in nutrient-rich and shallow lakes. The water body then becomes overgrown by shoreline and aquatic vegetation growing in the basin. After their colonization of a site, peat mosses start to modify the environment by making it more acidic and anoxic, making it more difficult for other plants to survive.

2) Forestland may become paludified (C in Figure 3.3). The peatland formation of forestland (C) begins when mire plants, especially peat mosses, gradually appear in waterlogged and low-lying patches of forest.

3) In addition, topographically flat shores can develop peatlands in areas with upheaving land, on alluvial river shores or on land where the surface of lake water has decreased (D). Primary paludification (peatland formation) occurs especially in land that was under glaciers. After the heavy glaciers melted, bedrock began to rise (referred to as isostatic rebound). This process is still continuing, albeit at a declining rate, particularly in the Hudson Bay Lowlands in Canada, around the Bothnian Bay in Finland and Sweden, and on the shores of the White Sea in the Russian Federation (D in Figure 3.3).

Another way of forming mire on formerly shallow lake basins has also been identified (Vitt, 2006). This has however, been included under primary paludification. Generally speaking, mire formation is favoured by a humid climate, small, shallow and stagnant waterbodies, alluvial and topographically flat landscapes, and poor and podzolic soils.

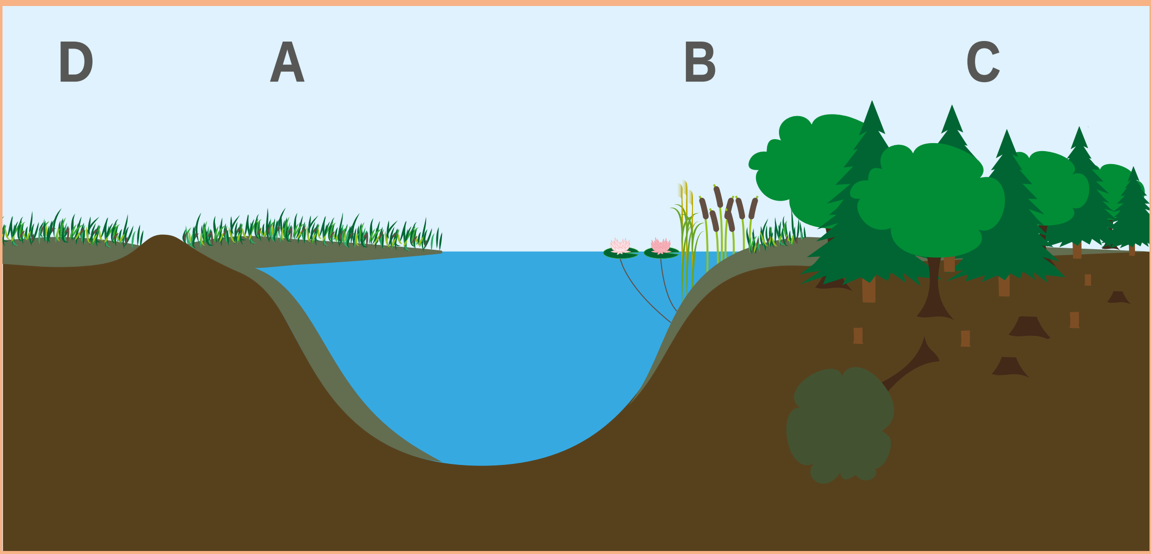



**Figure 3.3** Schematic display of a mire formation (modified after Eurola, 1999).

# 4. Mapping of Peatlands

*Luca Montanarella*

## 4.1 State of the art of peatlands mapping

There is a basic lack of consistent peatland mapping at the global scale. The lack of data is a consequence of various factors that make global peatland mapping particularly difficult. These factors include:

- a lack of mapping standards, starting with an agreed definition of peatlands;
- difficulties in using remote sensing technologies due to multiple land uses, especially in northern latitudes;
- highly fragmented distribution patterns that require high resolution detection and mapping; and
- in many cases, difficult environmental conditions for conducting ground observations and field surveys.

The lack of data on peat thickness and the differences in peatlands classification systems in different countries are the causes of the large range of peatland estimates at national and global scales. Peatland areas can be estimated with remote sensing data and available soil maps, but the total peat volume cannot be estimated without reliable information on peat thickness. The area of peatlands (combined with their land use status) provides data on the amount of current GHG emissions from the site, whereas the thickness of the peat indicates the amount of potential future GHG emissions. Collecting data on thickness requires time-consuming direct measurements in the field. In addition, when the peat is up to 10 metres or more thick and contains a large proportion of hard tree remains sampling becomes very difficult. Even when values are available, there is usually no information on the sampling methods or the methods used for evaluating and interpolating the data (Page *et al.*, 2011b, Dommain *et al.*, 2011). There are some positive examples of national peat inventories and maps, for example in Ireland (Malone and O'Connell, 2009) and Indonesia (Wahyunto and Nyoman, 2008).

## 4.2 Comparison of different available maps

Currently, global peatland mapping is based on soil data and maps, especially the Harmonized World Soil Database, and extracting the information about histosols.

Global maps of distribution of peatland come from three different scientific groups:

- the peat and peatland scientific research community;
- the soil science community; and
- the remote sensing community.

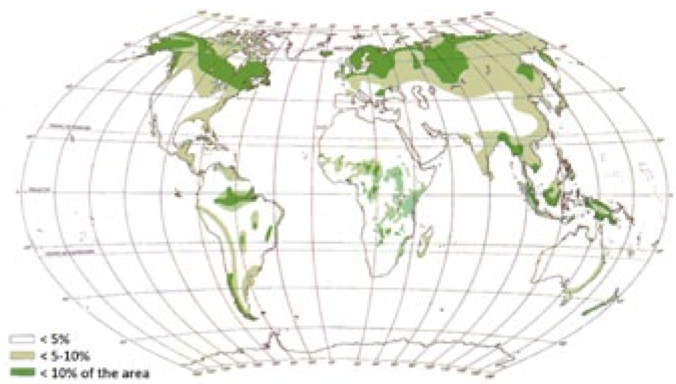



**Figure 4.1** Rough distribution of mires in the world (Lappalainen, 1996).

Typically the peat research community bases its maps on inventories of peat areas at the national and local level and then aggregates these data to produce global maps (Figure 4.1). Data on peatland coverage can be aggregated at the national level (Figure 4.2), which allows for the ranking of countries according to their importance for peatland management.

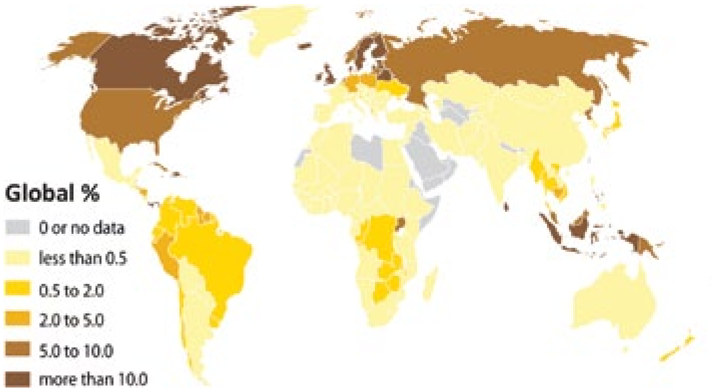



**Figure 4.2** Percentage of the area covered with peatland by country (Parish *et al.* 2008, Wetlands International).

More detailed assessments of peatlands are possible when using global and regional data on soils and histosols. For example, the currently available assessment of peat distribution in Europe (Figure 4.3), derived from the 1:1 000 000 European Soil Database (ESDB), used histosols data as the proxy information for possible peat areas. Care should be taken when using such approaches. Available soil survey data are often out-dated and used in a highly aggregated manner when incorporated in small scale maps like the 1:1 000 000 scale soil map of Europe. Nevertheless, soil information systems are currently the most complete source of georeferenced information on the occurrence of organic soils for large areas at the continental or global scale. The extension of the ESDB to cover the Russian Federation has allowed for an estimate of the distribution of organic soils in boreal Eurasia (Figure 4.4). The limits of using the WRB classification system for assessing the distribution of peat in boreal areas has become obvious since evidence has been found of much larger organic carbon pools in permafrost-affected areas than had originally been estimated by using only soil data (Tarnocai *et al.*, 2009).

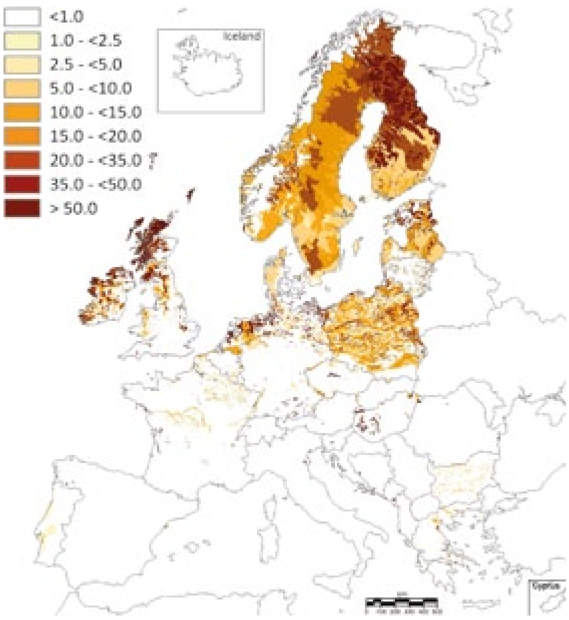



**Figure 4.3** Relative extent (%) of histosols in the Soil Mapping Units of the ESDB (Montanarella *et al.* 2006).

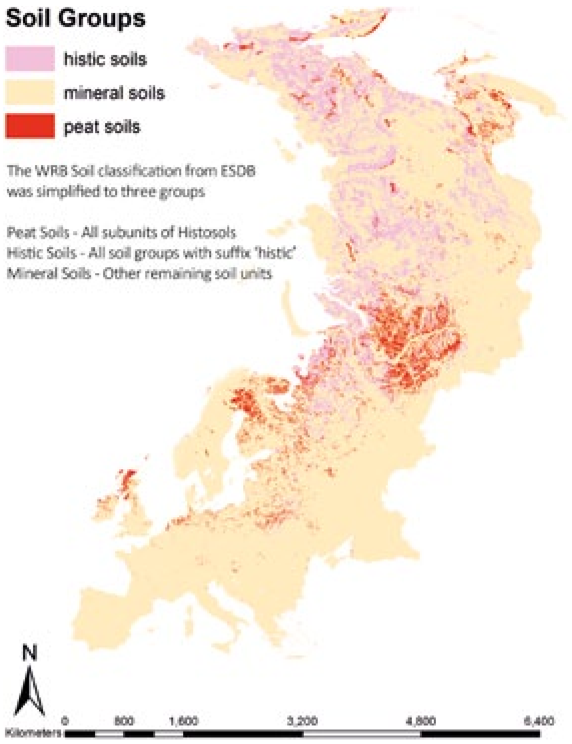



**Figure 4.4** Distribution of peat soils, histic soils and mineral soils in boreal Eurasia (European Soil Information System).

Unfortunately, there exists only limited georeferenced information on peatland distribution in tropical areas. Most regional assessments of tropical peatlands are focused on Indonesia. More extensive surveys and detailed mapping would be necessary to arrive at a complete assessment.

## 4.3 Priority actions for improved peatlands mapping

There are several areas of potential improvement for peatland mapping. First of all a set of common definitions is needed. Mapping peatlands is not equivalent to mapping organic soils (histosols). The definition of histosols originates from the field of traditional soil surveys that often do not take into account crucial information for peatland mapping. For assessing GHG emissions, it is especially important to distinguish between the mapping of natural peatlands and mapping of managed peatlands under different land uses. Crucial parameters like peat depth and applied management systems (e.g. drainage networks, pasture and grassland management) need to be included in an operational peatland information system. Precise georeferencing of the peatland data and the delineation of peatland at large scales (1:10 000–1:5 000) is the prerequisite for compiling updated geographical information systems on peatlands.

Remote sensing techniques may be effective tools for delineating potential peatland areas. Nevertheless, detailed field surveys will be always necessary to assess peat depth and verify the remote sensing data through ground truthing. Ideally, future global peatland mapping systems should be based on aggregated data from local and national peat information instead of on estimations derived from global soil maps, like those currently available from the Harmonized World Soil Database. The first step toward establishing a fully operational global peatland information system would be a complete inventory of the available national and global peatland information. This would serve to identify gaps and priority areas for field surveys and further data collection activities. The first tangible result of such an activity could be a Global Peat Atlas. Detailed peat inventories would then follow, especially in areas where information is scarce and obsolete. For this to become a reality, precise guidelines based on common methodologies, training and technical support, and financial resources are needed.

These activites could lead to a fully operational global peatlands information system that can provide updated and reliable data on the extent of peatlands, peat thickness and applied management practices. The system could also be used for monitoring, reporting and verifying peatlands emissions and ecosystem services in various policy frameworks at the global and national level.

# 5. Utilization of peatlands and peat

*Jack Rieley*

Peatlands have been important to human societies for millennia. The utilization of boreal and temperate peatlands has differed greatly from tropical peatlands. Peatlands supply local communities with a range of products and services. Since long ago, peatlands have been drained and used for agriculture and forestry. Peat has been used for many purposes, including growing media and soil improvers, building material, livestock bedding and fuel for generating heat and energy. In some countries, naturally forested peatlands are a valuable source of timber. In others, where trees are not a natural component of peatland ecosystems, they have been planted with trees to create commercial plantations.

## 5.1 Low-intensity use of peatlands[5]

It is probable that peatlands and other associated wetlands have always been a source of food, materials and cultural and spiritual inspiration. The impact of modern humans on pealtands dates back to the transition from the last glacial period to the present interglacial period, some 10 000 years BP. During this time, the combination of changing climates and expanding and migrating human populations exterminated a considerable part of the global mega fauna, including wetland species. Bog bodies, tools, ornaments, weapons and other archaeological remains found in abundance in wetland sediments and peats testify to the long and intimate relationship between people and wetlands during the Holocene period.

In more recent times the peatlands of northern Europe, for example, provided fish, fowl, game, summer grazing and winter hay, fuel for cooking and heating and roof thatching. Initially, these resources were free and held in common by local communities who guarded their rights. However, as populations increased and migrated, disputes and conflicts arose over the ownership and use of peatlands.


Jelutung agroforestry.
Photo: Wim Giesen

On acid bogs, especially in some Scandinavian countries, wild mushrooms and berries are important sources of nutrition and vitamins (especially vitamin C) for local communities. The sale of these products also contributes to the local economy. Wild berries are well adapted to the peatland habitat and can overwinter under thick snow cover. Natural peatlands play an important role in the retention, purification and release of water and in the mitigation of droughts and floods. They also provide a space for activities related to culture, health, leisure, recreation, religion and education. The large areas of continuous landscape covered by peatlands are beautiful and can be important tourist destinations and conservation areas. Because all peatlands are repositories of palaeoenvironmental information on past vegetation, former climatic conditions and the rate of peat and carbon accumulation, they have a scientific value that goes beyond their plant and animal diversity. Peatlands are also a reservoir of geochemical information that can reveal the nature of the peat and the depositional processes from the atmosphere that occurred during peat accumulation. Many of the species living in peatland ecosystems are not found anywhere else. In addition, because their swampy environment often makes peatlands inaccessible to people, many species that may not be completely confined to these habitats, still depend on them for the food and shelter they provide.

[5] Low-intensity peatlands utilization includes all types of usage that do not require drainage.

For centuries, tropical lowland peatlands have provided important resources for the livelihoods of indigenous people, including food, fibre, and other materials. The extensive peat swamp forests of Southeast Asia are sources of timber, bark, and a range of non-timber products, such as rattan, resin, latex, fungi, honey and medicinal plants. Fish from blackwater streams and rivers that drain from tropical peat swamp forests are important sources of protein and calcium for local people. These peatlands also provide sheltered habitats for spawning, nursery areas for newly hatched fish and habitats for adult fish to survive during periods of drought. Edible species found in these ecosystems include eels, snakeheads and catfish. Tropical peatlands are also home to a number of species of ornamental fish that have a high economic value. In spite of its dark red colour, blackwater from undrained tropical peat swamp forests is a source of potable water.

## 5.2 Intensive use of peatlands[6]

Peat in Europe is used mainly as a fuel for domestic and commercial use, and as a constituent of growing media in amateur and professional horticulture. Some peatlands have been drained and used for forestry. 'Turf' has been cut for domestic fuel for many centuries. In Denmark and the United Kingdom, for example, there is archaeological evidence of peat cutting in the pre-Roman period and turves have been found that are more than 2 000 years old. In northern Europe, peatland drainage for agriculture was initiated by the Romans in the lands that they conquered. The Roman scholar Pliny the Elder in his Natural History described the utilization of peat by German tribes along the Rivers Elbe and Ems in the 1st century AD.[7] By medieval times, peat largely replaced wood for fuel as forest cover declined. Peat charcoal was used to heat pottery kilns and furnaces for smelting iron ore. The demand for peat continued to increase until the beginning of the 19th century when native woodlands were cleared to make charcoal for iron industries and extensive rail and road networks were established to transport coal.

Peat turves cutting in Ireland.
Photo: Marcel Silvius

**Peatland converted to agriculture**

Although the Romans initiated peatland and other wetland drainage in some of the lands they ruled, these activities were relatively small-scale and the drained areas were mostly abandoned when the Roman Empire collapsed in the 5th century. Starting from the 8th century, the extensive peatlands of Holland were drained, colonised and used as meadow, pasture and arable land. As early as 1 100 techniques for peatland reclamation and colonisation had achieved such success that Dutch expertise was exported to Germany and later to England and Scotland. The church, eager to derive economic benefit from this agricultural development, was an important driving force for the reclamation of marshes and peatlands in various parts of Europe during the Middle Ages. Large-scale wetland drainage in England accelerated in the 17th Century and continued into the late 19th century, notably in the fenlands of eastern England where the drained areas were used as pasture for livestock. In the Netherlands, where many peatlands are at or below sea level, an extensive system of dykes (polders) was constructed within which water table levels were kept low. Initially, drainage was done by gravity using a network of drains and channels. As technology advanced, wind-powered and electrical pumps enabled much larger areas of peatland to be drained and kept free from flooding. In the former Soviet Union alone, 2.5 million hectares of peatland were drained, equal to almost 27 percent of the total global area of peatland drained for agriculture.

Drained fen peatlands have provided some of the most fertile soils for crops and support high levels of production. On the other hand, drained bogs have problems of high acidity and waterlogging. Only marginally fertile, these produce low yields of grasses and crops. Agriculture on drained peatlands has always depended on local socio-economic conditions, and the agricultural use of peatlands has changed over time with many areas having been abandoned.

6 Intensive peatlands utilization includes all types of usage which requires drainage.
7 Similar stories on peat use can be also found in the peri-Himalayan areas of Pakistan, China and India.

Peatland drainage and conversion to agriculture have virtually ceased in boreal and temperate zone countries. However, the drainage of peatlands is increasing in the tropics, especially in Southeast Asia where it was originally promoted by the Indonesian and Malaysian governments to boost rice cultivation. In Indonesia, peatland drainage was also part of the government's transmigration programme for relocating poor, landless people from Bali, Java and Madura to less populated provinces in Kalimantan, West Papua and Sumatra. Currently, the palm oil and paper industries are fuelling rapid agricultural development in both countries. Between 1990 and 2010, more than 5.1 million hectares of peat swamp forest in peninsular Malaysia, Sumatra and Borneo were lost. At the same time, the area used for industrial plantations of oil palm and paper pulp trees increased by 3.1 million hectares and covered 20 percent of the region's peatland (Miettinen *et al.*, 2012). It is predicted that, unless there are changes in land use policies or the markets for palm oil and pulp, by 2020 the area under industrial plantations will increase to between 6 and 9 million hectares.

**Peatland forestry**

Some peatlands support a natural tree cover; others do not. In their natural condition, forested mires provide timber and other non-timber forest products to local communities, particularly in tropical areas. Draining peatlands allows wood production to be carried out more intensively and at less cost. Globally, around 12 million hectares of peatland, mostly in northern boreal and temperate zones, has been drained for forestry. The principle countries that have drained peatlands for forestry are Finland and the countries of the former Soviet Union, but it has also been done in Norway, Sweden, United Kingdom and the United States. Finland, Sweden and the countries of the former Soviet Union together account for 80 percent of the area of peatland drained for forestry.

Conversion of peatland for oil palm plantation, Indonesia. Photo: Susan Page

In the tropics, there is no long-term plantation forestry on peatland similar to that in the northern hemisphere. Instead, the focus is on selective logging or clear-cutting of natural forests. These natural forests are mostly replaced with plantations of oil palms or planted with rapid growing trees, such as *Acacia* spp. that are managed in short production cycle (6–10 years) for the paper industry.

**Peat extraction for fuel and horticulture**

By the end of the 19th century, coal largely replaced peat as domestic fuel in all but the remotest areas and most impoverished communities. In the first half of the 20th Century, the use of peat as a fuel in factories, heating plants and electricity generating stations increased. Initially, peat extraction was carried out by hand cutting sods or using small excavators, a process that left behind deep, irregularly shaped trenches in the surface of the peatland. The hand-cut sods were dried on site before being transported to homesteads or factories. Peat is now mostly extracted by large machines that remove a few centimetres of peat from a large area of bog by grinding (milling) the bare peat surface. The milled peat is left to dry for a few days until the water content falls to around 50 percent, and is then collected and transported to power stations or processing plants. Some milled peat is compressed into briquettes for domestic use or pellets for power stations.

The use of peat for generating electricity depends on national and local economic conditions and on the availability of other fuels. Peat is used for energy mostly in Europe, which accounts for, over 95 percent of peat extraction and consumption globally. Belarus, Finland, Ireland, the Russian Federation and Sweden account for 90 percent of the peat extracted for energy. In 1918, construction began on the first (and largest) Russian peat-fuelled Shatura Power Station near Moscow. The first peat-fired power station in Ireland was built in 1924 to provide electricity for a peat excavator on the Turraun peatland in the Irish Midlands from which peat was transported along the Grand Central canal to Dublin. During World War Two, because Ireland did not have an adequate supply of local coal, the country turned its attention to peat as the principal fuel for domestic heating and industrial power. At the same time, political decisions were taken by the Irish Government to develop peat-fuelled power stations next to major peat bogs so the country could become less dependent on imported coal and oil. All of the original milled peat stations have been closed due to the declining availability of peat. They have been replaced by three new, more efficient, power stations that will operate until 2025 to 2030 when peat use for electricity generation in Ireland will cease. At one time the former Soviet Union had more than 100 peat-fueled power stations. In Finland and Sweden, peat is used for fuel mostly for local district heating in winter or is co-fired with wood.

The modern horticultural industry originated as a response to changing socio-economic conditions after World War One, when an increasingly urbanised workforce required more food and began to cultivate vegetable gardens as well as ornamental plants. The first commercially available standardised growing media (the internationally recognised 'John Innes' mixes of loam, peat and sand) were developed in the 1930s in the United Kingdom. Peat replaced loam in the 1970s as good quality supplies of loam became difficult to obtain, and the growing medium was difficult to handle and expensive to transport. As people gained more leisure time and their demand for a regular supply of quality fruit, vegetables and ornamental plants increased, the horticulture industry boomed in developed countries. Peat is now used as the principal ingredient in most growing media mixes because of its consistency, reliability and low market price.

Transportation costs generally ensure that peat is used for energy mostly in areas where it is extracted. However, peat used for horticulture is traded internationally and may be transported over large distances. Countries with little or no peatlands import peat for use in the horticultural industry.

Peat extraction, especially in the European Union and North America is strictly controlled by local planning and mineral extraction conditions and codes of conduct implemented by private companies.

**Other uses of peatlands and peat**

Peat moss can absorb liquids up to 10 times its dry weight. From the mid-19$^{th}$ century until World War Two, peat moss litter was used throughout much of Europe as a bedding material for animals, especially horses. Peat has also been used as a filter for gases, odours and liquids (e.g. in biofiltration systems for the treatment of septic tank effluent). It has also been used to make charcoal. In pharmaceutical industries, peat, along with activated charcoal, has been used to absorb impurities in liquids and gases. Peat has also been heat treated to absorb spilled oil. Peat mixed with tar and plaster of Paris (gypsum) has been used to make insulating material and wadding for the building industry.

Numerous other products have been derived from peat or peatland plants, including:

- textiles from the fibres of the leaves and stems of cotton grass (*Eriophorum* spp.);
- bitumen, oil and charcoal;
- plastic composites that can replace oil-based raw materials;
- flavouring in the production of malt whisky through the imparting of phenols into barley that is 'malted' over a peat fire; and
- baby nappies and wartime field dressings.

In addition, many peat preparations, some with cosmetic value, have been used in human and animal medicine. Peat partly replaced mud in balneology, the science of application of water from curative springs and peloids (mud or clay containing humus and minerals) in the early 19$^{th}$ Century. The oldest spas still practising peat therapy are in Austria, the Czech Republic and Germany.

Several countries are considering the suitability of blueberry cultivation on cut-over peatlands. The Canadian peat industry, for example, operates mainly in rural areas, and the cultivation of berry plants after peat extraction could bring social and economic benefits to these communities. This type of production, however, must be integrated within a management programme that combines ecosystem restoration and reclamation goals.

Interest is growing in paludiculture, a management activity that uses biomass from wet and rewetted peatlands under conditions that maintain the peat mass, promotes peat accumulation and provides some of the ecosystem services associated with natural peatlands. Many time-honoured collecting activities on natural peatlands, such as berries and fungi, are examples of paludiculture. In recent years, however, alternatives for changing land use on wet and rewetted peatlands have been implemented and assessed. Some of these alternative practices reintroduce traditional forms of land use but use the biomass for new and novel products, such as construction materials, insulation panels and biofuels.

# 6. Environmental impacts and consequences of utilizing peatlands

*Susan Page and Aljosja Hooijer*

## 6.1 GHG emissions from drainage

Unlike other soils, peat is fundamentally unstable. When it is drained, which removes water from the soil pores, oxygen can enter into the pores and oxidize the peat through biological and chemical processes. Drainage also increases the risk of fire. Carbon is emitted, mostly as $CO_2$ to the atmosphere (as a result of biological oxidation) or as a combination of $CO_2$, CO and $CH_4$ (as a result of fire). Both drainage and fire also lead to enhanced discharge of carbon as DOC and POC into downstream aquatic ecosystems. A further impact of drainage is the lowering of the peatland surface (land subsidence). In the first few years after drainage, physical peat compression processes (consolidation and compaction) are dominant factors causing subsidence (Andriesse, 1988; Den Haan *et al.*, 2012; Hooijer *et al.*, 2012). Subsequently, the loss of peat volume occurs mainly through biological oxidation (but also fire, in some locations). Over time, subsidence will increase the risk of flooding and often leads to losses in agricultural productivity on drained peatlands. Non-carbon GHG emissions ($N_2O$) from drained peatlands can be a consequence of microbial breakdown of the peat, but these emissions are also associated with fertilizer application.

Subsidence in peatlands.
Photo: Bambang Setiadi

**Controlling factors**

As biological decomposition is a temperature-dependent process, the rates of emission and of subsidence are higher in tropical climates than in temperate and boreal regions. Emission rates are also higher in open areas than in forest areas where soil temperatures are lower due to canopy shading (Hirano *et al.*, 2009; Jauhiainen *et al.*, 2012a). In all climate zones and land cover types, there is a clear relation between $CO_2$ emissions and the water table depth below the peat surface (Figure 6.1). Emissions increase proportionally as water tables are lowered below 0.5 metres, which is necessary for most crop production and plantations on peatlands. Further details on water table and $CO_2$ emissions relation are presented in the IPCC's Wetlands Supplement (IPCC 2013).

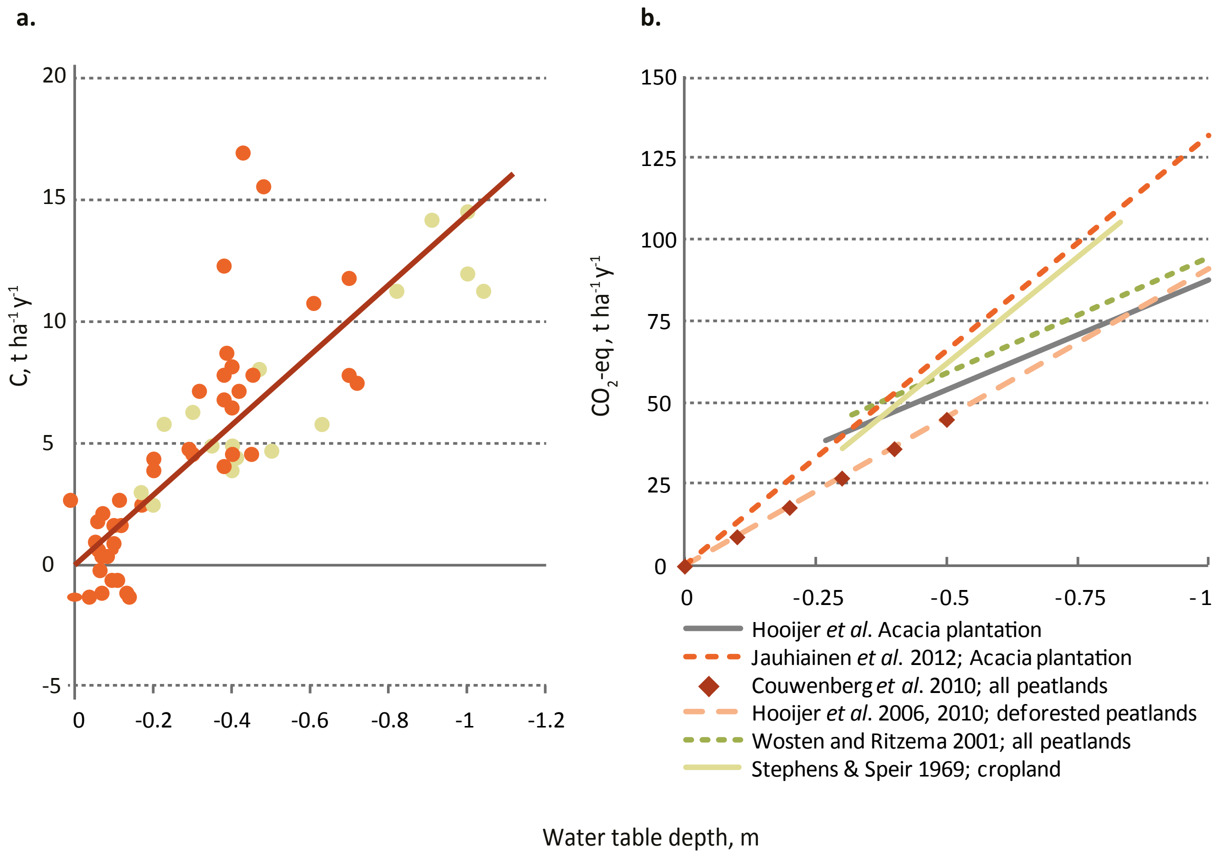



**Figure 6.1** Relations between water table depth and $CO_2$ emission (more than 5 years after drainage) for temperate/boreal and tropical peatlands that have been drained and managed for croplands and plantations (a: from Couwenberg and Hooijer, 2013, b: from Hooijer *et al.*, 2012). Note that recent research indicates that emissions from non-agricultural peatlands are lower even at the same water table depth.

**Timing of emissions**

Emissions after peatland drainage are not constant; they vary as water tables and peat characteristics change. In typical plantation development in Southeast Asia, the initial peatland drainage usually involves a rapid lowering of the water table to depths of around or below 1 metre to over 3 metres. In the first few months or years after drainage, the peat surface will change rapidly through a combination of peat oxidation and soil compression. In this transition phase, emissions are far higher than the default emission factors the IPCC provides for the later more stable phase (Hooijer *et al.*, 2012). Once a new equilibrium is found, emissions stabilize, with similar subsidence and emission values commonly reported 5 to 25 years after drainage. Longer records are scarce for most regions. In peat with high mineral content, carbon loss through oxidation may, over decades, create a mature topsoil layer with decreased organic content. This process is accompanied by decreased potential for emissions and subsidence. However, the peat in many types of peatland, including temperate *Sphagnum* bogs and tropical forested peat domes, usually has an organic content above 95 percent and often above 99 percent. In such peatlands, oxidation will not produce a ‘matured’ topsoil with higher mineral content and there will be no perceptible slowdown in carbon emissions and subsidence beyond the first years after drainage. Oxidation and subsidence will proceed at a more or less stable rate until the peat surface is at or close to the local drainage level. At that point, the increased frequency and duration of flooding will slow down the processes of biological degradation.

**GHG emission factors**

The latest insights with respect to emissions from drained peatlands are reflected in the 2013 update of the IPCC Guidelines (Table 6.1; IPCC, 2013). The IPCC’s emission factor values exclude the $CO_2$ emissions in the first 5 years after drainage (which are higher), as well as emissions from fires and the potential emissions from POC flushed into aquatic ecosystems.

**Table 6.1** Emission factors from drained peatlands (IPCC, 2013).*

| | | | *Unit** | Forest | Shrubland | Grassland | Rice | Cropland | Plantation | General |
|---|---|---|---|---|---|---|---|---|---|---|
| Boreal | $CO_2$ | | 1 | 0.25—0.93 | — | 5.7 | — | 7.9 | — | — |
| | DOC | | 1 | — | — | — | — | — | — | 0.12 |
| | $CH_4$ | land | 2 | 2—7 | — | 1.4 | — | 0 | — | — |
| | $CH_4$ | ditch | 2 | 217 | — | 527—1 165 | — | — | — | — |
| | $N_2O$ | | 2 | 0.22—3.2 | — | 9.5 | — | 13 | — | — |
| Temperate | $CO_2$ | | 1 | 2.6 | — | 5.3—6.1 | — | 7.9 | — | — |
| | DOC | | 1 | — | — | — | — | — | — | 0.31 |
| | $CH_4$ | land | 2 | 2.5 | — | 1.6—39 | — | 0 | — | — |
| | $CH_4$ | ditch | 2 | 217 | — | 527—1 165 | — | — | — | — |
| | $N_2O$ | | 2 | 2.8 | — | 1.6—8.2 | — | 13 | — | — |
| Tropical | $CO_2$ | | 1 | 5.3 | 5.3 | 9.6 | 9.4 | 14 | 15 | — |
| | DOC | | 1 | — | — | — | — | — | — | 0.82 |
| | $CH_4$ | land | 2 | 4.9 | 4.9 | 7 | 143 | 7 | 2.7—26.2 | — |
| | $CH_4$ | ditch | 2 | — | — | — | — | — | — | 2259 |
| | $N_2O$ | | 2 | 2.4 | — | 5 | 0.4 | 5 | 1.2—3.3 | — |

* 1: t C $ha^{-1}$ $yr^{-1}$; 2: kg $ha^{-1}$ $yr^{-1}$

Field measurements indicate the clear influence of climate and temperature have on the rate of peatland $CO_2$ emissions. This is especially true for peatlands that have been well drained, where emissions are the highest. For instance, the IPCC's carbon emission factors for drained forest in boreal areas (0.25–0.93 tonnes of carbon per hectare a year) are about 10 times lower than those for drained forests in tropical areas (5.3 tonnes per hectare a year). Emission factors for drained forests in temperate areas are 2.5 tonnes per hectare a year or about half the amount for tropical areas. Likewise, carbon emission factors for croplands are about twice as high for tropical areas (14 tonnes per hectare a year) as they are for temperate areas (7.9 tonnes per hectare a year).[8]

In recent years, it has also become clear that drainage of peatlands not only produces high $CO_2$ emissions from the land surface, but also $CH_4$ emissions from ditches and canals, where plant materials and peat detritus flushed from the land accumulate and decompose under anaerobic conditions. For grasslands on peat soils in temperate climates, the IPCC 2013 Guidelines propose a 'ditch' $CH_4$ emission of 527–1 156 kilograms per hectare a year (Table 6.1), which translates to a $CO_2$-eq emission of 11–24 tonnes per hectare a year using a 100-year 'global warming potential' (GWP)[9] factor of 21.

The yearly ditch $CH_4$ emissions from tropical plantations were found to be even higher, at 2 259 kilograms (47 tonnes of $CO_2$-eq) per hectare. Such high ditch $CO_2$-eq emissions are of a similar magnitude to the actual known land $CO_2$ emissions from these areas. However, it has to be considered that these values are valid for the actual area occupied by the ditches. Hence, their impact on the overall emissions from one hectare of land is relatively small.

Drained peatlands can also be a net emitter of $N_2O$. This is an important GHG since it has a GWP of around 310 over a 100-year time horizon. While emissions of $N_2O$ from wet peat surfaces are usually

[8] Estimates are presented in units of carbon ($CO_2$-C).

[9] Editors' note: The GWP values (21 for $CH_4$ and 310 for $N_2O$) are those required for UNFCCC reporting (FCCC/SBSTA/2006/9) for both Annex I and non-Annex I parties, and are based on the IPCC Second Assessment Report. Starting in 2015, Annex I countries are required to use updated values from the IPCC Third Assessment Report (23 for $CH_4$ and 296 for $N_2O$). The most recent IPCC Fifth Assessment Report indicates GWP values of 34 for $CH_4$ and 298 for $N_2O$ with the inclusion of climate-carbon feedbacks. The values of the Fifth Assessment Report have not been adopted for UNFCCC reporting.

close to zero, those from drained peats can be significant. However in terms of $CO_2$ equivalents, they are much lower than $CO_2$ or $CH_4$ emissions. $N_2O$ emissions are a consequence of the mineralization of nitrogen compounds during peat decomposition and are further enhanced by applications of mineral and organic nitrogen fertilizers. The IPCC (2013) guidelines present $N_2O$ emission factors for cropland on drained peatland of 13 kilograms (4 tonnes of $CO_2$-eq) per hectare a year for the boreal and temperate zone, against 5 kilograms (1.5 tonnes of $CO_2$-eq) for the tropical zone. There are a limited number of studies of $N_2O$ emissions on tropical peatlands. This may explain why the tropical cropland emission factor value is two times lower than the boreal/temperate value even though it might be expected that higher temperatures would result in increased rates of peat mineralization and hence higher $N_2O$ emissions. In addition, no study to date of tropical $N_2O$ emissions has adequately captured the spatial and temporal variations that occur during and immediately following peatland drainage and fertilization. For this reason, the existing emission factors for tropical plantations may be considered conservative.

**Spatial distribution of emissions**

When quantifying emissions from drained peatlands, it should be considered that the depth of the water table in some situations (e.g. where drainage ditches and canals are far apart) will not be uniform, but will depend on the distance from ditch or canal. Carbon emissions can, as a consequence, be highly variable over the land. This is particularly evident in areas where undrained peatland is located next to intensively drained croplands or plantations. In such situations, the drainage impact will extend into the supposedly undrained peatlands over distances of hundreds of metres in the short term and over several kilometres in the longer term, as the effect of subsidence on hydrology progresses over the years. It is necessary to account for this enduring long-distance effect when accounting for carbon emissions.

**Global impact of peatland emissions**

As conversion rates and unit emissions per hectare are so high, the significance of emissions from the 25 million hectares of tropical peatlands in Southeast Asia has been much publicized in recent years. Regional emissions from peat decomposition more than 5 years after drainage were found to amount to 355–855 tonnes per year or the equivalent of between 1.3 and 3.1 percent of current global $CO_2$ emissions from the combustion of fossil fuel in 2006 (Hooijer *et al.*, 2010). These regional emissions are predicted to rapidly increase until at least 2020 (Miettinen *et al.* 2012). Emissions from fire (Page *et al.*, 2002; Hooijer *et al.*, 2010) and decomposition in the first years after drainage (Hooijer *et al.*, 2012) may be of similar magnitude.

## 6.2 Subsidence and flooding

A few years after initial drainage, subsidence in peatlands of low mineral content is almost entirely the result of peatland carbon loss, and therefore provides a particularly useful measure of $CO_2$ emissions. However, the more direct and practical consequences of subsidence are the changes it triggers in the area's hydrology. The first change is the increase in the slope of the peat surface, which increases the velocity of water flow into canals and (when soils are waterlogged) over the land surface. In the short term, this can reduce the likelihood of surface inundation by local rainfall. However, the longer-term change is that the peat surface may fall to river flood levels or (in coastal areas) within the reach of high tide levels, which increases the frequency of waterlogging and eventually allows river or seawater to flood the area.

Initial subsidence following drainage will be very rapid especially in tropical regions (Andriesse, 1988). In tropical areas, the surface typically falls by about 1 metre in the first year (DID, 2001) or 1.5 metres in the first 5 years (Hooijer *et al.*, 2012). In temperate areas, the subsidence rate is probably similar. Afterward, the rate of surface lowering, in situations where the water table reaches a level typical for agricultural production, varies from 1–2 centimetre per year in temperate climates to 3–5 centimetre per year in tropical areas. Higher rates occur when water tables are deeper (Stephens *et al.*, 1984; DID, 2001; Hooijer *et al.*, 2012; Couwenberg and Hooijer, 2013) and the peat has a lower mineral content (Deverel and Leighton, 2010). Over a period of 130 years, a total subsidence of over 3.9 metres was recorded in the fenlands of England (Hutchinson, 1980). In the Sacramento Delta (California, United

States) where the peat has high organic content, which reduces the subsidence rate, subsidence has nevertheless exceeded 5 metres in some areas over the course of a century (Deverel and Leighton, 2010). Other notable examples of subsidence include:

1. The Everglades in Florida, United States - around 2.5 metres in 60 years (Stephens and Speir, 1969);

2. Venice Lagoon in Italy - up to 2 metres in 70 years (Gambolati *et al.*, 2003);

3. Johor in Malaysia - around 2.8 metres in 28 years (Wösten *et al.*, 1997); and

4. Hula Valley in Israel - around 2 metres in 22 years (Levin and Shoham, 1984).

Whether subsidence results in flooding and the loss of agricultural production depends on local hydrological conditions and drainage options. The options for drainage are determined by the level of the peat surface and peat bottom relative to the local drainage base, which in turn is controlled by river and sea levels. In the Netherlands, the Sacramento Delta of the United States and the fens of eastern England, where the subsided areas are relatively small but densely populated and rainfall rates are relatively low, drainage by pumping has been possible and the peatlands remain productive even up to 6 metres below sea level. However, it would appear that in most areas where populations and investments are low and rainfall rates high, such as the coastal peatlands in Southeast Asia, pumped drainage will not be cost-effective or technically feasible. In these areas, agriculture will probably end when gravity drainage becomes impossible.

Apart from flooding, carbon loss and subsidence, the draining of peatlands may also lead to production loss in areas where the underlying mineral deposits are unsuitable for agriculture. In the Everglades peatlands in Florida, it has long been known that agriculture will end when the limestone bedrock is exposed. This was predicted to happen in 2000 (Stephens and Speir, 1969) but has been delayed as new crops (mostly sugar cane) have allowed for higher water tables and lower subsidence rates. In Southeast Asia, many coastal peatlands are underlain by acid sulphate clay soils that are unsuitable for most crops (Andriesse, 1988).

## 6.3 Vegetation removal and deforestation

In ombrotrophic peatlands (boreal/temperate bogs and tropical peat swamp forests), the low availability of nutrients imposes a natural limit on plant productivity. Under these conditions, the production of plant biomass is determined by the input of nutrients from atmospheric precipitation and by the decomposition and recycling of organic matter. In minerotrophic peatlands (fens in the boreal and temperate zones, open and forested swamps near rivers in the tropics), groundwater or surface runoff provide additional inputs of nutrients into the peatland ecosystem. In this situation, the vegetation may be more productive and diverse.

When only slightly disturbed, anthropogenic modification of peatlands may result in reduced biomass production, resulting in a decreased input of organic material to the peat carbon store. For example, in tropical peat swamp forests, selective logging removes some of the forest biomass but also opens up the forest canopy. This changes light and temperature conditions inside the forest, reduces the amount of tree litter and increases the temperature of the peat surface, all of which enhance microbial oxidation. Likewise, on some temperate peatlands (e.g. blanket bogs in the United Kingdom) and high altitude peatlands (e.g. marshlands in the eastern Tibetan Plateau), grazing by livestock may lead to changes in the composition of plant species. When livestock densities are high, patches of bare peat are created, which may lead to peat erosion. Extensive areas of fen peatland in Europe are managed as marginal grazing lands and for the production of hay. In the Himalayan region, including the Tibetan Plateau, peatlands are used as winter pastures by nomadic herders, and occasionally peat is collected for fuel as there is normally a lack of firewood in high-altitude pastoral areas. These practices may have led to shifts in both plant species and communities. Sometimes they may have increased local and adapted biodiversity and consequently raised the conservation value of the peatlands. Crop cultivation, forestry and peat extraction are more intensive forms of peatland use that disturb the ecosystem to much greater extent. These land uses not only lower the water table through drainage, which leads to increased $CO_2$ losses through peat oxidation, but also destroy peat-forming vegetation, eliminating the peatland's carbon sequestration mechanism. Vegetation disturbance and peat drainage also increase the risk of fire, which causes additional and rapid losses of carbon from the vegetation and the peat.

## 6.4 Main hazards related to the utilization and management of peatlands

### Fires


Fire-affected peat swamp forest, Central Kalimantan, Indonesia. Photo: Susan Page

The surface of an intact peatland is usually too wet to support a fire. However, if there is loss of moisture from the upper peat layer, both natural climatic variation and anthropogenic disturbances can increase the risk of fires. In a few peatland locations, fire is used as a prescribed management tool. For example, some blanket bogs in the United Kingdom are burnt to encourage the growth of heather (*Calluna vulgaris*) and increase the carrying capacity of the land for the red grouse (*Lagopus lagopus scoticus*), a popular game bird. But many fires on peatland are a direct, though often accidental consequence of land use change brought about by disturbances of the natural ecosystem. These disturbances greatly increase the risk of ignition and severe burning of both vegetation and peat. Some of the most extensive peatland fires of the last two decades have occurred on peatlands that were either being used for, or were in the process of being converted to, agricultural use. In 1997, forest and peatland fires were widespread across the Southeast Asian region. Around 24 000 square kilometres of peatland were burned, which released an estimated 0.81–0.95 gigatonnes of carbon emissions (Page *et al.*, 2002). These fires were the result of a prolonged period of drought driven by the El Niño Southern Oscillation. Critically, most fires were centred in disturbed peatlands where logging and drainage had heightened the fire risk. Despite the drought conditions, undisturbed peat swamp forest remained at low risk of fire. Several more peatland fires occurred in this region over the following years. They have now become a frequent feature of the dry season when weather conditions provide a suitable window for the use of fire as a cheap way of clearing the land. Land clearance is driven in part by recent rapid conversion of peatland to industrial-scale plantations for palm oil and pulpwood (Miettinen *et al.*, 2012).

The combination of drainage, drought and abandonment has also been responsible for extensive peatland fires at high latitudes. During the summer of 2010, an extreme period of high temperatures and low rainfall resulted in widespread and prolonged fires on drained peatlands in the Russian Federation. Peatlands that had been drained for agriculture and afforestation during the 1960s but that had been abandoned and were not supervised after the collapse of the Soviet Union became highly susceptible to ignition and severe burning during the extended drought. Wherever they occur, peat fires are very difficult to extinguish. They are often located at some distance from roads, making it difficult to apply conventional fire-fighting techniques. In addition, the nature of the smouldering combustion means that the fires can persist for weeks, or even months, burning slowly at and below the peat surface. Under very dry conditions, smouldering fires can continue to burn even following days of rain (Davies *et al.*, 2013) and under snow cover (Abel *et al.*, 2011). Smouldering fires will eventually be doused by a rising water table.

Peat fires are a particularly large source of carbon emissions to the atmosphere when compared to the combustion of above-ground vegetation. This is because peat fires can consume a considerable thickness of surface peat (a substantial amount of organic matter) and persist for long periods of time (weeks to months). The amount of organic matter that burns during a peatland fire, and hence the scale of GHG emissions, are determined by the extent of the fire and the depth of the burn. Both of these determining factors are strongly affected by soil water content, which is in turn influenced by position of the water table. In simple terms, the lower the water table, the greater the volume of dry peat that is available for combustion. A further important consideration in terms of the type of emissions is whether the fire is a flaming surface fire or a smouldering fire, burning within the peat. Smouldering fires burn in moist peat with low oxygen availability. As a result, they have lower combustion efficiency and, in addition to $CO_2$, are a significant source of the products of incomplete combustion, such as CO, $CH_4$ and a range of hydrocarbons. Some of these emissions pose significant regional health risks. Fires also produce large quantities of fine, unhealthy particulates ('black carbon') that also present serious health risks and contribute to climate warming. Tropical peat fires emit as much as 3 to 6 times more particulate matter than fires on grasslands, forests, plantations and other types of biomass (Heil *et al.*, 2006).

The scale of recent peatland fires, such as those in Indonesia and the Russian Federation, has contributed to global climate change. The 1997 Indonesian peat fires were a major contributor to the sharp increase in atmospheric $CO_2$ concentrations detected in 1998 when the yearly average from 1990-99 for carbon emissions (3.2 gigatonnes) rose to 6 gigatonnes (Page *et al.*, 2002). Peat fires greatly reduce the air quality throughout the entire region, causing health problems and destabilizing the economy. They can also spread black carbon over glaciers or permanent snow-covers on high mountains and accelerate melting. Communities near the fires face the possibility of losing lives, property and livelihoods.

**Salt water intrusion**

Peatland drainage changes the timing of peak flows and low flows in adjacent river systems. With ditches and canals in place, rainfall is quickly removed during wet periods when the peat is nearly saturated. This increases downstream peak floods and lowers water levels and discharges during subsequent dry periods. The reduction in low flows may be compensated to some extent by the further canal drainage in dry periods, which can ensure continued flow in canals and lead to even lower water levels in the peat. However, the net effect of drainage often appears to be that streams depending on peatland discharge have lower flows in periods of prolonged rainfall deficit. In coastal areas, this means that seawater can intrude further upstream and inland, affecting the ecosystem and the potential intake of fresh water.

**Drought**

The lowering of peatland water levels after drainage, which is intended mainly to reduce water levels during the wet season, also has a profound effect on dry season water levels. If water levels are lowered from the peat surface to 0.5 metres or more during the wet season, as is required for most types of agriculture on peatlands, they will frequently drop below 1 metre in the dry season when rainfall is insufficient to compensate for evaporative losses, especially where agriculture is rainwater fed. Depending on crop water requirements and the peat's moisture holding capacity, this can produce drought stress in crops. Other likely consequences of drainage-induced drought conditions, apart from increased fire risk, include reduced vegetation cover and increased risk of surface erosion, which accelerates the loss of peat volume and increases in carbon emissions.

**Off-site effect on the water quality**

As mentioned earlier, the drainage of peatlands has an impact on downstream aquatic ecosystems, including enhanced export of POC and DOC, changes to water colour, pH, nutrient and metal contents (Holden *et al.*, 2004). In parts of northern and central Europe and North America, peatlands are important water catchments. Over recent decades, however, increased concentrations of DOC in drainage waters have been observed, which may be due in part to peatland drainage (Worrall *et al.*, 2007). Increased DOC produces water that is unpleasant looking and poses a higher risk of contamination. DOC consumes the free residual chlorine used for water purification and can also result in the formation of potentially carcinogenic tri- halomethanes (Worrall *et al.*, 2003).

## Box 6.1 Methods to measure peatland GHG emissions and DOC loss.

*Armine Avagyan*, *Aljosja Hooijer, Lars Kutzbach, Susan Page* and *Benjamin R. K. Runkle* (in alphabetical order).

GHG exchanges between the land surface and atmosphere can be quantified using a variety of methods. The choice of method used often depends on local topographic features, the resources available and specific research questions. In the scientific community the three most common methods are: the subsidence method, the use of closed chambers and the eddy covariance technique. Regardless of the method used, two years of coverage is often considered a minimum for thorough research.

**Subsidence method**: The subsidence method works on longer time scales (annual or longer) and measures the loss in peat elevation from peat consolidation, peat compaction and peat oxidation to derive an estimate of landscape carbon losses. It also incorporates waterborne carbon losses as dissolved or particulate organic carbon in a way that the other methods do not.

Measurements of land subsidence have the benefit of:

- integrating the impact of variable conditions over long periods of time;
- covering total carbon loss through different processes;
- being relatively cost-effective and simple;
- allowing large numbers of locations to be monitored simultaneously; and
- being fully replicable and verifiable as the soil record remains in place (Hooijer *et al.*, 2012).

Peat subsidence at an oil palm plantation in Indonesia.
Photo: Jyrki Jauhiainen

Methods to distinguish between the contribution to subsidence resulting from carbon loss through oxidation as opposed to physical compaction have been demonstrated in many studies including Stephens and Speir (1969); Wösten *et al.* (1997); Deverel and Leighton (2010); Couwenberg and Hooijer (2013).

Results have yielded values from 60 percent to over 90 percent for cumulative subsidence after drainage, including during the early stage when consolidation is dominant. In Europe, an oxidation percentage of 70 percent is usually accepted based on studies in the 1970s (Kasimir-Klemedtsson *et al.*, 1997). In the later stages after drainage, this percentage approaches 100 percent, especially in warm climates (van den Akker *et al.*, 2008; Leifeld *et al.*, 2011; Couwenberg and Hooijer, 2013). The disadvantages of the subsidence approach are that at least two years of measurement time are required. Longer records also are more representative in variable climates. In addition, the subsidence method does not differentiate between emission types (i.e. gaseous vs. aquatic exchanges). Measurements of subsidence can be done also with a laser distance meter, which consists of a laser and a reflected light detection system that records the ground surface level change.

**Chamber method**: The chamber method directly measures $CO_2$ and $CH_4$ by analysing the accumulation or depletion of gases within a chamber headspace over soil, vegetation or water surface. Different methods use in-line gas measurement systems or laboratory-based measurements of gas samples taken at the field. These methods require less time, but allow for only limited measurement numbers and locations. Improvements in the chamber method have created automated systems for gathering quasi-continuous measurements over long periods (years), reduced random sampling errors and allowed for investigations of changing ecological and


Chamber measurement at a peatland in Indonesia.
Photo: Jyrki Jauhiainen

climatic drivers of peatland GHG fluxes. The chamber method is particularly useful for identifying the role of microtopography, different vegetation communities and locally changing features (e.g. water level) in determining GHG exchanges. In heterogeneous landscapes, this method has revealed large spatial and temporal variability (e.g. Bubier *et al.*, 2003), resulting in potentially high uncertainty when scaling up GHG emissions (Page *et al.*, 2011a).

**Eddy covariance method**: The eddy covariance or 'flux tower' method is a micro-meteorological technique employed on a tower with instrumentation typically located above the vegetation canopy. This method determines the surface-atmosphere flux from source areas (hectares to square kilometres) by measuring the covariance between fluctuations in the gas's mixing ratio and the vertical wind velocity. Its measurements are most accurate with a flat, homogeneous topography and steady atmospheric conditions. In contrast to closed chambers, this method provides continuous, whole ecosystem gaseous flux measurements over relatively large areas. An increasing number of studies in northern peatlands have used this method, but there are few published eddy covariance studies addressing $CO_2$ balances from tropical peatlands (Hirano *et al.*, 2012).


Eddy covariance tower.
Photo: Armine Avagyan

The DOC content is determined by measuring the oxidation of organic matter to $CO_2$, which is generally accomplished using high-temperature combustion or persulfate oxidation. The spectrophotometric method is used as a complimentary method for determining DOC content. For estimating the total loss of DOC it is also necessary to measure the total discharge and define the catchment area.

**Cost implementation**: Chamber and eddy co-variance methods are relatively expensive for monitoring GHG fluxes outside of research projects. For practical purposes proxy methods based on factors such as land use type, water table depth, vegetation types, or subsidence rates are used to monitor, report and verify emissions. IPCC 2013 Guidelines provides emissions factors for estimating the GHG emissions and DOC losses from peatlands (IPCC, 2013).

# SECTION 2
## Improved management practices

# 7. Rewetting of drained peatlands

*Hans Joosten*

Most of the negative environmental impacts caused by peatland drainage can be reversed by restoring stable water tables around the land surface, a process known as rewetting.

There is no universal strategy for rewetting a drained peatland. There can be various causes for the drained conditions, and the rewetting options vary widely depending on climate, water availability and topography. Stable high water levels must be achieved by adequate hydrologic practices that include:

- decreasing water losses from the peatland;
- increasing water supply to the peatland; and
- enlarging water storage in the peatland.

In most cases, excessive water losses from installed surface or subsurface drainage structures are the main cause of excessively low water levels. Water losses can be decreased by:

- damming or infilling of drainage canals and ditches (e.g. with peat collected at site);
- raising overflow heights of weirs and sluices;
- establishing and allowing obstructions in water courses (trees, rocks, vegetation growth, beaver dams);
- removing subsurface drainage pipes by excavation or destruction;
- reducing evapotranspiration from tree growth in the peatland (only in originally treeless peatlands); and
- establishing hydrological buffer zones with higher water levels.

Dams have to be progressively built decending from higher to lower areas to maintain access for ongoing construction as the areas at the higher elevation become wet. Optimal times for access could include periods of high water (access by water), low water (access by land) or frost (increased soil carrying capacity). Choice of building material should be guided by suitability, availability, costs, loading capacities and the expected life span of the material. Local materials (peat, wood, wood chips, sand/loam) are generally cheaper to purchase and transport. The use of artificial materials (concrete, plastic or metal sheets) may be required in some cases.

Dams construction for rewetting. Photo: Zhang Xiaohong

Care has to be taken to allow outflow of surplus water. The constructions should be sufficiently stable to prevent failure even at peak discharge. In cases where there is surplus water, the constructions should disperse, not concentrate water flow in order to prevent peat erosion. It is important to remember that peat has the same bulk density as water.

Builders should consider safety regulations, take professional advice for design and ensure regular inspections and necessary management to prevent the collapse of dams.

In cases where substantial water supply of the peatland was originally provided by the surroundings, inflow can be increased by:

- decreasing groundwater extraction and/or increasing groundwater recharge in the catchment area (this can be done by reducing drainage, removing surface sealing, and converting the forest to less evaporating species);
- diverting water into the site;
- irrigating by pumping into the site; and
- perforating stagnating (secondarily humified and compacted) surface peat soil horizons to restore discharge of artesian groundwater.

Attention should be paid to the quality of the introduced water. Water rich in sulphates (e.g. some river water, sea water) aggravates peat oxidation and should be avoided.

Where peat extraction or soil degradation has led to the presence of compact top layers, the storage coefficient (porosity) of the peat is generally too low to maintain sufficiently high water levels during the dry season when there are high losses from evapotranspiration. In such cases, peatland internal storage can be increased by:

- installing bunds (elongated dams) to increase water storage over the peat surface;
- creating paddy field-like cascades to rewet sloping peatlands; and
- maintaining or creating hollows (e.g. dammed canals) to increase depression storage.

Flooding during the wet season should be deep enough to compensate for evapotranspiration losses during dry periods. To minimize wind and wave erosion, hollows and bunded areas should not be too large.

As it is unfeasible to sufficiently rewet single plots surrounded by fields that continue to be drained, rewetting of peat soils often requires investments throughout the entire hydrological unit (polder, catchment area). Rewetting may demand that hydrological restructuring, land re-allotment and consolidation be done at a scale similar to the often huge projects that drained the peatlands in the first place. As with drainage schemes, individual landholders and land users must consider the rewetting process as irreversible. Because of the important ecosystem services generated for a wide range of beneficiaries, it is reasonable to expect that peatland rewetting projects be supported by central planning and public financing.

## Box 7.1 The Bord na Mona Bog restoration programme

*Mark McCorry and Catherine Farrell*

Since its establishment in 1946, Bord na Móna (the Irish Peat Company) has acquired extensive areas of Irish peatlands to develop fuel, energy and horticultural growing media. Following an ecological appraisal of all Bord na Móna sites (2009–2012), several raised bogs that were partially drained in the 1980s were identified as having substantial ecological and conservation value and significant restoration potential. They now form the core of the Bord na Móna Raised Bog Restoration programme (2009-present), which is part of the company's Biodiversity Action Plan (2010–2015). The restoration involves rewetting peatlands by blocking drains with peat dams.

In 2009, restoration work began at Abbeyleix Bog in County Laois. The work was managed and co-funded by Bord na Móna and the National Parks and Wildlife Service. Initially drained in the 1980s, the margins of the 109-hectare bog had been cut for domestic use. Before the restoration, a comprehensive public consultation was carried out with local community and statutory consultees. The methodology used for the restoration was developed in the 1990s by the National Parks and Wildlife Service under the Dutch-Irish Restoration programme. A topographical survey was initially carried out to identify peat dam locations. This was followed by an extensive drain-blocking programme. Over a four-month period, a specially modified excavator installed over 3 500 dams (one for every 10 centimetre fall in height). The work raised water levels and rewetted the bog, which will spur the development of *Sphagnum*-rich plant communities and revitalize the peatland's habitat function.

Bord na Móna has since successfully used this methodology as part of the company's wider bog restoration programme at other sites, including Cuckoo Hill Bog in County Roscommon in 2011, Moyarwood Bog in County Galway in 2012 and Ballydangan Bog in County Roscommon (ongoing).

Over 500 hectares of raised bog have now been restored using this methodology. Bord na Móna will continue rewetting other sites in Galway and Roscommon Counties, with another 1 500 hectares targeted for restoration in the coming years. At such an early stage, it is difficult to make definitive conclusions about the impacts of this restoration, but in general, water levels have been responding quickly and are being maintained very close to the bog surface. Changes in habitat quality of these sites will be monitored to assess the success of the work in the short and long term. GHG fluxes on the restored bogs are also being monitored as part of an Environmental Protection Agency-funded network of projects to assess the potential offset of carbon achieved by rewetting the Bord na Móna bogs.

This restoration programme can provide significant ecosystem services, including maintaining carbon storage within these bogs and enhancing active peat-forming *Sphagnum*-rich vegetation. Rewetting within these sites will also help Ireland meet its biodiversity objectives, including its commitments to conserve raised bog habitats as agreed upon in the European Union Habitats Directive. One of these sites (Ballydangan) is already providing areas for the conservation of species of particular interest, such as the Red Grouse (*Lagopus lagopus*).

# 8. Croplands and paludicultures

Hans Joosten

Drained peatlands are primarily found in densely populated areas of temperate zones and in the tropics and the subtropics where the climate is favourable for agriculture. They are also concentrated in the boreal zone of Scandinavia and the Russian Federation, where extensive peatland areas have been drained for forestry.

The fact that mainstream western agriculture originated in the 'fertile crescent' of the Middle East is the root cause of drained peatland agriculture. In the ancient cradle of arable farming, farmers the domesticated dryland plants that now constitute our major cereal, legume and fibre crops. This 'semi-desert' agriculture firmly established the idea that productive land must be dry and soils must be continuously tilled. This paradigm was also applied to wet, organic soils, and consequently, the intensive use of peatlands has always been associated with drainage. Because of this, African desert plants, such as Aloe vera, are cultivated on deeply drained peat in Indonesia; arid South American maize is grown on deeply drained peat in Germany; and strongly water-demanding East Asian sugar cane is planted on deeply drained peat in Florida, in the United States.

It is urgent that new techniques be developed that combine the (re-) development of the productive use of wet peatlands with the restoration and maintenance of the ecosystem services these areas provide. A motto that needs to be followed is: 'If you need to use peatlands, use them wet!' The wet alternative to drainage-based agriculture and forestry on peatlands is called 'paludiculture' (from Latin 'palus' for 'swamp').

Paludiculture species: *Sphangum* spp.
Photo: Anja Prager

In contrast to conventional agriculture, paludicultures produce biomass from wet and rewetted peatlands under conditions that maintain the peat body, may facilitate peat accumulation and maintain natural peatland ecosystem services. Paludiculture makes use of any biomass from wet and rewetted peatlands by harvesting spontaneous vegetation on natural sites or artificially establishing crops on rewetted sites. Besides producing traditional agricultural products such as food, feed, fibre and fuel, the biomass can be used as a raw material for industrial biochemistry, for producing high-quality liquid or gaseous biofuels and for other purposes, such the extraction and synthesising of pharmaceuticals and cosmetics (see Box 8.1 and Box 8.2).

Paludicultures can also deliver substantial co-benefits by preserving and sequestering carbon, supporting climate change mitigation and adaptation activities, regulating water dynamics (flood control) and water quality (purification), and conserving and restoring peatlands' typical flora and fauna.

Rewetting substantially reduces GHG emissions from peat oxidation. Emissions are further reduced when the biomass replaces fossil raw materials and fossil fuels. For example, common reed has a conservative annual yield of 8 tonnes dry weight per hectare and a heating value of 17.5 millijoules per kilogram of dry weight. The amount of common reed harvested from one hectare of land and used for heat and power cogeneration could replace fossil fuels that would otherwise emit 10 tonnes of $CO_2$-eq. With emissions from handling (mowing, transport, storage, delivery and operation of the plant) amounting to 2 tonnes of $CO_2$-eq per hectare per year, the emissions reduction from rewetting (15 tonnes of $CO_2$-eq per hectare per year) and replacement of fossil fuel (10 tonnes of $CO_2$-eq per hectare per year) adds up to about 23 tonnes of $CO_2$-eq per hectare per year.

## Box 8.1 Paludiculture plants for the temperate and boreal zones of the northern hemisphere

*Susanne Abel*

For temperate and boreal zones, the Database of Potential Paludiculture Plants contains 473 entries: 62 trees, 73 shrubs, 235 herbs, 85 graminoids, 13 ferns and one moss genus. Around 80 of these species are promising for commercial paludiculture. They can be used in a variety of ways, including medicine, fuel, food and fodder. Listed below are five important examples.

**Common reed** (*Phragmites australis*): The common reed is highly productive and, under wet conditions, an important peat-forming species. In several countries, including Germany, Netherlands, Poland and the United Kingdom, reed has been traditionally used for roof thatching and is a good construction material. In China, reed is harvested for large-scale paper production. Reed biomass can be used directly as a fuel or converted to biogas. Pellets for direct combustion can be produced for more convenient handling and reduced transport costs. The calorific value of *Phragmites* (17.5 millijoules per kilogram of dry mass) is only marginally less than that of wood (18.5 millijoules per kilogram of dry mass). Other promising plant species for bioenergy production in paludiculture include *Arundo donax*, *Carex spp*. and *Kosteletzkya pentacarpos*.

**Cattails** (*Typha spp.*): *Typha angustifolia*, *Typha latifolia* and *Typha x glauca* are highly productive on nutrient-rich sites. The long erected leaves contain a sponge-like tissue with very low thermal conductivity making the species well suited for the production of insulation materials and construction boards. The biomass, with its high energy content, is also a good source of energy. The cultivation of cattails has also been well studied from the perspective of wastewater treatment.

**Reed canary grass** (*Phalaris arundinacea*): In contrast to reed and cattails, which grow with water levels far above the surface, reed canary grass grows on moderately rewetted peatland. Winter and summer harvested biomass can be utilized for direct combustion (16.5 millijoules per kilogram of dry mass). Summer harvested biomass can also be used for biogas. Reed canary grass provides good fodder and can be used for pasture and for the production of silage and hay. In northern Europe, the species has been grown on moist cut-over peatlands for several decades with only slight peat oxidation. For reed canary grass cultivation, the water level should be raised to between 0 and 20 centimetres to stop or at least retard further peat oxidation. Wet peatlands are traditionally used as hay meadows or pastures. A good example is coastal transgression mires, where trampling by cattle can favour the formation of salt grassland peat. The following plant species have good fodder values and are adapted to high water tables: *Agrostis stolonifera, Calamagrostis canadensis, Echinochloa crus-galli, Glyceria maxim*a and *Lotus pedunculatus*.

**European black alder** (*Alnus glutinosa*): Black alder grows naturally on wet, nutrient-rich sites and is potentially peat forming. The highest peat accumulation rates are found in alder carrs (fen woodland or scrub that is typically dominated by alder or willow) with mean annual water tables of 0–20 centimetres below the surface. Rewetted fens with a top layer of degraded consolidated peat or cut-away peatlands are suitable for cultivating black alder. The high quality wood is valuable for turnery, carpentry, interior fittings and furniture. Because of its coppicing ability, short rotation alder also provides biomass for direct combustion (e.g. as woodchips).

A wide range of trees are adapted to wet conditions. Vast areas of the natural forested peatlands in North America are used for harvesting high quality timber species, such as *Acer rubrum, Chamaecyparis thyoides, Larix laricina, Nyssa aquatica, Picea mariana* and *Taxodium distichum*.

**Peat moss** (*Sphagnum spp*.): *Sphagnum* farming has successfully been tested on rewetted bogs that had been drained and used as grassland and on bogs after peat extraction. Species tested in northwest Germany include: *Sphagnum palustre, S. papillosum and S. fallax, S. palustre* seems to be the most promising as it establishes quickly, has high productivity and is suitable for providing a renewable alternative to fossil peat in horticultural growing media. Fresh peat moss biomass has similar properties as slightly humified *Sphagnum peat* ('moss peat') and allows for plant cultivation without a loss of quality.

In contrast, biogas from maize cultivated on drained peatlands causes eight times more GHG emissions per terajoule of energy produced than using fossil fuel. From a climate point of view, it is better to burn the biomass produced by paludiculture than to cultivate biofuels on drained peatland.

Combining bioenergy generation and the rewetting of drained peatlands makes paludiculture an extraordinarily cost-effective climate change mitigation option that can generate income both from carbon credits and from biomass production.

In the vast areas of drained and deeply subsided peatlands where flooding is a threat, paludiculture greatly reduces pumping costs. By providing sustainable income from abandoned or degraded sites, peatland rewetting and subsequent paludiculture can also generate unemployment and counteract social disintegration in rural areas.

Because the concept of paludiculture has (re-) emerged only recently, some of its various elements still have to be modified to permit large-scale implementation. Optimization is needed with respect to:

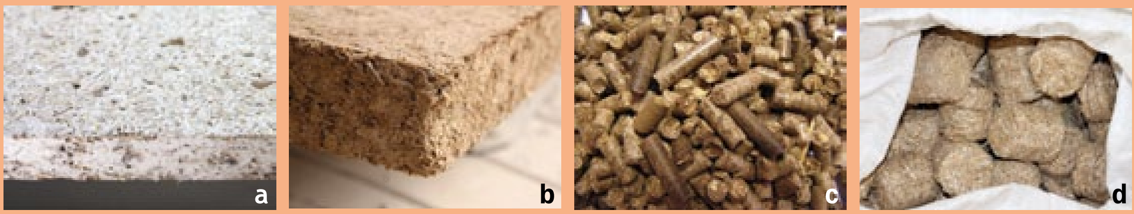
- the identification, selection and propagation of suitable (preferably perennial) species, provenances and cultivars;
- the technical challenges (low soil pressure machinery) and logistics for harvesting wet and inundated peatlands;
- the development of production lines adapted to new types of biomass;
- the improvement of agricultural consultation for site-adapted peatland use;
- the adaptation of laws, rules and regulations that can accommodate wet peatland agriculture;
- the removal of market distortions (e.g. when subsidies are given to support drainage-based peatland agriculture with no similar support provided for paludicultures); and
- the development of payment structures (payments for ecosystem services) that adequately consider external costs and benefits.

Further research and pilot implementation are necessary in temperate zones, where paludiculture is being developed on rewetted peatlands, but they are especially urgent in the tropics, where paludiculture must be established as an alternative for rapidly expanding drainage-based peatland agriculture and forestry.

## Box 8.2 Research and development for biomass use from rewetted peatlands - Vorpommern Paludiculture Initiative

*Christian Schröder*

Vorpommern Paludiculture Initiative research and development project sought to develop new processing lines based on wetland biomass. The project was supported by Germany's Federal Ministry of Education and Research, which provided €4 million in funding. Over the course of the project, which was carried out in Germany's Mecklenburg and Western Pomerania regions, scientists and small- and medium-sized companies worked together to implement alternative land-use practices on rewetted peatlands. In these regions, paludiculture can be carried out on recently drained peat soils only if the harvested biomass has some economic potential. This is a crucial point: if there is no demand for the biomass, there can be no large-scale implementation of paludiculture. For this reason, the project assessed the whole processing line, from harvesting to the utilization of the biomass. New products were made from reeds (*Phragmites australis*), sedges (*Carex* spp.) and canary grass reeds (*Phalaris arundinacea*), which are dominant in many places in Germany after rewetting.




Products developed from reed biomass (*Phragmites australis*). a: fire resistant panel, (photo: Christian Schröder); b: construction board with reed fibres and clay (photo: Nina Körner), c: pellets (photo: Tobias Dahms); d: briquets (photo: Nina Körner).

Fire resistant boards or insulation plasters partly made from reed fibers and excellent insulation material made from the tissue of cattail are just two examples of construction materials made of wetland biomass. The production of biofuels is another option on rewetted peatlands. Biogas can be produced from fresh or ensilaged biomass, while reed harvested in winter has much better combustion properties than straw. Making pellets or briquettes from wetland biomass offers another new opportunity for regional development. In addition, the meat of water buffaloes that have grazed on rewetted peatlands can also be profitable. The project also developed a design for new harvesting machinery for making biomass available from wet sites.

The project's results have shown that there are various options for utilizing wetland biomass from paludicultures. However, the problem for the interested companies is that the needed biomass is not yet available. To promote land-use change on peatlands, more incentives are needed that can enable farmers to adapt their management practices so that land degradation ceases and arable land is saved for future use. In this regard, payments for the ecosystem services provided by the wet use of peatlands may represent one possible way forward.

# 9. Restoring degraded pastures

*Xiaohong Zhang*

Over the centuries, vast areas of European peatlands have been damaged or lost because the water has been drained for pastures, sown grasslands, haymaking, crop cultivation or other purposes.

In Africa, where the pressure to increase grazing lands is growing, most peatlands are severely threatened by erosion. The destruction of peatlands is mainly caused by grazing and trampling. Gullies are easily formed in the mineral soil, creating a rapid flow of water and permanently draining the peatlands.

In Asian countries, mostly in central, northeast, and north Asia, the Tibetan Plateau and its adjoining high altitude areas in the Himalayas, most rangelands adjacent to wetlands are heavily used for grazing or farming to feed the increasing population. Local communities largely depend on natural resources for their subsistence, so most of the region's peatlands have been drained or reclaimed for crop production and livestock grazing.

In South America, especially in the Andes Mountains, some of the peatlands (locally referred to as páramo) have been converted to cropland and grazing lands. Due to the intensive grazing in South America and the resulting degradation of pastures, erosion is increasing and livestock productivity is declining.

Degraded pastures restoration. Photo: Zhang Xiaohong

In Asia, Africa and South America, traditional grazing has been practiced by different pastoral groups in remote areas where natural conditions, such as extreme cold or drought, do not allow for crop cultivation. Over the last decades, semi-settled and settled livestock production has progressively replaced migratory pastoralism. This shift presents new challenges to ecosystem management in peatlands and elsewhere. In some areas, landscape degradation has worsened as the land has become denuded of vegetation and can no longer be used for livestock grazing. Developing countries that largely depend on livestock for survival must take into account the trade-offs between biodiversity conservation and pastoral development. Only when the ecosystem services from peatlands are scientifically assessed and valued, and the benefits to local communities fully appreciated, can peatlands in pastoral areas be conserved and sustained for the future.

In recent years, efforts to enact legislation, build the knowledge base and raise public awareness about peatlands have signalled an increasing commitment to conserving peatlands. In Europe and the United States, peatland conservation programmes began in the 1960s and 1970s, but they have only recently started in Africa, Asia and South America where governments or NGOs have begun negotiating with landowners to buy or lease peatlands and surrounding pastures to protect or restore degraded lands.

Currently, extensive restoration and management practices have been tested and implemented to enhance ecosystem services provided by peatlands and improve the capacity of local communities to adapt to changing conditions, including climate change. The main restoration activities are:

- the blocking of canals or ditches using dams and weirs made with different materials to raise water levels;
- fencing pastures for rotational grazing;
- replantation or reseeding of forage species; and
- supplying water to overcome acute drought spells and sustain peat formation.

A case study in this guidebook shows the significance of high-altitude peatlands for providing services to local livelihoods and downstream watersheds (see Section 3: Restoration and sustainable grazing in China). However, these high-altitude peatlands are being degraded by continuous overgrazing. Gully erosion from peat loss speeds up the water discharge leading to more frequent downstream flooding and reduces the capacity of the peatlands to regulate water flow and storage.

Restoring peatlands could help conserve biodiversity, regenerate vegetation, replenish freshwater resources and reduce GHG emissions. However, due to the insufficient scientific research and long-term monitoring data, there are still knowledge gaps concerning the mechanisms and effects of GHG emission reduction and carbon sequestration during the restoration process.

## Box 9.1 Rewetting alkaline fens with support of sustainable grazing in Germany

*Holger Rößling, Michael Zauft and Pamela Hafner*

200 years ago, alkaline fens were quite common in northeastern Germany. Alkaline fens are mostly developed on spring and percolation mires and nurtured by mesotrophic, slightly alkaline ground water. They are characterized by a rich diversity of plant species, such as *Menyanthes trifoliata, Succisa pratensis, Dactylorhiza incarnata, Liparis loeselii* and *Epipactis palustris*, as well as brown mosses, such as *Drepanocladus vernicosus*, *Paludella squarrosa*, *Helodium blandowii* and *Scorpidium scorpidium*. The main threats to these sensitive habitats are fluctuating groundwater levels or water levels below the soil surface, which lead to increased eutrophication.

Akaline fens are among the rarest and most endangered habitats in Brandenburg. The changing profitability of agriculture has had a heavy impact on fen habitats. When profitable to do so, drainage ditches were used to convert the fens into arable land so they could provide feed and bedding for livestock. Over the last several decades, as agricultural use of the areas became unprofitable, the fens have been abandoned. However, the drainage ditches have remained active, causing degradation and mineralization of the peat soils. The increased availability of nutrients in combination with the lower water levels allowed reed, willow shrubbery and woods to overgrow the fens and dramatically alter the naturally open landscapes.

To counteract these threats, *Naturschutzfonds Brandenburg* is implementing the LIFE Nature Project Alkaline Fens in Brandenburg from 2010 to 2015. This project aims to remove nutrients and stabilize water levels closer to the surface level.

Alkaline fen in Brandenburg.
Photo: S. Luka

**Restoration**: In one of the project's first steps, biomass was removed, where possible, to reduce the amount of nutrients in the area. In some project areas, converted 'Pisten Bullies' were used to mow the wet and soft peaty soil and remove shrubs. In other areas, a different approach was taken. The project worked in collaboration with local farmers to establish pastures for Asian water buffalo and sheep. With proper grazing management, the livestock keep the growth of reed and other larger vegetation to a minimum.

To improve the hydrologic conditions of the fens, the entire drainage system had to be eliminated. On sloped fens, the ditches were filled completely. The filling material was obtained by removing the topsoil near the ditches. Normally 15 to 20 centimetres of the top peat layer is cut to obtain material to fill the ditches. This method creates bare soil locations after the degraded topsoil layer is removed. This soil is also an excellent sealing material.

To prevent the formation erosion channels, small dams are left along the contour lines within the peat cuts. These dams hold the water and provide starting points for the fen vegetation to settle into the new raw-soil locations.

**Cooperation with stakeholders**: Farmers and their families have lived and worked with moors and fens over centuries, mowing the difficult areas by hand. But after the formation of the German Democratic Republic (the former East Germany), family farms in Brandenburg were merged into large farming cooperatives in the 1960s. Farmers' interest in working on small and difficult fen areas declined. To gain support for conservation activities, the project team has taken an informal approach when dealing with local people. Many discussions are held around kitchen tables, explaining the importance and uniqueness of fens to owners and farmers.

Water buffaloes grazing at fen meadows.
Photo: Holger Rößling

**Result**: At present, restoration measures have been carried out in six project areas. One hundred and fifty hectares of reed were mowed, 27 kilometres of drainage ditches were filled, and peat was cut on an area of about 14 hectares. Water buffalos are grazing on more than 30 hectares. Monitoring shows that water levels in the rewetted areas have mostly risen to the ground surface and fluctuations have been reduced significantly. Two months after these restoration measures, the project identified fen species in some areas.

The results of the conservation measures carried out by this project offers hopeful signs that the initial moor restoration has been successful. Over the next several years and decades, it will become evident whether the extent of the damages caused by drainage is reversible or not. In some areas, land use will have to be continued after the rewetting measures. In each case, the experience gained is an asset for the further implementation of the LIFE Nature project and for similar future projects.

# 10. Forestry practices on peatlands

*Harri Vasander, Kari Minkkinen and Jyrki Jauhiainen*

In the tropics, the main peatland forestry practices include:

1. selective logging in natural tree stands without major disturbances to peat hydrology (removal of timber by temporary rails built on the forest floor);

2. selective logging that disturbs the hydrology (removal of harvested trees by canals dug into peat);

3. the establishment of plantation forestry by clearcutting the original forest and deep drainage of the soil for growing trees in monoculture by rotation cultivation; and

4. smallholder agroforestry on drained peat that may involve growing timber and fruit trees together with other crops, such as vegetables, rattan and rubber.

In selective logging, the original tree stand is allowed to regenerate naturally or seedling stock is enriched by planting. Reharvesting is done after several years. Plantation timber production, on the other hand, is typically based on *Acacia crassicarpa* pulp production using rotations of five to six years. Despite only a decade of experience with pulp wood production on peat, plantations currently represent the main forestry land use on tropical peat soils.

Of the abovementioned forestry approaches, selective logging without drainage has the least impact on the peat swamp forest because it has the lowest impact on hydrology. Selective logging allows for continued input of peat-forming litter to the wet peat. It also maintains diverse seed production. Under this approach, the gaps formed in the upmost canopy are not likely to significantly affect temperatures on the forest floor.

Harvesting six years old *Acacia crassicarpa* at an industrial pulp-wood plantation on about 9 m deep peat in Sumatra. Photo: Jyrki Jauhiainen

Increased drainage, which occurs when canals are dug for timber transport, increases the risk of carbon loss (Hirano *et al.*, 2007). In the conversion of natural peat swamp forest to pulpwood plantation, clearfelling causes immediate and permanent collapse of plant biomass, halting litter production. Drainage up to 0.6 metres or more in depth provides sufficient aeration for the roots of planted trees, but the increase in the depth of the water table also increases the volume of surface peat and litter that is exposed to continuous aerobic decomposition. Increased peat temperatures after the clearfellings carried out at the end of each rotation may further accelerate decomposition (Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012b).

Deep drainage also increases the risk of fires. Drained areas that have been logged or that have experienced one forest fire can produce a large load of dead and fallen timber that increases the risk of more fires. Secondary vegetation becomes dominated by highly flammable fern and scrub vegetation, which reduces the period between fire outbreaks (Page *et al.*, 2009).

Intensive forestry operations in tropical peat swamp forests always lead to a reduction in the capacity of the system to maintain the overall carbon store, particularly the carbon stored in peat. Carbon losses from peat are evident as the soil surface lowers in drained areas. The subsidence rate is positively related to increased depth of the water table below the peat surface (Hooijer *et al.*, 2012, Couwenberg and Hooijer, 2013). In the tropics, physical compaction and shrinkage comprise a substantial part of subsidence only during the first years after drainage. Up to 90 percent of long-term carbon losses measured from peat subsidence are due to oxidative decomposition (Hooijer *et al.*, 2012; Couwenberg and Hooijer, 2013). In addition, about twice as much POC and DOC leaches from drained peat swamp forest as it does from intact peat swamp forests (Moore *et al.*, 2013).

## Box 10.1 Paperbark tree in the Mekong Delta, Viet Nam

*Wim Giesen*

*Melaleuca cajuputi* (or paperbark) is found from Myanmar to northern Australia. It grows naturally in coastal freshwater swamps, both on mineral soils and on deep or moderately deep peat and at the landward end of mangroves. *Melaleuca* poles are used for construction (piles, scaffolding) and thicker trunks are used for timber, high quality fuel wood and charcoal. Etheric (cineol) oil is derived from its leaves, and its flowers produce quality honey. Fishing and harvesting of edible ferns (e.g. *Stenochlaena palustris*) is common in seasonally flooded areas and trees are often intercropped with sedges (e.g. *Lepironia articulata*) to provide material for weaving.

*Melaleuca* once extended over 40 000 hectares in Viet Nam's Mekong delta, both on mineral soil and deep peat. However, due to the use of napalm and agent orange during the war, and canal and road construction, by 1980 this area had declined to only a few thousand hectares. In the 1980s and 1990s, various government-sponsored *Melaleuca* rehabilitation projects were implemented, usually incorporating three elements: pole, honey and cineol oil production. Pre-feasibility studies indicated that a productive system could be developed, potentially with a very high internal rate of return of 56 percent. Based on a 9-year cycle and low inputs, annual returns of US$300 per hectare were expected. By 1986, thanks to government programmes, the area where *Melaleuca* was grown increased to 16 000 hectares. Overall, more than 50 000 hectares were re-established.

Transportation of harvested paperbark in Viet Nam.
Photo: Wim Giesen

The initial success, however, was short-lived. By the mid-1990s, fires had reduced the *Melaleuca* growing areas to only 3 000 hectares. Most sites have been abandoned or are operating at sub-optimal capacity, most likely due to a combination of harsh working conditions and poorer than expected results.

Key issues were:

- canals providing access caused peat to dry out and created a high fire risk;
- no thinning was carried out, making densities too high, which also increased fire risk;
- *Melaleuca* growing areas were converted to rice cultivation, as local farmers perceived that even low returns from rice on peat (less than one tonne per hectare per year) was preferable to the long-term benefits from *Melaleuca*;
- lack of fire management;
- theoretical maximum production was seldom reached as the management for better poles requires flooded conditions, which leads to lower oil production as the leaves do better in drier conditions.

Drained conditions and increased mineralization in peat substrate increase not only $CO_2$ emissions but $N_2O$ emissions as well. Natural peat swamp forests are not fertilized. There is no information on fertilization and its relation to $N_2O$ fluxes in tree plantations. Large drainage canal systems required for water management on plantations and water in the canals may be notable sources of $CH_4$ and $N_2O$ emission in tropical peatlands (Jauhiainen and Silvennoinen, 2012).

## 10.1 Northern peatlands

In most countries, drainage is a prerequisite for peatland forestry. It is needed to enhance the productivity of the tree stand and make forestry operations easier. Drainage also causes ecological changes in the peatland ecosystem, affecting its ability to function as a carbon sink and altering its GHG dynamics.

In the Nordic countries, peatland forestry is based on the use of natural tree stands with low management intensity. In temperate zone countries, such as Ireland and the United Kingdom, forestry is mainly based on plantations grown on originally treeless peatlands. This type of forestry involves a number of activities, including soil preparation and repeated fertilizations. Often these forests are former peat extraction areas that have been afforested. In both extensive and intensive peatland forestry, the stands are cut and regenerated, either by planting or through natural regeneration. In the Nordic countries, continuous cover forestry (in which no clearcutting takes place) has attracted more interest recently, but it remains marginal. The intensity of forestry operations is reflected in stand productivity, but unfortunately also in its negative environmental impacts.

The greatest ecological changes in peatlands are caused by enhanced drainage. Following drainage and the consequent drawdown of the water level, mature plant structures collapse and the peat surface subsides rapidly. Decomposition and oxidation of organic matter increases compared to natural mires. Consequently, $CO_2$ flux from peat to the atmosphere also increases (Silvola *et al.*, 1996).

Drainage starts a succession in peatland vegetation in which typical mire plant species are gradually replaced by forest flora. Despite the replacement of common mire-forming plants, perennial plant cover remains and continues to fulfil ecosystem functions. During the vegetation succession, primary production and biomass in the ecosystem increases, with the largest increases concentrated in enhanced tree growth (Laiho *et al.*, 2003). This succession also modifies the quality of litter. Litter dominated by moss and grass is replaced by coarser woody litter (needles, branches, cones, roots and trunks).

These changes affect the peatlands' ability to function as a carbon sink. The direction of the change depends on changes in the ratio between primary production and decomposition of organic matter. Typically, the carbon pool in the biomass increases faster than the carbon that may be lost from the soil (e.g. Laine *et al.*, 1996; Ojanen *et al.*, 2013). This means that drained peatland ecosystems are carbon sinks during the first tree stand rotation. However, since the carbon in harvested trees is eventually lost back into the atmosphere through the decomposition of wood products, only the changes in the soil carbon pool should be considered.

The majority of peatlands drained for forestry are fertile sites, where soil carbon loss is typical. In these sites, drainage is usually deep (up to 0.5–0.7 metres) as the sites are sloping, tree stand evapotranspiration is high and aeration is good. As a result, soil organic matter decomposition exceeds the production of litter. In contrast, in poor sites (originally ombrotropic sites with low amount of nutrients), litter production may be as high as or even higher than soil organic matter decomposition, and the sites remain carbon-neutral or carbon sinks (Minkkinen and Laine, 1998; Ojanen *et al.*, 2013). This surprising ability of drained poor sites to retain their function as a carbon sink is connected with low nutrient levels, which slow down bacterial activity. In addition, poor sites have even topography with low horizontal water movement, so water level drawdown can be kept shallow enough (0.1–0.3 metres) to restrain decomposition but high enough to increase litter production. In these conditions where drainage is shallow, the capillary rise of water to the peat surface is retained, as is the continuous cover of moss and shrub. At the same time, soil temperatures and pH decrease because of the shading and the nutrient uptake of the growing tree stand, which slows down the decomposition rate of soil organic matter.

The changes in net $CO_2$ exchange are not the only changes that affect the climate. After drainage, the emissions of $CH_4$ decrease (e.g. Ojanen *et al.*, 2010). Ditches, however, become large sources of $CH_4$ emissions, sometimes even counteracting the decreasing impact of drainage (Roulet and Moore, 1995; Minkkinen and Laine, 2006). Emissions of $N_2O$ may increase in the most fertile and well-drained sites (Martikainen *et al.*, 1993).

Less information is available from temperate forests. The general trend appears to be that after drainage there is a significant increase in carbon losses from the soil but significant increases in carbon sequestration in the biomass. Losses and gains are more or less balanced during stand growth and the first rotation (Meyer *et al.*, 2013). After that, soil carbon losses will dominate the long-term carbon balance. As these losses are very high in the temperate climate, the net effect is climate warming. This warming impact is even more pronounced because highly productive forestry sites use more intensive activities, such as fertilization and soil preparation.

The abovementioned predictions are valid as long as the first post-drainage tree stand is growing and binding carbon (rotation times cover several decades). After felling, carbon is liberated back into the atmosphere, first from decomposing slash, then from off-site biomass burning (side products are used for energy) and finally from wood products. Even if a new tree stand is established, it cannot decrease the atmospheric carbon stock more than the first generation did, unless the site's production capacity for some reason considerably increases.

## 10.2 Possibilities for responsible peatlands management

Climate change mitigation in peatland forestry is not straightforward. Forestry affects the environment in many different ways, depending on the type of forestry, the initial state of the forest and the climate. In general, high water tables are beneficial for maintaining the carbon stocks in peat. Overdrainage should always be avoided.

In the tropics, GHG emissions from peat could be reduced by permitting a higher water table. This could be achieved, for example, by finding plantation species that are more tolerant of higher water tables. In addition, improvements that would maintain fluctuations in the peat plantation's water table within a narrow range throughout the year are preferable to precautionary overdrainage to prevent floods during periods of high precipitation.

Similarly, in boreal forests, drainage should be avoided unless it is absolutely necessary for tree survival. Although deepening the water table slightly increases productivity, it is not necessary after the tree stand volume has exceeded 100–150 cubic metres per hectare (Sarkkola *et al.*, 2010). After this threshold has been reached, the tree stand itself, through efficient transpiration, maintains sufficient drainage.

Another mitigation option is to move towards continuous cover forestry and the avoidance of clear-cuts. This is a feasible option, but it is currently seldom used. In the tropics, this approach could involve selective logging without drainage. This would be beneficial as it would eliminate periods when litter production is severely diminished and carbon input to the system would be steadier than it is in rotation-based silviculture. Although the idea seems plausible, there is no empirical data to confirm its validity.

Restoration is an option for mitigating carbon loss, since it effectively reduces the oxidation of soil organic material and lowers $CO_2$ emissions. In peatlands, however, restoration has the downside of increasing $CH_4$ emissions in the short term (e.g. Tuittila *et al.*, 2000; Jauhiainen *et al.*, 2008). In temperate and tropical peatlands, where carbon losses after drainage are higher, the prospects of successful hydrology and vegetation restoration as a means of mitigating carbon loss are better. Successful restoration is also closely connected to successful fire control. There are only in a few cases (in the boreal region where the site is very infertile) where the best option would probably be to let these poor sites remain as they are. Tree stands will probably continue to grow, but at a gradually slower rate as they age and ditches deteriorate. Slowly the sites will rewet, and mire vegetation and functions will return.

In summary, the best mitigation option depends on the nature of the site. For most peatlands suitable for forestry, the abovementioned options, such as increasing the water table, moving towards continuous cover forestry and avoiding clear-cuts should be implemented. Particularly, in the tropics, where decomposition and recurring fires may deplete peat soils rapidly, responsible interventions over drained peatlands may significantly reduce the negative impacts of peatland forestry on climate.

## Box 10.2 Utilizing non-timber forest products to conserve Indonesia's peat swamp forests

*Wim Giesen*

In 2013, an assessment was carried out by the Netherlands Partners for Water Programme and the Indonesian National Planning Agency (Bappenas) on the opportunities for paludiculture in degraded Indonesian peatlands (Giesen, 2013). The assessment involved cross-referencing a peat swamp forest plant database with existing literature on uses. In Southeast Asian swamps, 1 467 plant species have been recorded, with 1 376 of these species found in lowland peat swamp forests. Of the lowland peat swamp species, 534 (39 percent) have a known use: 222 for timber, 221 for medicine, 165 for food (e.g. fruits, nuts, oils) and 165 for other uses (e.g. latex, fuel, dyes). Many species have multiple uses, and 81 non-timber forest product species have a 'major economic use'. It is interesting to note that only 8–10 percent of peat swamp forest plant species are restricted to this particular habitat. Many species of economic interest also occur in dryland areas and even village gardens. These include candlenut (*Aleurites moluccana*), rambutan (*Nephelium lappaceum*), mangosteen (*Garcinia mangostana*) and longan (*Dimocarpus longan*). An initial economic assessment has indicated that some indigenous peat swamp forest species, such as candlenut, illipe nut (various *Shorea* species) and swamp jelutung (*Dyera polyphylla*) are potentially competitive with oil palm and *Acacia* (Figure 10.1). In addition, swamp jelutung, which is used in the production of latex, is an attractive alternative for local communities, as return on labour is greater than for oil palm.

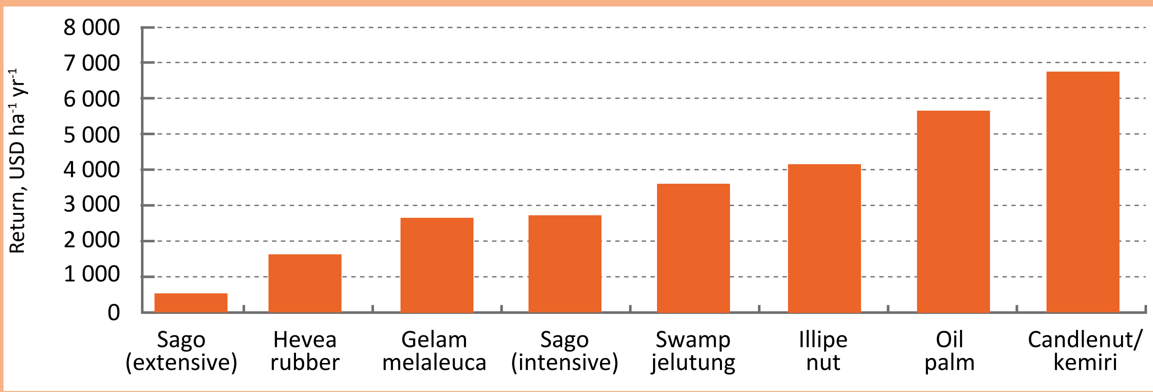



**Figure 10.1** Return of commodities on peat.

# 11. Plantations in Southeast Asia

*Marcel Silvius*

## 11.1 Plantations expansion and peatlands conversion

In recent decades, plantations have rapidly expanded on peatlands in Southeast Asia, especially in Malaysia and Indonesia. This expansion, especially the development and management of oil palm and pulp wood (*Acacia*) plantations, has had an impact on social conditions (e.g. land tenure, work conditions, human rights) and the environment (e.g. increased GHG emissions, greater frequency of fires and loss of biodiversity). Recently, the issue of peatland subsidence and flooding has become a key issue, one that is of prime importance to many local stakeholders. Moreover, the development of single species plantation landscapes has come at the expense of extensive multi-functional landscapes with a broad mix of productive and subsistence land uses and related cultures and extensive natural forests.

Oil palm plantation on peat more than 7 metres deep in Indonesia. Photo: Aljosja Hoojer

Tropical peat swamp forests in Indonesia and Malaysia cover about 24.8 million hectares and contain 77 percent of the entire peatlands carbon store (Page *et al.*, 2011; Hoojer *et al.*, 2012). Seven million hectares are in Sumatra, and almost 6 million hectares in Kalimantan. Malaysian peatlands cover almost 2.5 million hectares, with almost 1.7 million in the State of Sarawak, 0.64 million in Peninsular Malaysia and 1.1 million in Sabah (Wetlands International, 2010). These tropical wetlands have deep layers of peat that lay like domes on the alluvial coastal flood plains. Some inland peat domes started to develop around 13 000 years ago. Other domes nearer to the coast began forming about 6 000 years ago in conjunction with rising sea levels (Dommain *et al.*, 2011). The peat base of the majority of these domes, most of which are over 3 metres high, now lies at or below sea level. This has major ramifications for the long-term sustainability of drainage-dependent land use in these landscapes.

Southeast Asian peatlands store over 68 500 megatonnes of carbon (Page *et al.*, 2011). However, drainage for peatland-based plantations, drainage for supplying water to plantations on adjacent mineral soils and drainage for related infrastructure all cause the peat to oxidize and carbon to be released as $CO_2$ to the atmosphere. Annual $CO_2$ emissions from plantations on drained peatland range from 14 to 20 tonnes of carbon ($CO_2$-C) per hectare[10] (Couwenberg and Hooijer, 2013; Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012b; Couwenberg *et al.*, 2011; Melling *et al.*, 2005). In addition to these continuous emissions under drained conditions, high one-off carbon losses result from deforestation and fires. Since the 1980s, large-scale fires in Indonesia's peatlands have increased both in frequency and intensity and have caused serious damage (Page *et al.*, 2002; Hope *et al.*, 2005). The largest recorded peat fires took place in Indonesia during the El Niño dry season of 1997–1998. The fires lasted for several months and destroyed millions of hectares of peat swamp and caused peat layers between 0.2 and 1.5 metres in depth to be lost (Miettinen *et al.*, 2011; Rein, 2009; Hope *et al.*, 2005; Siegert *et al.*, 2001). Severe fires also broke out in 1982, 1991, and 1994, and later in 1998, 2002, 2004, 2006, 2010 and 2013. Studies have shown that the peat drainage needed for the development of oil palm and Acacia plantations contributed significantly to fire and smoke problems in Indonesia (e.g. Barber and Schweithelm, 2000; Suyanto *et al.*, 2000). Although burning for land clearing is forbidden by law in Indonesia, it is nevertheless a common practice (Langner *et al.*, 2007) because it is cheap and effective (Tomich *et al.*, 1998). By removing or disturbing the peat swamp forest, the risk of large-scale fires increases as these disturbances dry the peat and leave considerable flammable plant debris (Page *et al.*, 2002).

[10] Editors' note: IPCC Wetlands Supplement Guidelines reports emission factors ranging from 11 to 20 tonnes $CO_2$-C per hectare per year for drained plantations, and 1.5 for shallow drained sago palm plantations.

Since 2007, there have been protests over plantation development on peatlands. The expansion of these plantations has been partly triggered by the international demand for biofuels to reduce the use of fossil fuels as a climate change mitigation measure. The 2013 IPCC default emission factor for existing oil palm plantations on peat (11 tonnes of carbon per hectare per year) is regarded as very conservative or low (Wetlands International, private communication). Nevertheless, it still suggests that palm oil production on peat results in such high GHG emissions that on a per energy unit, palm oil biofuels produced on peatland pollute 2 to 4 times more than energy derived from burning fossil fuel. This clearly has a pronounced implications for any evaluation of the merits of the use of palm oil as biofuel in terms of climate change mitigation, especially in Indonesia and Malaysia, where a significant portion of all palm oil is currently produced on peatlands (22 percent and 13 percent in Indonesia and Malaysia, respectively) (Gunarso *et al.*, 2013). Serious concerns have been expressed in some major palm oil importing countries (European Union, United States of America) and led to consumer demand to reduce the use of palm oil in both the bioenergy and food sectors.

In conjunction with GHG emissions, peatland drainage leads to land subsidence. Soil subsidence is caused by several processes: consolidation, compaction and oxidation. These processes continue until the carbon store is totally depleted or until the drainage limit is reached. For many Southeast Asian peatlands these limits may be reached within 50 years and for most within 100 years. Even though the consequences of subsidence can be expected to be severe, especially for local stakeholders, the issue has hardly come up in policy and land use planning discussions.

Peat subsidence has occurred in many parts of the world, and while certain technological solutions have been applied to mitigate the impacts, the subsidence itself cannot be stopped under drained conditions. In the temperate zone, extensive and very costly dike and pump-operated drainage systems have been established to avoid flooding after peat soil subsidence. Under pump-operated drainage, subsidence has continued to such an extent that a country like the Netherlands is now 30 percent under sea level, with some areas and cities lying as low as 8 meters below the sea. In the wet tropics, pump-operated drainage has proven to be impossible and not cost-effective (e.g. Alabio polder, South Kalimantan) because the precipitation is much greater and the water loads and fluxes much higher. In addition, the affected areas will be much larger and require tens of thousands of kilometres of costly dikes and an enormous (if not impossible) pumping and power capacity.

Huge profits can be made in some plantation industries. For this reason, there appears to be a reluctance to acknowledge the issue of subsidence, as the consequences of addressing the problem (removing drainage dependent plantations from peat and rewetting and restoring the eco-hydrology) will inevitably result in loss of capital, reduced productivity and the redirection of investments. It is therefore likely that under business-as-usual development and management, the vast coastal peatland areas of Southeast Asia will become increasingly prone to flooding and will end up being covered with large lakes or be inundated by the sea as the coastline retreats. A substantial area of land may be lost in some provinces, such as Riau (Sumatra) in Indonesia and the Malaysian State of Sarawak (Borneo).

## 11.2 Urgent need for conservation and responsible use of peatlands

Peat swamp forests have a high biodiversity and are very scenic. They have tremendous potential for tourist activities, such as jungle trekking and wildlife viewing. Along with widely recognized species such as the orangutan and tiger, there are many other less well known plant and animal species that live only in peat swamp forests. The value of this wetland habitat for biodiversity conservation has received relatively little scientific attention and is still poorly understood (Posa *et al.*, 2011, Dow and Silvius, 2014). This is especially true for freshwater species, such as fishes and Odonata[11] (Dow and Silvius, 2014). Destroying and fragmenting these habitats through deforestation and conversion to plantations causes tremendous and irreversible losses of plant and animal species. The need to conserve peat swamps forests in the Indo-Malayan region is clearly urgent. The biodiversity of both large mammals and other endemic plant and animal species must be included in in High Conservation Value Area assessments[12] when considering their value for biodiversity and nature conservation.

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[11] Odonata is an order of aquatic insects which consist of two main suborders: dragonflies and damselflies.

[12] High Conservation Value Area (HCVA) is a natural habitat which has outstanding significance or critical importance due to their high environmental, socioeconomic, biodiversity or landscape values.

Peat swamp forests provide a range of ecosystem services to surrounding lands and downstream areas. Of particular importance are the services related to the retention and supply of water. In Indonesia, peat swamp forests occupy a specific place in the lowland landscapes of Sumatra and Kalimantan. The forests create a mosaic of different vegetation types in mangroves, between old beach ridges and river levees, and at the interfaces with freshwater swamp forests. The key position occupied by peatlands has generally not been considered in land-use planning. Natural intact transitions between mangroves, freshwater swamp forests and peat swamps have become extremely rare. This is primarily because coastal alluvial areas have been prime targets of agricultural development, including coconut plantations. Drainage and irrigation systems for agriculture on mineral soils next to peat swamp areas often depend on the peat swamp forests for ensuring a continuous supply of freshwater for irrigation and to prevent saltwater intrusion. In areas with potential acid sulphate soils, this freshwater is even more important as it prevents soil oxidation and acidification (Silvius *et al.*, 2000). Disturbing the peatlands on the inland side of the peat domes has had similar effects. For instance, the drainage related to oil palm plantations in the upper catchment of the Berbak National Park has had significant effects on the hydrology within the park and in downstream agricultural areas (Wösten *et al.*, 2006; Silvius, 2005).

Peatlands are also drained for forestry, including widespread illegal logging activities. Small channels are dug in the peat soil to provide access for people and heavy logging equipment and for removing logs. These channels form extensive networks in most peat swamp areas in Indonesia and have a significant impact on drainage. Logging and deforestation is a first step in the process of converting land to agriculture. For the establishment of plantations larger drainage channels and networks are developed, which intensify the negative environmental impacts. The rate of deforestation of Indonesian peat swamp forests between 1985 and 2000 was almost double the rate in non-peatland areas (1.3 percent versus 0.7 percent). Between 2001 and 2005, the peat swamp deforestation rate in Borneo was 2.2 percent (Langner *et al.*, 2007). The deforestration rate in peat swamp forests in Sarawak was around 8 percent per year and was driven mainly by the conversion of forsest land to oil palm plantations (SarVision, 2011). Deforestation as a source of land for expansion of oil palm varied from 48 percent between 1990 and 2000 to about 20 percent between 2001 and 2005, and 36 percent between 2006 and 2010 (Gunarso *et al.*, 2013). In 2010, the total area of oil palm in Indonesia and Malaysia was reported at 7.7 million hectares (Miettinen *et al.*, 2012 a, b, c). For Indonesia and Malaysia together, the area of oil palm plantations on peat increased from 418 000 hectares (12 percent of total oil palm area) in 1990 to between 2.43 and 3.1 million hectares by 2010 (Gunarso *et al.*, 2013; Carlson *et al.*, 2012, 2013). The increase in Malaysia alone was about 0.8 million hectares, 37 percent of which was in Sarawak (Omar *et al.*, 2010; Miettinen *et al.*, 2012 a,b,c). Business-as-usual projections of future conversion rates, based on historical rates over the past two decades, indicate that 6–9 million hectares of peatland in insular Southeast Asia may be converted to plantations by the year 2020 (Miettinen *et al.*, 2012 a,b and c).

## 11.3 A paradigm shift in the use of peatlands

The increasing awareness on peatland issues has placed considerable pressure on plantations and plantation development in Southeast Asia. There have been strong calls for a paradigm shift from unsustainable land uses on peatlands to their conservation and sustainable use.

This has led to some significant changes in industry. For instance, in April 2013, the Roundtable for Sustainable Palm Oil (RSPO), an international association that promotes the growth and use of sustainable palm oil, adopted a new set of principles and criteria (RSPO, 2013a) that recognized the need for special measures for peatlands. The principles and criteria describes the steps, including a requirement to have plans in place to reduce pollution and emissions, that should be taken to address GHG emissions and other issues related to peat soils. The principles and criteria are linked to indicators requiring an assessment of all polluting activities, including the identification of GHG emissions. It is also required that plans be implemented to reduce or minimize emissions. These plans must have a monitoring system for pollutants and emissions from estate and mill operations. RSPO also has developed a tool, the PalmGHG tool, that enables growers to monitor and report their GHG emissions and identify and address their main sources of emissions. The PalmGHG tool also allows for comparisons to be made between companies.

The new RSPO principles and criteria also require that extensive planting on fragile soils, including peat, be avoided. 'Extensive' is identified in such a way that the total area of planting on fragile soil within a new development should not be greater than 100 hectares, and for smallholders (developments of 500 hectares or less) not more than 20 percent of the total area (RSPO, 2013b). Special consideration is given to existing plantations on peat soils, which are required to monitor and minimize soil subsidence. To determine the possible negative impacts and the long-term viability of the drainage needed for growing oil palm, drainability and environmental impact assessment are required before replanting on peat. RSPO provides guidance on optimal drainage depths for minimizing impacts. When drainability assessments indicate that continued use of a peatland area for oil palm cultivation will lead to flooding or saltwater intrusion within two crop cycles (or about 45 to 50 years), RSPO also provides support for developing plans for appropriate rehabilitation or alternative use of the peatlands. RSPO requires new plantation developments to be designed to minimize net GHG emissions, which involves estimating carbon stocks and major potential sources of emissions (such as peat soils).

Recently, major pulp companies on both the supply and demand sides have publicly announced new policies that exclude peatlands from further developments and from the supply chain. A crucial shortcoming in the RSPO system is the reluctance to set a clear threshold for maximum GHG emissions and the lack of a clear definition for high carbon areas. This shortcoming enables palm oil to be certified as sustainable even though it is grown on peat or at the expense of peat swamp forests.

A crucial question remains: what to do with existing plantations on peat? Even under best management practices, GHG emissions and land subsidence can only be slowed down; it cannot be stopped. While recent steps are encouraging, they may be too little and too late. Clear, time-bound strategies will be required to move the unsustainable drainage-dependent plantations off the peat and into degraded mineral soil areas. It is not realistic to assume, even with highest possible awareness and concern for the environment, that these plantations will be removed immediately. Effectuating change will require a long-term strategy that includes both negative and positive incentives from government and the marketplace. Recently some palm oil companies on both the supply and demand sides have established the Palm Oil Innovation Group. The Group has announced new policies that should phase out peatlands from the production and supply chain through 'Strategies to progressively restore critical peatland ecosystems, with a preference for replanting on mineral soils, including via 'land swaps'. Such phasing out will also require socially and economically viable alternative land uses to be explored and developed. In this light, the recent identification of options for paludiculture are promising. However, these new or under-developed paludiculture crops will require piloting to gain a better understanding of their technical and commercial potential. To avoid the disastrous business-as-usual scenarios while maintaining a healthy economy and reducing poverty, financial resources are urgently needed for these pilot programmes.

Given the current state of knowledge, a key priority is the conservation of remaining peat swamp forests, including forests that have been subject to selective and illegal logging and other types of degradation. Projects associated with reducing emissions from deforestation and forest degradation (REDD+) that are financed and stimulated through the emerging voluntary carbon market and the policies of the UNFCCC, may offer an additional source of income and attract foreign and national investors. Peat swamp forest habitats may be particularly attractive for REDD+ projects aimed at conservation, rewetting and restoration given the very high emission avoidance and emission reductions that can be achieved from maintaining the soil carbon store and conserving and sequestering carbon in the biomass. Also, the UNFCCC's Nationally Appropriate Mitigation Actions (NAMAs) process could become an important tool for fundraising and for the field implementation of new technologies and policies (see Box 11.1 for further details on NAMAs).

## Box 11.1 Nationally Appropriate Mitigation Actions for peatlands management

*Riccardo Biancalani*

Nationally Appropriate Mitigation Actions (NAMAs) are voluntary actions undertaken by countries to reduce GHG emissions or enhance carbon sinks in the context of national sustainable development. It is a broad concept, which includes many different types of actions, from general country-level policies to local actions implemented though projects. A NAMA can be generic or specific, and it can aim at achieving a defined mitigation goal or solely give general indications on mitigation objectives. Although a NAMA can be defined only on the basis of general actions and targets, a Monitoring, Reporting and Verification (MRV) process should always be forecast when planning a mitigation action (Sharma and Desgain, 2013).

While NAMAs can be formally defined at the project level, the concept behind NAMA is to move from a restricted, project-based scope to a broader perpective, where the impacts of the actions can be felt at the national level. The new Biennial Update Report (BUR) will be the mechanism where the NAMA and its impact should be reported. This implies that countries should prepare a baseline of emissions based on a country-wide inventory to be reported in the BUR. NAMAs need to have an MRV mechanism that can support the inclusion of their benefits in terms of emission reduction into the national reporting in the BUR. Consequently, the NAMAs should be constructed in such a way that their impact can be recorded at the national level, according to the appropriate tier level in any given country, so that they can be used by the country to demonstrate their achievements in reducing emissions according to their voluntary commitments. This is particularly important for NAMAs in the agricultural sector, given the higher uncertainty in emissions measurements compared to other sectors like energy or transport.

So far, there are relatively few NAMAs in the agricultural sector and none specifically for peatlands. This can be at least partially explained by the problem of uncertainty. Defining the impacts of a peatlands NAMA is more problematic than it is for actions in other sectors. The importance of peatlands emissions in some developing countries, particularly in Southeast Asia, calls for a change in this situation.

Since 2010, Indonesia has included sustainable peatlands management among the actions to be implemented in order to fulfill its voluntary commitment to reduce by 2020 its GHG emissions by 26 to 41 percent. However, to date, only a feasibility study on this subject has been prepared for a project-based approach targeting 10 000 hectares. Initiatives are in place to allow Indonesia to identify, prepare and implement a NAMA for peatland management at the national level. This initiative will benefit from synergies with the BUR preparation activity and will be based on three specific pillars:

- improved mapping of peatlands;
- an estimation of the relevant GHG emissions, including the definition of nationally based emission factors; and
- the identification and implementation of improved land management systems in the peatland areas, including GHG-neutral food systems.

This initiative, framed in the context of the REDD+ programme, will reduce the uncertainties described above and will lay the groundwork for the identification of the national baseline and reduction targets to be described and reported in the subsequent BURs.

# 12. Aquaculture and tropical peatland fishery

*Bambang Setiadi*

For many tribes in the tropics (e.g. the Kutai and Banjar tribes in East Kalimantan) fishing in peatland catchments is their main livelihood. They traditionally catch fish and reptiles, and collect fuel wood and grass in peatlands.

A study on the abundance and diversity of fish in acidic waters, common in peatlands indicates that aquatic biodiversity can be quite high (Nurdawati *et al.*, 2005). In the acidic rivers and lakes in Kalimantan and South Sumatra, around 60 species of fish have been found including: *Scleropages formosus, Puntius gemellus, Rasbora cephalataenia, Chitala lopis, Rasbora tornieri, Brevibora cheeya, Mystus singaringan, Oxygaster anomalura, Hemibagrus hoevenii, Ompok fumidus, Bagroides macropterus*.

Fishing in a peat swamp forest.
Photo: Bambang Setiadi

In January and February, the fish migrate into the waters in forest for mating and breeding. During this season fisherfolk have relatively little catch since most fish are in the shallow inland waters far inside the peat forest.

Since 1950, fishers in peat swamp forests have used a fishing method known as beje. Fishers using the beje method take advantage of fluctuations in the movement of water or overflow of river water during the rainy season from November to March to trap the fish in artificial ponds or special containers. The traps allow fish to breed in the pond. The fish are later harvested during the dry season when the water recedes from April to October. A schematic representation of the beje practice in peatlands is illustrated in Figure 12.1.

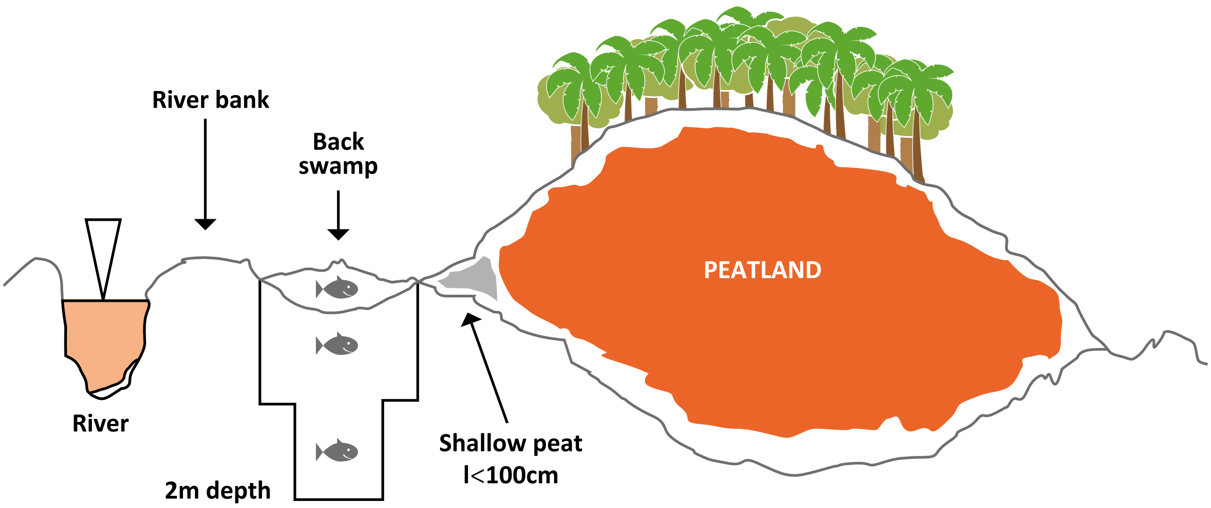



**Figure 12.1** A schematic representation of beje system in peatlands.

Trapping fish using the beje method requires no additional feed and makes use of natural processes. Therefore, the development of beje fishing in peatlands does not increase GHG emissions. The beje method also plays an indirect role in reducing carbon emissions by encouraging people to keep peatlands wet, which inhibits the spread of fires. In addition, the method may accelerate vegetation growth.

Rupawan (2004) conducted research in 40 beje sites, randomly chosen from 176 beje located in South Kalimantan. The study found that there were 5–12 types of fish species caught at the beje sites. The dominant species is marsh fish (black fish) from the family Anabantidae and Nandidae. Other types of fish caught are: Sepat siam (*Trichogaster pectoralis*), Sepat rawa (*Trichogaster trichopterus*), Gabus (*Channa striata*), Betok (*Anabas testudineus*), Tambakan (*Helostoma temminckii*), Baung (*Mystus nemurus*), Singgaringan (*Mystus nigriceps*), Lundu (*Mystus Gulio*), Lais lampok (*Cryptopterus limpok*), Lele (*Clarias spp.*), and Kakapar (*Peristolepis fasciatus*).

Drainage and disruptions in the peatlands' ecological functions have decreased the ability of communities in the region to obtain food using the beje method. Four years after the launch of the Mega Rice project (Box 12.1), a study was carried out to determine the effects of swamp land reclamation on the production and composition of fish species in beje fisheries in Kapuas. The results, based on data observed in 70 beje locations, showed that annual fish production in beje fisheries declined sharply from 500–2 000 kilograms per beje before the swamp land reclamation in 1996 to 5–150 kilograms per beje. The tremendous decline in production (94.6 percent) was mainly due to changes in water fluctuations caused by the construction of irrigation canals and damage to fish habitat.

As a result of the Mega Rice project, the composition of dominant fish species caught in beje changed from gabus (*Channa striata*) to pepuyu (*Anabas testudineus*). The size of the fish (*gabus* and *sepat*) also decreased. For gabus the size decreased from between 500–2 500 grams per fish to 50–200 grams and for sepat size decreased from 50–150 grams per fish to 25–75 grams.

## Box 12.1 A lesson learned: the Mega Rice Project

*Bambang Setiadi*

Between 1980 and 1990, Java, Indonesia's most fertile island, faced serious problems caused by high population growth that was reducing the availability of land for growing rice. During that 10-year period, agricultural land was converted to housing and roads at a rate of 100 000 hectares per year. The Indonesian government looked to other areas of the country to make up for the loss of agricultural land in Java. Central Kalimantan was selected as the new location for rice cultivation because of its low population density and vast areas of peatland, which was viewed as being idle and economically worthless. Peatland in Central Kalimantan has a depth between one metre to over 20 metres. In 1995, a project, popularly known as the one-million hectare Mega Rice Project, was launched to establish a major rice producing area over one million hectares. To provide freshwater for irrigating the planned rice fields, a canal was built that extended over 100 kilometres and connected the two major rivers, Sungai Barito and Kahayan.

The project encountered major problems as canal construction cut into the peat dome, which released water and dried the peat. During extreme dry weather conditions of the El Niño Southern Oscillation phenomenon in 1997, the area was burned and a large amount of carbon was released into the atmosphere from the peat and the biomass.

The Mega Rice project encountered three major obstacles: the low productivity of rice, environmental degradation and socio-economic and infrastructure problems (Setiadi, 2005, 2007). In addition, rice cultivation is a major source of GHG emissions. The focus should now be placed on the restoration of the former mega-project area and the rehabilitation of peat swamp forest within the new Sebangau National Park. This should be done by incorporating three key elements to ensure income generation by local people: fire prevention, profitable land use and water management.

In 2013, a two-level beje was built in Palangkaraya on a trial basis. In this improved design, the ponds are dug with two levels of depth, one metre on the periphery and two metres on the inside. The purpose of the two-tiered pond is to keep trapped fish during dry seasons when water level drops to one metre below the surface.

Communities in the area also make fish ponds that are generally dependent on rainwater. These ponds are built in peatlands and are used to cultivate food crops in combination with fish production (e.g. *Clarias* spp.). Unlike the beje method, in this system, the fish are fed and maintained.

Because it is highly adaptable and can live in waters with low levels of dissolved oxygen and low pH levels, *patin* or *pangas catfish* (*Pangasius pangasius*) is a fish species that has been selected to reinvigorate the aquaculture sector in Indonesia's peatlands (Zainuddin, 2009). This species is known to have a high content of omega-3 fatty acids, which are important for nutrition (Panagan *et al.*, 2011).

To cultivate the catfish, ponds are dug 2.5 metres deep into the peat until the clay layer is reached. The bottom of the pool is treated with lime to reduce the acidity and avoid fish diseases. Manure, urea and N-P-K (containing nitrogen, phosphorus and potassium) fertilizers are then added to promote plankton growth. For the past two years, the cultivation of tilapia fish, which has also shown commercial promise, has been developed in various peatland areas in Indonesia (Zainuddin, 2009). Further study is needed on these practices, as little is known yet on the GHG effect of aquaculture in peatland ponds.

Fishing in the rewetted peatlands to support local economies is a strategy that may potentially both sequester carbon and preserve existing carbon stores. Increasing peat surface water, maintaining peat forest density and fighting fires promptly are key activities for ensuring tha fishery practices in tropical peatlands that can maintain low carbon emission levels. The promotion of fisheries in rewetted peatlands holds great prospects for success since it does not involve starting an unfamiliar venture, but rather rejuvenating a long-standing activity that has been practiced in natural peat swamp landscapes. However, studies are needed to evaluate the impact of aquaculture practices on GHG balance and livelihoods of local communities. Peatland aquaculture has great potential, but aquaculture that requires external feeds may increase emissions. Appropriate management practices, including the re-utilization of pond sediments in agricultural production, minimal external feeding, and culture-based fisheries, may need to be adopted to realize peatland aquaculture's potential to improve livelihoods in climate-responsible ways.

# 13. Participatory and negotiated approach to responsible peatland management

*Jordan Treakle and Paolo Groppo*

Peatlands provide a wide variety of important resources and environmental services for local communities, including agricultural communities. Many farmers, particularly small-scale producers, are dependent on peatlands and their biodiversity for food security and livelihoods. Local producers also play a vital role in sustainably managing peatlands (Runsten and Tapio-Biström, 2011). All farmers, no matter the scale of their operations, are important stakeholders in global climate change mitigation efforts involving peatland conservation and rehabilitation (Runsten and Tapio-Biström, 2011; Joosten *et al.*, 2012).

As mentioned earlier, peatland ecosystems are used for agriculture, pastoralism, aquaculture and forestry. All of these land uses involve diverse and complex management and tenure systems (Lo and Parish, 2013). Along with environmental impacts, the degradation of peatlands, particularly the expansive clearing and draining of peatlands for large-scale agriculture, timber harvesting and mining, can have significant social consequences. When considering the steps for responsible and adaptive peatland management, it is essential to address the many social issues, such local communities' access to and use of natural resources. If unclear and overlapping natural resource management systems are not addressed through a fair and bottom-up approach, particularly in areas where customary tenure rights are in place, efforts to introduce more responsible resource governance strategies will be compromised (Runsten and Tapio-Biström, 2011). For instance, the likelihood of social conflict will increase when resource users do not feel their tenure rights are being recognized and respected, or when changes in resource governance do not accommodate the needs and interests of local stakeholders. Social conflicts can lead to the overexploitation of natural resources or prevent the effective implementation of climate-responsible strategies. Even when there is no conflict, unclear governance and tenure insecurity deters long-term natural resource management and planning, which can lead to the unsustainable use of resources and exacerbate peatland degradation. It is critical that responsible peatlands management be locally adaptive and:

- incorporate the interests of local stakeholders into natural resource governance strategies;
- promote the recognition and security of local stakeholders' tenure rights (whether formal or informal); and
- support capacity development of local communities so that changes in peatland management do not harm livelihoods and food security.

Integrating these activities into peatland conservation and climate-smart agriculture strategies can be both challenging and time-intensive, but it is critical for the long-term sustainability of any environmental conservation plan. For this reason, the framework of the Voluntary Guidelines of Tenure of Land, Fisheries and Forests in the context of National Food Security (FAO, 2012), which is based on decades of FAO community-orientated territorial development fieldwork, recommends a participatory and negotiated approach to addressing complex governance and tenure issues in adaptive peatlands management. Participatory Negotiated Territorial Development (PNTD) offers a field-tested methodology that focuses on creating an environment of open dialogue, fair negotiation and social legitimacy from the local to the national level when introducing and implementing climate-smart agriculture strategies (FAO, 2005).

The PNTD process has three core components:

- determining interests and acknowledging rights through participatory identification and mapping of stakeholders, tenure arrangements and natural resources;
- promoting efforts to secure natural resource tenure for stakeholders; and
- supporting sustainable natural resource governance by engaging local actors in fair negotiations when making decisions on natural resource management and use.

By investing time and resources in a participatory and negotiated approach to governance and tenure issues, local stakeholders become equal actors in decision-making processes regarding natural resource management. To be successful, this approach requires capacity development for local communities and farmers, sensitization and communication campaigns, and the building of long-term relationships based on trust and transparency between local and national stakeholders. This process seeks to avoid social conflicts that could threaten the sustainability of peatlands management and foster partnerships that allow the introduction of effective climate change mitigation strategies.

## 13.1 Participatory identification and mapping of stakeholders

The initial core component the PNTD approach is the analysis and mapping of the often complex systems that diverse stakeholders use in the management of natural resource. The stakeholders and the different management systems may be transitory, seasonal, culturally unique and contextually specific. This systematic diagnostic process involves assessing the interdependencies and power asymmetries among actors in the given area. It is a first step in ensuring that the views and interests of all stakeholders, particularly marginalized groups, can be represented, negotiated and incorporated in a peatland management strategy. Utilizing an inclusive process of engaging stakeholders and consulting them on natural resource use and their relationships with other actors is essential for adequately identifying and mapping the area. During this mapping process, the interests of the local actors should also be assessed to determine their needs, priorities, and constraints in relation to peatland resources. The information collection and mapping phase is important for arriving at an accurate analysis of the peatland territory and building a foundation of mutual partnership with local actors in the eventual design and implementation of more sustainable natural resource management strategies.

## 13.2 Promoting efforts to secure stakeholder natural resource tenure

After identifying all concerned stakeholders and mapping natural resource use in the peatland territory with geo-spatial tools, a process of consultation and research must take place to determine the status of the local actors' land tenure. Even in countries with well-established property rights regimes, this process is important for identifying the wide range of potential stakeholders, including owners and renters, absentee owners, foreign investors, and governments.

All of these stakeholders will need to be considered when implementing a responsible peatlands management strategy. The tenure research process should begin with consultations with the local communities and continue, if needed, into state land registries. Regardless of whether the land rights of the stakeholder communities are formally recognized or established through customary practice, the rights of these communities and farmers must be respected in the implementation of any responsible peatland management strategy. In contexts where tenure is unclear or insecure, steps should be taken to support the formal legal recognition of customary landholders through appropriate governmental mechanisms, if they are available. In some cases, this support for tenure security may include mapping and delimiting a community's land and natural resources. For more information on land delimitation see FAO's Participatory Land Delimitation publication (Tanner *et al.*, 2009). Supporting this process builds trust and transparency among local stakeholders and national experts. It also offers opportunities for more sustainable natural resource management strategies to be introduced and maintained over the long term. In addition, tenure security gives local communities incentives to invest more time and resource in long-term natural resource planning.

## 13.3 Supporting sustainable natural resource governance through negotiation

Perhaps the most important, as well as most time-intensive, part of the PNTD approach is the process of negotiation among the national experts who are helping to design and implement peatlands management strategies, the local stakeholders, and government officials on the roles and responsibilities of all actors in the management plan. The number of stakeholders, the extent of the territory and the interests and needs of the local actors will all have significant impact on the negotiation process. It is important to recognize that this process must go beyond simply seeking the consent of interested parties; it should go beyond a simple Free, Prior and Informed Consent (FPIC) approach.

To be legitimate, fair, and sustainable, all relevant actors (or their chosen representatives) must have their interests and land tenure arrangements recognized and have the opportunity to negotiate their interests in any potential agreement. It is highly recommended that a trained, experienced and impartial facilitation team that has been agreed upon by all stakeholders be used to coordinate the negotiation process, which may be very complex. FAO's PNTD offers more detailed technical information on this facilitation process (FAO, 2005).

Capacity development for local farmers and communities can play an important role in helping stakeholders (most importantly marginalized groups and small-scale producers) who may be dependent on peatland resources to adapt and adopt more sustainable practices for natural resource management and use. To be considered responsible, peatlands management strategies should be locally adaptive, include services to support farmers' transition to alternative production practices and provide fair incentives for sustainable resource conservation.

If consensus and agreement on new natural resource management strategies are reached by all actors during this phase of the PNTD process, then the management implementation moves forward as agreed upon by the stakeholders. All parties must agree to abide by the negotiated plan, with clear stipulations for when and how future negotiations, if needed, will take place. It is also critical that a clear agreement on the establishment and functions of procedures for resolving disputes, ensuring accountability and maintaining transparency be negotiated by all stakeholders.

## Box 13.1 Advances in peatlands management in Tierra del Fuego, Argentina

*Rodolfo Iturraspe* and *Adriana Urciuolo*

In several countries of the world, peatland use is commonly regulated by mining laws. However, in most cases, there are environmental regulations available for the rational management of mires based on a participatory planning process. The peatlands of Tierra del Fuego in Argentina are an example of such a case.

In the Argentinean island province of Tierra del Fuego (53°S–55°S), situated at the very southern tip of South America across the Magellan Strait, there is a wide variety of peatlands that cover around 2 700 square kilometers. These wetlands are an important component of the regional landscape, especially in the center and in the south of the island, where they interact with Nothofagus forest, glaciers, lakes, rivers and sea. The services that mires provide have been prioritized in most of the territory of Tierra del Fuego. These services include: the regulation of hydrology, the conservation of scenic landscapes, the protection of fresh water sources and the stabilization of the carbon cycle.

Low population density and the fact that cattle ranching is done on the grasslands to the north of the peatlands, means that there is relatively low pressure on the mires. However, over the last decades, peat extraction for horticultural substrates has increased markedly.

Mining law has been used as the unique source of regulation governing peatland use. A great part of accessible sphagnum peatlands were opened up for peat extraction, especially those located on public lands. In addition, speculative activities that sought to profit from renting or selling peat concessions prevailed over productive activities. Several peatlands were drained and abandoned without being exploited due to economic difficulties or poor organization.

In recent years, local authorities have recognized the environmental and economic problems associated to peat extraction and the urgency of improving regulations regarding the use of the mires. The first decision on this area was the provisional suspension of peat mining permissions, which was declared in 2008. Close to one hundred requests for permission were blocked. Meanwhile, an interdisciplinary commission for the integrated planning for the use of peatlands was established. The commission was coordinated be the Provincial Agency for Water Resources and included agents from the Provincial Management Agencies for Mining, Forests, Environment and Protected Areas.

After a participative planning process promoted in 2004 by the Provincial Agency for Water Resources, the 'Strategy and Action Plan for the wise use of the mires of Tierra del Fuego' was formulated in 2008 with the support of two non-governmental organization: Fundación Humedales-Wetlands International and Fundación Ambiente y Recursos Naturales. The main elements of the Action Plan are:

- Inventory;
- suspension of peat mining concessions practices for two years;
- integrated economical analysis;
- environmental planning;
- urgent protection of unique areas;
- regulation of mire use;
- integral application of norms;
- development of technical norms and best practices;
- capacity building;
- community participation; and
- education and research.

Natural peatland in Tierra del Fuego.
Photo: David Holl

A new policy for mire management is an essential point of the strategy. Under this policy, the mining regulation is made subordinate to the national and provincial environmental regulatory framework. The entire range of mire uses and the environmental services provided by mires are analyzed to determine the most rational use of peatlands. Peatlands are considered mines, but they are also wetlands and as such they are covered by the Ramsar Convention on Wetlands, which Argentina has signed.

To establish zoning regulations for peatland use, a new participatory process was undertaken to define the criteria for deciding what kind of mires should be protected and where. About 35 criteria were determined with the following factors taken into consideration:

- existing plans and development measures;
- social and economical issues;
- hydrological issues; and
- ecosystem issues.

The main guidelines for peatlands management were promulgated by the Secretariat of Sustainable Development and Environment in the Resolution SDSyA 401/2011. Based on criteria established through discussions and agreements in public and participative workshops, the Resolution determines three categories for peatland areas in Tierra del Fuego:

- A conservation zone that covers the main mire areas of Tierra del Fuego, where drainage and peat mining are not allowed because of the value of provided environmental ecosystems. In this zone tourism activities are allowed.
- Peatlands with potential future extractive use, but that are preserved for the next 30 years. Total peatland area in this category is 17 571 hectares.
- A 'sacrificed zone' where all new peat mining activities will be carried out under regulated conditions. This zone is located in the center of the Province, close to the town of Tolhuin, where many peatlands are already affected. At least 40 percent of peatlands must be preserved in this zone to ensure adequate hydrological regulation. Total peatland in this area is over 10 311 hectares.

Peat mining concessions must be approved by the interdisciplinary Mire Commission that verifies the correct application of the criteria for responsible use. The local Peat Producers Association participated in the discussion and accepted the conditions of the peatland zoning regulations. The new regulation also does not affect previous concessions.

Following the Action Plan in 2009, part of the Andorra Valley was declared a Ramsar Convention site. The Valley includes several kinds of peatlands, glaciers, rivers and lakes, all of which provide fresh water for the city of Ushuaia. The Andorra Valley is the world's southern most RAMSAR site.

Concentrating peat mining settlements in areas where the activity is already on-going and using the town of Tolhuin as the service center for productive activities, facilitated the organization of user cooperatives and the development of common infrastructure and services. They have also improved the access to, control over, and awareness of peatlands mine operators. One of the innovative concepts incorporated into the plan is the importance of defining the potential productive uses for areas that are under preservation for 30 years. This concept follows the generational equity principle and allows for the possibility of the more profitable use of the peat in the future.

In summary the new regulation contributes to the wise use of the peatlands without harming the livelihoods of existing peat extractors. It should be also kept in mind that the use of peatlands should not be oriented towards a single economic sector. This is especially true when the peatland use is not in line with the general interest of the local community or other economic sectors, such as tourism.

# SECTION 3
## Case studies of management practices

# 14. Smallholder sago farming on largely undrained peatland

Meranti Island district and Riau Province, Indonesia

Oka Karyanto

Sago plantation on largely undrained deep peatland in Indonesia.

## Summary

Sago (*Metroxylon sagu*) is an Indonesian indigenous plant species. Sago needs periodical inundation for better performance, so it can be planted on slightly drained or even undrained peatland. Sago flour is used for many food items and chemical products. About 150–250 kg of dry sago flour can be produced from one palm tree. Once sago seedlings are transplanted, they start to grow and produce clusters vegetatively. The clusters are then ready for consecutive, unlimited production cycles. Sago palms require only negligible maintenance, which makes sago plantations among the most productive systems that can be operated at almost no maintenance cost. Small-scale sago cultivation without drainiage results in a high sago self-propagation rate, short harvesting cycles and high starch content. This is because farmers use their traditional knowledge of the area to grow sago only on fertile peatland.

After smallholders farmers had established sago plantations on slightly drained peatlands, there was no significant increase in $CO_2$ emissions compared to secondary forest cover. However, young sago palms require an open canopy, which increases peat temperatures and could increase $CO_2$ emissions. Sago plantations produce much less biomass than secondary peat swamp forest.

This study indicates that even under minimal drainage and maintenance, sago grows well on deep peat. However, when grown on tidally-influenced deep peat, sago produces less starch and takes longer to mature (more than 12–17 years) compared to cultivation on shallow peat, where mature trunks are produced 8–12 years after planting. The poor growth of sago palms on deep peat is likely caused by the lack of nutrients in the peat strata rather than low pH. More research is needed to improve sago cultivation. Drainage for log transport should be avoided.

## I. Practice description

| | | |
|---|---|---|
| Area of the site | 30 000 ha | |
| Current land cover/use | Sago accompanied by secondary regrowth of former peat swamp forest species. | |
| Previous land cover/use | Mixed, tall peat swamp forest is dominant. Shallow peat near coastal areas has long been used for rubber plantations with limited drainage. | |
| Origin of intervention | Introduced from the Moluccas by local people. | |
| Types of intervention used in the area | ☐ Rewetting<br>☐ Drainage<br>☐ Cultivation of crops<br>☐ Grazing<br>☑ Forestry<br>☐ Aquaculture<br>☐ Fishery<br>☐ Other | |
| How long the practice has been applied? | Since 1900 | |
| Main purpose of the practice | Source of income. | |
| Level of technical knowledge | ☑ Low<br>☐ Medium<br>☐ High | |
| Water table depth from surface | 0 to -0.5 m | |
| Present active drainage system | Width of channels | No artificial channels |
| | Distance between channels | - |
| Subsidence | Before practice | - |
| | During practice | - |

## II. Implementation of activities, inputs and cost

| N | Establishment of activities | Input/ materials | Duration | Cost |
|---|---|---|---|---|
| 1 | Land clearing, preparation of planting hole, canal blocking (if required) | seedlings | 10 years from planting to continuous harvesting when grown on tidally-influenced peatland | Most of the cost relates to labour and the transport of seedlings |
| 2 | Weeding | | | Low |
| 3 | Pruning the dead fronds and rearing if there are too many young sago in a single cluster | | | Low |

## III. Environmental characteristics

| | | |
|---|---|---|
| **Climate** | ☑ **Tropical**<br>☐ **Temperate**<br>☐ **Boreal** | |
| **Average annual rainfall** | 2 500–3 500 mm | |
| **Altitude** | 3–20 m a.s.l. | |
| **Slope** | - | |
| **Peat depth (cm)** | ☐ **≤ 30**<br>☐ **30–50**<br>☐ **50–100**<br>☑ **100–300**<br>☑ **>300** | |
| **Peatland type based on the water source** | ☑ **Fen**<br>☐ **Bog**<br>☐ **Undefined** | |
| **Hydrologic network** | Connected to a network of small streams, rivers and a small lake on Padang Island. | |
| **Main vegetation species** | **Before practice** | Secondary peat swamp forests, with many *Calophyllum* spp., *Campnosperma auriculatum*. |
| | **During practice** | Monoculture of Sago with the regrowth of native peat swamp forest tree species (mainly *Macaranga* spp.). |
| **Water quality** | **Water pH** | 4–5 |
| | **Water turbidity** | - |
| | **Dissolved organic carbon content** | - |

## IV. Socio-economic dimension

| | |
|---|---|
| **Local stakeholders** | Most of the sago is owned by local farmers. There is, however, an increasing tendency for the sago to be owned by outside investors. |
| **Land tenure** | Planted in areas where customary rights apply and then legally incorporated into state forests. |
| **Land, water, and other natural resource access and use rights** | Most of this deep peatland has been given to an international paper pulp plantation company. |
| **Conflicts** | There have been unresolved land tenure conflicts between locals and government-supported, large-scale concessionaires. |
| **Conflict resolution mechanism** | Local NGOs, village groups and academicians have been trying to resolve the conflicts and promote this undrained peatland farming system. |
| **Legal framework** | The small-scale sago plantations are not protected by law. There is an ongoing intitiative to include this practice under the legal framework of a community plantation programme. |
| **Products derived from the peatland** | The sago flour has been mainly used for sago noodle production. It can be also used for bioethanol production and other produces (e.g. film, solvents). |
| **Market orientation** | Sago flour is a well-established nationally and internationally traded material. |

## V. Assessment of impacts on ecosystem services

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| | | |
|---|---|---|
| Provisioning services | Agricultural production | 7 |
| | Food security and nutrition | 6 |
| | Employment | 6 |
| | Income | 6 |
| | Non-timber forest products yield | 6 |
| | Livelihoods opportunities | 6 |
| | Resilience and capacity to adapt to climate change | 6 |
| Socio-cultural services | Level of conflicts | 1 |
| | Gender equality | 3 |
| | Learning and innovation | 6 |
| Regulating services | Waterborne carbon (DOC) loss | 2 |
| | Fire frequency | 1 |
| | Biodiversity | 3 |
| | Subsidence rate | 2 |
| Off-site benefits | Water quality | 6 |
| | Frequency of flooding | 2 |

## VI. Climate change mitigation potential

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| Impact | Rate | Estimate (t ha $^{-1}$ year$^{-1}$, $CO_2$-eq) | Remarks |
|---|---|---|---|
| Net GHG emission | 5 | - | Minor increase compared to undrained secondary peat swamp forest, but considerable decreases compared to open drained peatland. |
| $CH_4$ emission | - | - | - |
| $CO_2$ emission | 5 | - | - |
| $N_2O$ emission | - | 10 | Compared to 40–90 t ha$^{-1}$ year$^{-1}$ for the drained peatland. |
| Carbon sequestration/ storage abovegrounds | | - | - |

# 15. Illipe nut plantation on undrained peatland

West Kalimantan, Indonesia (00º 14’ 923”N, 109º 17’ 904”E)

Dwi T Adriyanti, Suryo Hardiwinoto, Wim Giesen, Peter van der Meer, Quirijn Coolen and Oka Karyanto


Line planting of illipe (*Shorea stenoptera*) near Segedong in West Kalimantan.

## Summary

Illipe species or *Shorea* spp. (local name: tengkawang) is a Southeast Asian climax forest tree. In term of GHG emissions, the impact of Illipe tree cultivation is neutral when compared to undrained secondary peat swamp forest. The Illipe nuts are an important non-timber forest product with a high commercial value. The fat derived from the nuts is used in chocolate and similar products. The fruiting, usually occurs every 3–4 years after a period of several rainless weeks. The tree also produces quality timber for plywood face-veneer.

The plantation described in this case study is located along the Segedong River on a coastal, shallow to moderately deep peatland. Illipe species were chosen for cultivation because they tolerate frequent inundatations and do not require drainage. Their rapid growth closed the forest canopy and reduced the high temperatures on previously sunlight-exposed peatland, which further reduced $CO_2$ emissions. After seven years, the plantation has started to fruit, but the harvest has not yet been assessed. The biomass accumulation makes the cultivation of this large climax tree species an efficient carbon sequestering system in tropical rain forests. The growth of the trees will continue to add to the positive carbon balance.

A strategy for restoring tropical peatforest based on illipe nut cultivation could target a number of objectives, including, carbon emissions reduction, biodiversity conservation and the provision of non-timber forest products for the food and cosmetics industry in cooperation with local community members. Further studies are needed to investigate the yield potential of Illipe trees grown on peatlands.

# I. Practice description

| | |
|---|---|
| **Area of the site** | 2 200 ha |
| **Current land cover/use** | Line-planted plantation of Illipe nut. |
| **Previous land cover/use** | Low-stocking timber forest. |
| **Origin of intervention** | Joint programme of GadjahMada University and Inhutani II. |
| **Types of intervention used in the area** | ☐ Rewetting<br>☐ Drainage<br>☐ Cultivation of crops<br>☐ Grazing<br>☑ Forestry<br>☐ Aquaculture<br>☐ Fishery<br>☑ Other non-timber forest products harvesting |
| **How long the practice has been applied?** | 11 years (started in 2003) |
| **Main purpose of the practice** | Production of on-timber forest products |
| **Level of technical knowledge** | ☐ Low<br>☐ Medium<br>☑ High |
| **Water table depth from surface** | 0 to -0.5 m |
| **Present active drainage system** | **Width of channels**: 1–5 m wide (only natural channels)<br>**Distance between channels**: - |
| **Subsidence** | **Before practice**: -<br>**During practice**: - |

# II. Implementation of activities, inputs and cost

| N | Establishment of activities | Input/materials | Duration | Cost |
|---|---|---|---|---|
| 1 | Establish nursery from fruits, wildlings or vegetative propagation | Semi-shaded nursery | 3 years | Low |
| 2 | Preparation of line planting (open 3–5 m gaps in the forest, prepare the planting hole and apply compost) | compost | - | Medium |
| 3 | Planting: spacing is 3 by 10 m with a north-south direction and lane width (line) is 3 m | - | - | Medium |
| 4 | Weeding up to 3 years after planting | - | - | Medium |

**Remarks:**

The annual diamater increment when line planted is about 1.5 cm. Total establishment cost for 3 years of maintenance is about USD 1000 per ha.

## III. Environmental characteristics

| | | |
|---|---|---|
| Climate | ☑ Tropical<br>☐ Temperate<br>☐ Boreal | |
| Average annual rainfall | 2 500–3 500 mm | |
| Altitude | 20 m a.s.l. | |
| Slope | - | |
| Peat depth (cm) | ☐ ≤ 30<br>☑ 30–50<br>☑ 50–100<br>☑ 100–300<br>☐ >300 | |
| Peatland type based on the water source | ☑ Fen<br>☐ Bog<br>☐ Undefined | |
| Hydrologic network | Connected by small streams to the Segedong River, and ultimately to the coast. | |
| Main vegetation species | Before practice | Secondary peatswamp forests with a wide range of species. |
| | During practice | Line planting of illipe nuts in secondary peatforest: *Shorea pinanga*, *S. macrocarpa*, *S. stenoptera*, *S. macrophylla*. |
| Water quality | Water pH | - |
| | Water turbidity | - |
| | Dissolved organic carbon content | - |

## IV. Socio-economic dimension

| | |
|---|---|
| Local stakeholders | The area is now under open access, but it is very remote and has remained intact from forest encroachment. |
| Land tenure | State owned forest, but its fruit and non-timber products may be harvested by the local community. |
| Land, water, and other natural resource access and use rights | The legal status of this particular area is a production state forest (hutanproduksi). |
| Conflicts | There is no documented conflict in this case study area as yet, but many illipe trees in West Kalimantan province and elsewhere have been lost due to illegal logging and deforestation. |
| Conflict resolution mechanism | Not available. |
| Legal framework | Cutting illipe trees is an illegal practice. |
| Products derived from the peatland | Illipe nut fat is marketed as a cocoa butter equivalent. |
| Market orientation | International markets. The principal foreign markets are in Japan, the Netherlands and the United Kingdom. |

## V. Assessment of impacts on ecosystem services

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| | | |
|---|---|---|
| Provisioning services | Agricultural production | 7 |
| | Food security and nutrition | 5 |
| | Employment | 6 |
| | Income | 6 |
| | Non-timber forest products yield | 6 |
| | Livelihoods opportunities | 6 |
| | Resilience and capacity to adapt to climate change | 6 |
| Socio-cultural services | Level of conflicts | 1 |
| | Gender equality | 3 |
| | Learning and innovation | 6 |
| Regulating services | Waterborne carbon (DOC) loss | 2 |
| | Fire frequency | 1 |
| | Biodiversity | 3 |
| | Subsidence rate | 2 |
| Off-site benefits | Water quality | 6 |
| | Frequency of flooding | 2 |

## VI. Climate change mitigation potential

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| Impact | Rate | Estimate (t ha $^{-1}$ year$^{-1}$, $CO_2$-eq) | Remarks |
|---|---|---|---|
| Net GHG emission | 1 | - | - |
| $CH_4$ emission | 4 | - | - |
| $CO_2$ emission | 6 | - | - |
| $N_2O$ emission | 4 | - | - |
| Carbon sequestration/ storage abovegrounds | 6 | - | Highly increases compared to low-stocking undrained peatforest |

# 16. Biomass from reeds as a substitute for peat in energy production

Sporovo region, Belarus (N 52.379330, E 25.136771)

Andreas Haberl and Wendelin Wichtmann


Biomass harvesting at wet peatlands in Belarus.

## Summary

More than half of Belarus' total peatland area (over 1.5 million ha) has been drained for agriculture, forestry and peat extraction. Out of this area, 122 200 ha are cutover peatlands that have been abandoned after peat excavation, and 36 800 ha are still being utilized. During the last few years, about 50 000 ha of drained peatlands have been rewetted. Another 500 000 ha are potentially available for hydrological restoration.

The sustainable cultivation of biomass from wet or rewetted peatlands (paludiculture) is being piloted at several sites in cooperation with local stakeholders (nature reserves, peat factories, collective farms, local energy suppliers). The regional production of biomass briquettes is opening up new income opportunities in rural areas. Peat factories in Belarus will be encouraged to re-orient their operations toward activities that use renewable biomass sustainably and replace land management practices that consume natural resources in ways that are not environmentally sound. Paludiculture on drained and degraded peatland sites that have been rewetted can improve habitats for threatened peatland species and reduce GHG emissions. Within the wetland-energy project, ecological and socio-economic monitoring activities been carries out during the creation of a fuel briquette production line that extends from the harvest of biomass to the finished briquettes. In the future, a gaps and needs analysis will de done with a view to scaling up the activities.

# I. Practice description

| | | |
|---|---|---|
| **Area of the site** | More than 1 000 ha | |
| **Current land cover/use** | Paludiculture cultivation | |
| **Previous land cover/use** | Near-natural very wet river valley peatlands with *Carex* spp. reedbeds. | |
| **Origin of intervention** | The project is an initiative of Michael Succow Foundation with the International Sacharov Environmental University, Minsk and the Institute for Nature Management of the Academy of Sciences, Belarus. | |
| **Types of intervention used in the area** | ☐ Rewetting<br>☐ Drainage<br>☐ Cultivation of crops<br>☐ Grazing<br>☑ Forestry<br>☐ Aquaculture<br>☐ Fishery<br>☑ Other | Paludiculture cultivation (reed) |
| **How long the practice has been applied?** | 2 years | |
| **Main purpose of the practice** | Replacement of fossil fuels and reduction of GHG emissions, income generation in rural areas. | |
| **Level of technical knowledge** | ☐ Low<br>☐ Medium<br>☑ High | |
| **Water table depth from surface** | Water saturated, with ranges -0.25 to 0.35 | |
| **Present active drainage system** | Width of channels | no artificial channels |
| | Distance between channels | - |
| **Subsidence** | Before practice | - |
| | During practice | 0 |

# II. Implementation of activities, inputs and cost

| N | Establishment of activities | Input/materials | Duration | Cost |
|---|---|---|---|---|
| 1 | Purchase and application of adapted harvesting machine and biomass-processing equipment | Special harvesting equipment for wet sites, pelleting/briquetting line for graminaceous biomass from wet peatlands | 0.5 year, partly ongoing activity | High (more than USD 50 000) |
| 2 | Optimization of biomass harvest machinery and production of biomass pellets | Local engineering with experience in developing special machinery for agriculture and scientists | 1.5 years | Medium |
| 3 | Market analysis and life cycle analysis of biomass fuel production | Literature and database as well as use of models | 0.5 year | Low |
| 4 | Dissemination of project; scaling up on the national level | Publications (e.g. in journals, brochures, booklets; participation in events. | 3 years | Low |

## III. Environmental characteristics

| | | |
|---|---|---|
| Climate | ☐ Tropical<br>☑ Temperate<br>☐ Boreal | |
| Average annual rainfall | ~600 mm | |
| Altitude | ~150 m a.s.l. | |
| Slope | 0 percent | |
| Peat depth (cm) | ☐ ≤ 30<br>☐ 30–50<br>☐ 50–100<br>☑ 100–300<br>☐ >300 | |
| Peatland type based on the water source | ☑ Fen<br>☐ Bog<br>☐ Undefined | |
| Hydrologic network | Yaselda River valley | |
| Main vegetation species | Before practice | Close to natural, wet *Carex* reedbeds with willow shrub encroachment |
| | During practice | Nearly natural, wet *Carex* reedbeds |
| Water quality | Water pH | 6.8–7.4 |
| | Water turbidity | - |
| | Dissolved organic carbon content | - |

## IV. Socio-economic dimension

| | |
|---|---|
| Local stakeholders | Nature conservation administration |
| Land tenure | State/government |
| Land, water, and other natural resource access and use rights | Public properties |
| Conflicts | Conflicts between different public property funds may arise (forestry/agriculture); after their abandonment, exploited peatlands fall under the forestry fund, which complicates putting the land to any use other than forestry. |
| Conflict resolution mechanism | The project will identify suitable mechanisms within the legal framework for changing land use from peat extraction to biomass production for energy. Activites that have been implemented as examples of best practices will be demonstrated. |
| Legal framework | No relevant legal obstacles have been noted. |
| Products derived from the peatland | Biofuels (energy briquettes and pellets from biomass) |
| Market orientation | Local and regional markets as well as export markets (replacement of peat briquettes) will be analysed. |

# V. Assessment of impacts on ecosystem services

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| | | |
|---|---|---|
| Provisioning services | Agricultural production | 5 |
| | Food security and nutrition | 4 |
| | Employment | 5 |
| | Income | 5 |
| | Non-timber forest products yield | 4 |
| | Livelihoods opportunities | 5 |
| | Resilience and capacity to adapt to climate change | 7 |
| Socio-cultural services | Level of conflicts | 4 |
| | Gender equality | 4 |
| | Learning and innovation | 6 |
| Regulating services | Waterborne carbon (DOC) loss | 2 |
| | Fire frequency | - |
| | Biodiversity | 6 |
| | Subsidence rate | 1 |
| Off-site benefits | Water quality | 6 |
| | Frequency of flooding | 3 |

# VI. Climate change mitigation potential

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| Impact | Rate | Estimate (t ha $^{-1}$ year$^{-1}$, $CO_2$-eq) | Remarks |
|---|---|---|---|
| Net GHG emission | 4 | - | - |
| $CH_4$ emission | 4 | - | - |
| $CO_2$ emission | 4 | - | - |
| $N_2O$ emission | 4 | - | - |
| Carbon sequestration/ storage abovegrounds | 4 | - | - |

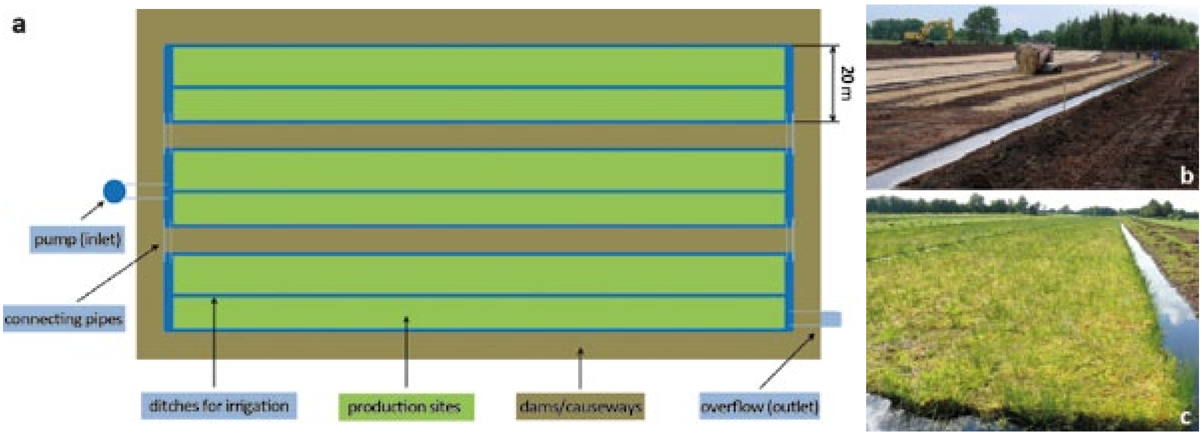
# VII. Additional information

Acknowledgements: Thanks to the EUAID External Actions programme of the European Union - DCI-ENV/2010/220-473 that supports the project. For more information see:
www.iseu.by/online/showpage.jsp?PageID=89222&resID=100229&lang=en&menuItemID=117646
www.succow-stiftung.de/wetland-energy-sustainable-use-of-wet-peatlands-in-belarus.html

# 17. *Sphagnum* farming for replacing peat in horticultural substrates

Rastede, Lower Saxony, Germany (53° 15.80′ N, 08°16′ E)

Sabine Wichmann, Greta Gaudig, Matthias Krebs, Hans Joosten, Kerstin Albrecht, Silke Kumar




*Sphagnum* farming: a: site with infrastructure for water management (pump, ditches, overflow) and dams used as causeways (maintenance, harvest, transport) (schematic representation: Sabine Wichmann) b: Preparation of a *Sphagnum* farming production site (photo: Sabine Wichmann); c: same site with established Sphagnum culture and irrigation system (photo: Sabine Wichmann).

## Summary

*Sphagnum* (peat moss) biomass provides a GHG-neutral alternative to fossil peat in professional horticulture. So far however, it has only been collected in the wild. Small-scale land-based *Sphagnum* farming is currently practiced on degraded peatlands. *Sphagnum* farming has also been tested on specially constructed floating mats that guarantee a constant water supply. This water-based cultivation allows bog waters to be used as reservoirs to irrigate cultivated areas in dry periods. It also creates additional *Sphagnum* farming areas. A mosaic of rewetted areas with land- and water-based cultivation may present the optimal combination for *Sphagnum* farming on degraded bogs. Experiments have also shown the suitability of growing media made of *Sphagnum* biomass for cultivating a wide variety of crops from seedling to saleable plant. *Sphagnum* biomass is also suitable for other uses, including gardening design, terrariums, sanitary items, insulation of buildings, water filtering and pharmaceuticals.

When *Sphagnum* is cultivated as a new agricultural crop on rewetted peatlands, the high and stable water levels greatly reduce GHG emissions and the subsidence of the formerly drained peat soil. Sphagnum farming combines long-term land productivity with climate change mitigation and sustainable employment in rural areas. It also provides habitats for rare bog species and preserves the land’s paleo-environmental archives.

This case study descibes a succesful small-scale test of a four-hectare, commercial *Sphagnum* farming pilot site established in the spring of 2011. The heavily degraded topsoil of a drained agricultural bog grassland was removed, a water management system installed and *Sphagnum* mosses were spread with a manure spreader mounted on a modified snow groomer. After a year and half, *Sphagnum palustre, S. papillosum and S. fallax* covered 95 percent of the area with an average lawn height of 8.3 cm (maximum 22.4 cm). These results demonstrate the feasibility of large-scale Sphagnum farming. Methods and machinery are now being developed to scale up cultivation.

# I. Practice description

| | | |
|---|---|---|
| **Area of the site** | 4 ha | |
| **Current land cover/use** | Wetland/*Sphagnum* farming (paludiculture) | |
| **Previous land cover/use** | Drained bog grassland used as pasture and meadow | |
| **Origin of intervention** | Applied research project; cooperation of universities and peat companies | |
| **Types of intervention used in the area** | ☑ Rewetting<br>☐ Drainage<br>☑ Cultivation of crops<br>☐ Grazing<br>☐ Forestry<br>☐ Aquaculture<br>☐ Fishery | |
| **How long the practice has been applied?** | Three years | |
| **Main purpose of the practice** | Production of a renewable, high-quality raw material for horticultural growing media; sustainable agriculture on wet peatland | |
| **Level of technical knowledge** | ☐ Low<br>☑ Medium<br>☐ High | |
| **Water table depth from surface** | From 0 to 0.1 m | |
| **Present active drainage system**[13] | Width of channels | 0.5 m |
| | Distance between channels | 10 m |
| **Subsidence** | Before practice | 2 cm year$^{-1}$ |
| | During practice | 0 cm year$^{-1}$ |

# II. Implementation of activities, inputs and cost

| N | Establishment of activities | Input /materials | Duration | Cost |
|---|---|---|---|---|
| 1 | Preparing production site | Excavator; removing degraded top soil, levelling of surface, infrastructure for water management. | Two months | High |
| 2 | Establishing moss lawn | Manure spreader mounted on an adapted snowgroomer. *Sphagnum* fragments, straw mulch. | One week | Medium |
| 3 | Rising and regulating water table | Elaborated water management using pumps, pipes, ditches for irrigation and outflows for water surplus. | Permanent | Medium |

**Remarks:**

High costs partly caused by the need to adopt an applied research project approach could be reduced for production systems.
Crucial point: availability of *Sphagnum* fragments and water table management.

[13] The channel system is established for irrigation which is ensured by constantly high water table (depth from surface 0 to 10 cm).

## III. Environmental characteristics

| | |
|---|---|
| Climate | ☐ Tropical<br>☑ Temperate<br>☐ Boreal |
| Average annual rainfall | 750 mm |
| Altitude | 0.5 m a.s.l. |
| Slope | 0 percent |
| Peat depth (cm) | ☐ ≤ 30<br>☐ 30–50<br>☐ 50–100<br>☑ 100–300<br>☐ >300 |
| Peatland type based on the water source | ☐ Fen<br>☑ Bog<br>☐ Undefined |
| Hydrologic network | Drainage water of the surrounding grassland is pumped to the North Sea (polder situation below sea level). |
| Main vegetation species | Before practice: *Alopecurus pratensis, Poa pratensis, Trifolium repens, Holcus lanatus, Ranunculus repens* |
| | During practice: *Sphagnum palustre, Sph. papillosum, Sph. fallax, Juncus effusus, Drosera rotundifolia* |
| Water quality | Water pH: 5.5 |
| | Water turbidity: - |
| | Dissolved organic carbon content: 20–130 mg $L^{-1}$ |

## IV. Socio-economic dimension

| | |
|---|---|
| Local stakeholders | Farmers, peat and growing media industry, environmentalists |
| Land tenure | Private |
| Land, water, and other natural resource access and use rights | Land is privately owned and has to be bought or rented; district authority has to authorize major changes in land use and how water from drainage channels is used |
| Conflicts | Limited peatland resources and multiple interests, including grassland for dairy cattle, peat extraction, maize cultivation and high nature value grassland (breeding waters) |
| Conflict resolution mechanism | Identification of priority areas for different land use types by landscape planning |
| Legal framework | Drainage-based grassland use is favoured by subsidies (EU Common Agricultural Policy); permission and compensation will be needed when transferring grassland into *Sphagnum* farming site |
| Products derived from the peatland | *Sphagnum* biomass as raw material for growing media in horticulture |
| Market orientation | Growing media producers and growers aiming at regional, renewable and peat reduced high-quality substrates for professional horticulture |

## V. Assessment of impacts on ecosystem services

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| | | |
|---|---|---|
| Provisioning services | Agricultural production | 4 |
| | Food security and nutrition | 2 |
| | Employment | 3 |
| | Income | - |
| | Non-timber forest products yield | 4 |
| | Livelihoods opportunities | - |
| | Resilience and capacity to adapt to climate change | 7 |
| | Long-term usability of peatland site | 7 |
| Socio-cultural services | Level of conflicts | 2 |
| | Gender equality | 4 |
| | Learning and innovation | 7 |
| | Preserving landscape archive in peat | 7 |
| Regulating services | Waterborne carbon (DOC) loss | 2 |
| | Fire frequency | 3 |
| | Biodiversity | 7 |
| | Subsidence rate | 1 |
| | Water retention | 7 |
| Off-site benefits | Water quality | 6 |
| | Frequency of flooding | 4 |
| | Local cooling effect, water evaporation | 6 |

## VI. Climate change mitigation potential

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| Impact | Rate | Estimate (t ha $^{-1}$ year$^{-1}$, $CO_2$-eq) | Remarks |
|---|---|---|---|
| Net GHG emission | 1 | 5 | 50 percent wet production site, 5 percent ditches, 45 percent dams |
| $CH_4$ emission | 6 | < 1 | mainly from ditches |
| $CO_2$ emission | 1 | 4 | mainly from dams |
| $N_2O$ emission | 1 | 0 | - |
| Carbon sequestration/ storage abovegrounds | 4 | 0 | Carbon accumulation in biomass is excluded from the balance due to regular harvest |

## VII. Additional information

*Sphagnum* farming in Germany has extensively been studied during the last decade in various research projects with promising results see www.sphagnumfarming.com for further details.

# 18. Peatland restoration and sustainable grazing in China

Ruoergai Plateau, China, Asia (32.20–34.10° N,102.15°-103.50° E)

Zhang Xiaohong, Wu Ning, Chen Huai and Li Wei


Peatland restoration. Blocking canals by a: wood plank; b: peat; c: concrete damming; and d: revegation

## Summary

Situated at the headwaters of the Yellow River, the sedge-dominated peatlands in the Ruoergai plateau in China, store water and supply it to downstream areas. These peatlands also support endemic and endangered Himalayan species and maintain the special aspects of Tibetan culture. In the 1960–70's, the Ruoergai peatlands, which had been drained for agriculture, began to be badly damaged by overgrazing. Assessments and field observations indicate that over 70 percent of the peatlands are severely degraded. As a result, a large amount of $CO_2$ stored in the peat has been released to the atmosphere and biodiversity has been lost. All of these environmental consequences have had an impact on local livelihoods.

With support from the Chinese government, the United Nations Environment Programme (UNEP) and the European Union (EU), activities for restoration the degraded peatlands, including the blocking of canals and cultivating vegetation, were tested and demonstrated in selected sites. The water table was raised to rewet adjacent areas and vegetation was regrown in their appropriate environment. The limited data presented below suggests that rewetted peatlands have enhanced carbon sequestration in the soil organic, reduced $CO_2$ production, and may have reduced emissions of $N_2O$. The restored sites also recreated proper habitats for endemic amphibians and birds. The water stored in previously dry canals provided water for livestock, which was highly appreciated by local communities. It is urgent to take further actions to prevent continued degradation of these natural peatlands.

# I. Practice description

| | |
|---|---|
| **Area of the site** | 4 733 ha |
| **Current land cover/use** | Grassland |
| **Previous land cover/use** | Degraded peatland, grassland |
| **Origin of intervention** | Peatland biodiversity conservation and climate mitigation |
| **Types of intervention used in the area** | ☑ Rewetting<br>☐ Drainage<br>☐ Cultivation of crops<br>☑ Grazing<br>☐ Forestry<br>☐ Aquaculture<br>☐ Fishery<br>☐ Other |
| **How long the practice has been applied?** | 6 years |
| **Main purpose of the practice** | Biodiversity conservation and reduction of GHG emissions |
| **Level of technical knowledge** | ☐ Low<br>☑ Medium<br>☐ High |
| **Water table depth from surface** | From -0.3 to 0.5 m |
| **Present active drainage system** | **Width of channels**: all channels were blocked<br>**Distance between channels**: - |
| **Subsidence** | **Before practice**: No data<br>**During practice**: No data |

# II. Implementation of activities, inputs and cost

| N | Establishment of activities | Input/materials | Duration | Cost |
|---|---|---|---|---|
| 1 | Blocking drainage canals and gullies | Tractors, peat or sand, wooden planks, boulders and bags | 5–7 days | Medium (USD 116 per dam, in total USD 164 000) |
| 2 | Revegetation: grass reseeding on the bare peat soil. | Grass seeds, bags, truck (the degraded land was levelled for seed growth by a truck) | 1–3 days | Low (50–80 per ha, in total USD 1 000) |
| 3 | One peat extraction site was restored by damming | Concrete, sand, tractor, grass seeds, levelling ground | One week | High (USD 5 300 per dam) |

**Remarks:**

The 2 m deep pit was levelled by a machine for reseeding in the peat extracted site and some dams were fenced to prevent trampling by yaks. PVC pipes were installed between the peat dams to avoid further erosion.

## III. Environmental characteristics

| | | |
|---|---|---|
| **Climate** | ☐ Tropical<br>☑ Temperate<br>☐ Boreal | |
| **Average annual rainfall** | 620–750 mm | |
| **Altitude** | 3400–3600 m a.s.l. | |
| **Slope** | 1.9–14.9 percent | |
| **Peat depth (cm)** | ☐ ≤ 30<br>☐ 30–50<br>☑ 50–100<br>☑ 100–300<br>☑ >300 | |
| **Peatland type**<br>**based on the water source** | ☐ Fen<br>☐ Bog<br>☑ Undefined | |
| **Hydrologic network** | Connected with Black River and White River. The two tributaries adjoin the Yellow River. | |
| **Main vegetation species** | **Before practice** | *Potentilla anserina, Leontopodium leontopodioides, Carex spp., Kobresia tibetica, Cremanthodium lineare Marim, Elymus nutans.* |
| | **During practice** | *Eriophorum angustifolium, Equisetum heleocharis, Potamogeton petctinatu, Carex muliensis, Deschampsia caespitose.* |
| **Water quality** | **Water pH** | 7.6 |
| | **Water turbidity** | 37 FTU |
| | **Dissolved organic carbon content** | - |

## IV. Socio-economic dimension

| | |
|---|---|
| **Local stakeholders** | Local stakeholders are mainly pastoralists, lamas (monks) and a limited number of farmers. |
| **Land tenure** | The land tenure belongs to government, but herders can use grassland for 70 years based on signed contracts. |
| **Land, water, and other natural resource access and use rights** | All the stakeholders have access to use land, water and natural resources for their daily life and agricultural production. |
| **Conflicts** | Reduced grazing intensity lowers revenues. |
| **Conflict resolution mechanism** | The government has implement a series of policies to solve this conflict, such as creating a resettlement programme, returning rangeland back to grassland, establishing a livestock quota based on the grassland stock capacity and increasing artificial grassland. |
| **Legal framework** | National Grassland Law, National Water Resource Law, National Wildlife Conservation Law, National Nature Reserve Administration Regulation, Gansu Wetland Conservation Regulation, Sichuan Wetland Conservation Regulation. |
| **Products derived from the peatland** | Fuel, medical plants, honey and fodders. |
| **Market orientation** | Livestock trade market |

## V. Assessment of impacts on ecosystem services

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| | | |
|---|---|---|
| Provisioning services | Agricultural production | 3 |
| | Food security and nutrition | 3 |
| | Employment | 4 |
| | Income | 4 |
| | Non-timber forest products yield | - |
| | Livelihoods opportunities | 4 |
| | Resilience and capacity to adapt to climate change | 2 |
| | Other: Potential tourism development | 3 |
| Socio-cultural services | Level of conflicts | 6 |
| | Gender equality | 2 |
| | Learning and innovation | 3 |
| Regulating services | Waterborne carbon (DOC) loss | 3 |
| | Fire frequency | 2 |
| | Biodiversity | 2 |
| | Subsidence rate | 3 |
| | Other: Water storage capacity | 3 |
| Off-site benefits | Water quality | 5 |
| | Frequency of flooding | 3 |

## VI. Climate change mitigation potential

1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing

| Impact | Rate | Estimate (t $ha^{-1}$ $year^{-1}$, $CO_2$-eq) | Remarks |
|---|---|---|---|
| Net GHG emission | 3 | 34.3 | - |
| $CH_4$ emission | 5 | 11.5 | - |
| $CO_2$ emission | 2 | 22.2 | - |
| $N_2O$ emission | 2 | 0.6 | - |
| Carbon sequestration/ storage abovegrounds | - | - | - |

# 19. Rewetting drained forest in Southern Sweden

Sweden, Jönköping County (57°65'N, 13°72'E)

Åsa Kasimir Klemedtsson and Johan Rova


Rewetting the peatland a: Excavator building dams and filling ditches in drained fens and wet forest and b: rewetted site immediately after the completed restoration actions.

## Summary

In the early 1970's, about 80 ha of rich fen, meadows and wet forest on the margins of the large and pristine raised bog 'Komosse' in Southern Sweden were drained by ditches to promote spruce (Picea abies) growth and forestry production. Draining had a dramatic impact on forest production on the nutrient-rich peaty soils downhill from the ditches. In 40 years, most of the meadows and fens had turned into dense forest. Because of the high nature conservation value (mainly birdlife) of the bog, the entire area (including surrounding forests) was later designated a Ramsar site, a nature reserve, and a Natura 2000 area.

In 2012, as part of the management of the Natura 2000 site, ditches were blocked to initiate natural processes to restore habitats on 40 ha of the drained area. Biodiversity is expected to improve and will be monitored repeatedly. Raising ground water levels in this relatively nitrogen-rich organic soil affects GHG emissions as calculated by the IPCC Wetland supplement. $CH_4$ emissions increase, however estimates are highly uncertain. The total GHG emissions are reduced by rewetting due to declinces in $CO_2$ and $N_2O$ emissions.

# I. Practice description

| | |
|---|---|
| **Area of the site** | 40 ha |
| **Current land cover/use** | Nature conservation (nature reserve, Ramsar, and Natura 2000 site), forest |
| **Previous land cover/use** | Forestry (until the mid-20th century) also haymaking and grazing |
| **Origin of intervention** | Government incentive |
| **Types of intervention used in the area** | ☑ Rewetting<br>☐ Drainage<br>☐ Cultivation of crops<br>☐ Grazing<br>☐ Forestry<br>☐ Aquaculture<br>☐ Fishery |
| **How long the practice has been applied?** | 3 years (restoration started in 2012) |
| **Main purpose of the practice** | Protection of indigenous species (birds), restoration of habitats. |
| **Level of technical knowledge** | ☐ Low<br>☑ Medium<br>☐ High |
| **Water table depth from surface** | At the surface level |
| **Present active drainage system** | **Width of channels**: 0–2 m<br>**Distance between channels**: 0–150 m |
| **Subsidence** | **Before practice**: 0.5 cm $year^{-1}$<br>**During practice**: 0 cm $year^{-1}$ |

# II. Implementation of activities, inputs and cost

| N | Establishment of activities | Input/materials | Duration | Cost |
|---|---|---|---|---|
| 1 | Applying for funding of restoration activities; gaining acceptance for project from private landowners in the area. | Field visits; checking legislative options; meetings with land owners. | 4 weeks (over 3 years) | USD 8 000 |
| 2 | Hydrological survey: mapping of drainage patterns, calculation of risks and benefits, optimization of drainage channel blocking sites. | Microtopographic land survey; field visits, GIS-software; computer facilities. | 8 weeks | USD 15 000 |
| 3 | Clearing of trees along drainage channels and piling up tree trunks where dams were to be built. | Manual work; chainsaws and protective garment; small forestry machines. | 3.5 weeks | USD 22 000 |
| 4 | Blocking drainage channels | Entrepreneur with excavator; cloth fibre; worker to assist excavator entrepreneur. | 5 weeks | USD 18 000 |
| 5 | Monitoring (aerial photos, water level, vegetation and water chemistry monitoring); information material. | Aerial photographer, field personnel; car for field, laboratory costs; writing reports; printing service. | 3 weeks (over 5 years) | USD 12 000 |

**Remarks:** The costs of economic compensation for landowners and salary for administration of the restoration project is not included here. Social charges for field staff and other workers are included when applicable.

## III. Environmental characteristics

| | | |
|---|---|---|
| **Climate** | ☐ Tropical<br>☐ Temperate<br>☑ Boreal | |
| **Average annual rainfall** | 880 mm | |
| **Altitude** | 310–330 m a.s.l. | |
| **Slope** | 2.4 percent | |
| **Peat depth (cm)** | ☐ ≤ 30<br>☑ 30–50<br>☐ 50–100<br>☐ 100–300<br>☐ >300 | |
| **Peatland type based on the water source** | ☑ Fen<br>☐ Bog<br>☐ Undefined | |
| **Hydrologic network** | Upstream: bog; downstream: streams and river | |
| **Main vegetation species** | **Before practice** | *Norway Spruce (Picea abies);* forest mosses *(e.g. Hylocomium splendens, Pleurozium schreberi); subshrubs (e.g. Vaccinium myrtillus, Vaccinium vitis-idaea)* |
| | **During practice** | Eventually, vegetation will shift to Scots *Pine (Pinus sylvestris);* birch *(Betula* spp.*);* peat mosses *(Sphagnum* spp.*)* |
| **Water quality** | **Water pH** | 5.8–6.4 |
| | **Water turbidity** | 2.9–43 FTU |
| | **Dissolved organic carbon content in drainage channels** | Total organic carbon: 14–52 mg $L^{-1}$ (DOC was not measured) |

## IV. Socio-economic dimension

| | |
|---|---|
| **Local stakeholders** | Hunters, mostly hunting moose, roe deer, and hare during autumn and winter. Occasional bird watchers, berry pickers and mushroom collectors. |
| **Land tenure** | Private and state/government. |
| **Land, water, and other natural resource access and use rights** | Private landowners are allowed to hunt. Everybody is allowed to use the area for a variety of outdoor activities (e.g. picking berries and mushrooms, bird watching). Nature reserve regulations prohibit forestry. |
| **Conflicts** | No serious conflicts. |
| **Conflict resolution mechanism** | Economic compensation to land owners when the nature reserve was established and before the restoration project started. |
| **Legal framework** | Swedish environment protection law; European legislation on Natura 2000 site management (Birds, and Species and Habitats directives). |
| **Products derived from the peatland** | Products from hunting, berries, mushrooms (very local use). |
| **Market orientation** | - |

## V. Assessment of impacts on ecosystem services

**1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing**

| | | |
|---|---|---|
| **Provisioning services** | Agricultural production | 4 |
| | Food security and nutrition | 4 |
| | Employment | 4 |
| | Income | 4 |
| | Non-timber forest products yield | 4 |
| | Livelihoods opportunities | 4 |
| | Resilience and capacity to adapt to climate change | 6 |
| **Socio-cultural services** | Level of conflicts | 4 |
| | Gender equality | 4 |
| | Learning and innovation | 5 |
| **Regulating services** | Waterborne carbon (DOC) loss | 3 |
| | Fire frequency | 4 |
| | Biodiversity | 6 |
| | Subsidence rate | 2 |
| **Off-site benefits** | Water quality | 5 |
| | Frequency of flooding | 3 |

## VI. Climate change mitigation potential

**1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing**

| Impact | Rate | Estimate (t $ha^{-1}$ $year^{-1}$, $CO_{2}$-eq) | Remarks |
|---|---|---|---|
| Net GHG emission | 2 | 3.2 (-2.2 to +14.5) | The figures in parenthesis indicate the 95 percent confidence interval. Emission size is based on Tier 1 emission factors in the IPCC Wetland supplement for boreal climate and nutrient rich soil. The case describes rewetting 90 percent of the area by filling 1 800 m ditches out of a total of 2 500 m. This reduced total emissions by around 50 percent. The $CO_2$ emissions change the site from a source into a sink while $CH_4$ emissions increased. However this has a large uncertainty. $CH_4$ emissions from ditches are negligible after rewetting. Rewetting is assumed to result in zero $N_2O$ emission, which can be viewed as a saving of 1.4 t $CO_2$-eq $ha^{-1}$ $yr^{-1}$ after rewetting. |
| $CH_4$ emission | 7 | +4.2 (-0.0 to +14.9) | |
| $CO_2$ emission | 1 | --1.5 (-0.6 to -2.3) | |
| $N_2O$ emission | 1 | 0.2 (0.1 to -0.2) | |
| Carbon sequestration/ storage abovegrounds | 4 | 0 | The tree cover is assumed not to change, but the species composition does. However the wetter conditions may decrease annual tree growth but stimulate growth of peat mosses, which accumulate carbon as peat. |

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# ANNEX

# Title

Location

Author(s), organization(s)

*Click inside the box to add an image.*

**Insert a title of the technical picture of the site and practice.**

## Summary

## 1. Practice description

| | |
|---|---|
| Area of the site (ha) | |
| Current land cover/use | |
| Previous land cover/use | |
| Origin of intervention | |
| Types of intervention used in the area | ☐ Rewetting<br>☐ Drainage<br>☐ Cultivation of crops<br>☐ Grazing<br>☐ Forestry<br>☐ Aquaculture<br>☐ Fishery<br>☐ Other |
| How long the practice has been applied? | |
| Main purpose of the practice | |
| Level of technical knowledge | ○ low<br>○ medium<br>○ high |
| Water table depth from surface (m) | |
| Present active drainage system (m). | Width of channels<br>Distance between channels |
| Subsidence (cm $year^{-1}$) | Before practice<br>After practice |

## 2. Implementation of activities, inputs and costs

| N | Establishments of activities | Inputs/materials | Duration | Cost |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |

Remarks

## 3. Environmental characteristics

| | |
|---|---|
| **Climate** | ◯ tropical<br>◯ temperate<br>◯ boreal |
| **Average annual rainfall (mm)** | |
| **Altitude (m a.s.l.)** | |
| **Slope (%)** | |
| **Peat depth (cm)** | ☐ ≤ 30<br>☐ 30–50<br>☐ 50–100<br>☐ 100–300<br>☐ >300 |
| **Peatland type based on the water source** | ◯ fen<br>◯ bog<br>◯ undefined |
| **Hydrologic network** | |
| **Main vegetation species** | Before practice<br>After practice |
| **Water quality** | Water pH<br>Water turbidity (FTU)<br>Dissolved organic carbon content (mg $L^{-1}$): After practice; Before practice |

## 4. Socio-economic dimension

| | |
|---|---|
| **Local stakeholders** | |
| **Land tenure** | |
| **Land, water, and other natural resource access and use rights** | |
| **Conflicts** | |
| **Conflict resolution mechanism** | |
| **Legal framework** | |
| **Products derived from the peatland** | |
| **Market orientation** | |

## 5. Assessment of impacts on ecosystem services

*1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing*

| | | |
|---|---|---|
| **Provisioning services** | Agricultural production | |
| | Food security and nutrition | |
| | Employment | |
| | Income | |
| | Non-timber forest products (NTFPs) yield | |
| | Livelihoods opportunities | |
| | Resilience and capacity to adapt to climate change | |
| | Other | |
| **Socio-cultural services** | Level of conflicts | |
| | Gender equality | |
| | Learning and innovation | |
| | Other | |
| **Regulating services** | Waterborne carbon (DOC) loss | |
| | Fire frequency | |
| | Biodiversity | |
| | Subsidence rate | |
| | Other | |
| **Off-site benefits** | Water quality | |
| | Frequency of flooding | |
| | Other | |

## 6. Climate change mitigation potential

*1 highly decreasing/ 2 moderately decreasing/ 3 slightly decreasing/ 4 neutral/ 5 little increasing/ 6 moderately increasing/ 7 highly increasing*

| Impact | Rate | Estimate ($t\ ha^{-1}\ year^{-1}$, $CO_2$ eq) | Remarks |
|---|---|---|---|
| Net GHG emission | | | |
| $CH_4$ emmission | | | |
| $CO_2$ emission | | | |
| $N_2O$ emission | | | |
| Increase carbon sequestration/storage aboveground | | | |

## 7. Additional information

Peatlands are lands with a naturally accumulated peat layer at their surface. In their natural state, peatlands support a large range of habitats and provide a home for unique biodiversity. Even though peatlands extend over a relatively small portion of the earth's land surface, they hold a large pool of carbon. Along with storing large quantities of carbon, peatlands also play an important role in the retention, purification and release of water and in the mitigation of droughts and floods. When drained, peatlands become net sources of greenhouse gas (GHG) emissions. Because of drainage, organic soils are currently the third-largest emitter of GHGs in the Agriculture, Forestry and Land Use sector. The aim of this guidebook is to support the reduction of GHG emissions from managed peatlands and present guidance for responsible management practices that can maintain peatlands ecosystem services while sustaining and improving local livelihoods. This guidebook also provides an overview of the present knowledge on peatlands, including their geographic distribution, ecological characteristics and socio-economic importance.

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