# Chapter 1: Introduction

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The Assessment on Peatlands, Biodiversity and Climate Change aims to provide a synthesis of knowledge of the important functions and roles of peatland ecosystems in relation to biodiversity conservation and sustainable use and climate change mitigation and adaptation. It has been prepared, over the period 2005–2007, by a team of specialists on peatland assessment and management, biodiversity, climate change and other fields. This chapter provides an introduction to the importance of peatlands as well as provides more details on the process of the development of the assessment.

## 1.1 Rationale for the Assessment

**Peatlands are key natural ecosystems**
Peatlands are one of the most important natural ecosystems in the world. They are of key value for biodiversity conservation and climate regulation and provide important support for human welfare. They cover over 400 million ha in about 180 countries and represent a third of the global wetland resource. Currently they are being degraded in many regions as a result of land clearance, drainage, fire and climate change. This not only causes a reduction in biodiversity and direct benefits for people – it also generates further problems. The protection and wise use of peatlands should be a global priority.

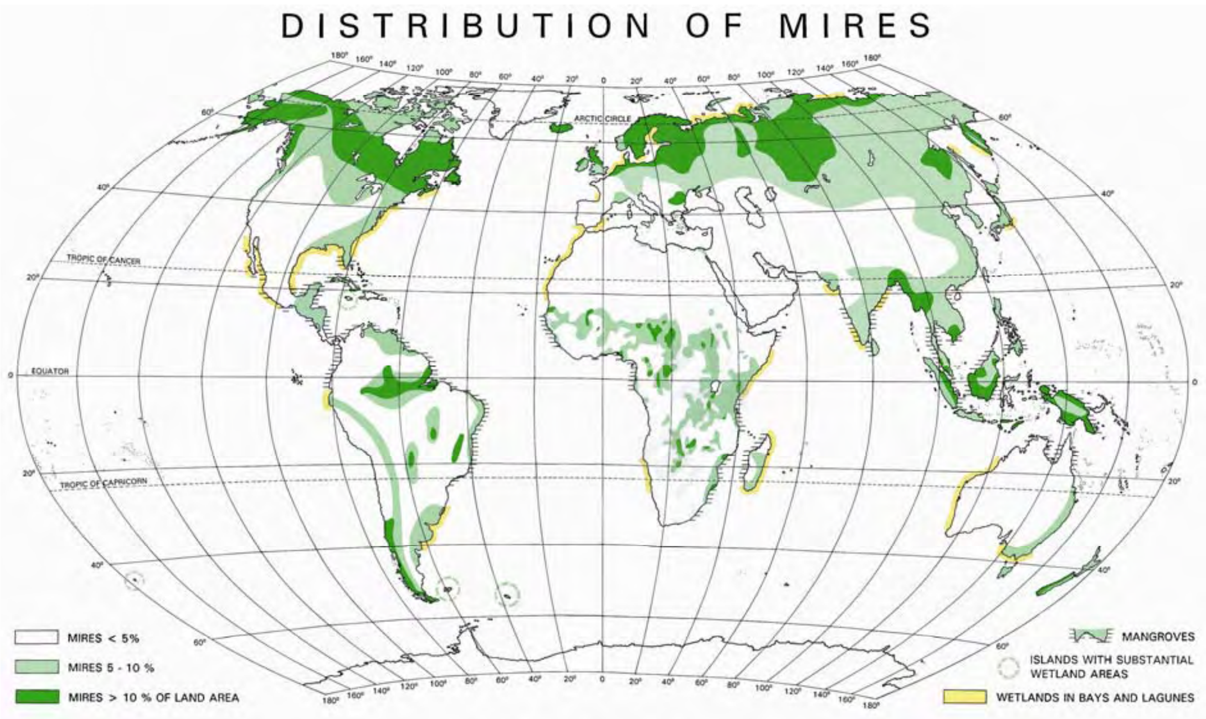



*Figure 1.1: Distribution of mires/peatlands in the world (After Lappalainen 1996[1]).*

Peatlands are wetland ecosystems that are characterised by the accumulation of organic matter called "peat" which derives from dead and decaying plant material under high water saturation conditions. In peatlands, water, peat and specific vegetation are strongly interconnected. If any one of these components is removed, or should the balance between them be significantly altered, the nature of the peatland is fundamentally changed.

There are two major types of peatland: bogs (which are mainly rain-fed and nutrient-poor) and fens (which are mainly fed by surface or ground water and tend to be more nutrient rich). However there are many different variations of peatland type, depending on geographic region, altitude terrain

[1] Lappalainen E. (Ed.). Global Peat Resources. International Peat Society and Geological Survey of Finland, Juskä.

and vegetation. Peatlands may be naturally forested or naturally open and vegetated with mosses or sedges. Another distinction that can be made is between peatlands where peat is currently being formed – these are known as mires – and areas which formerly had peat formation, but due to human interventions or climate change, peat is no longer developing.

**Box 1.1: Peat**

Peat accumulates where plant growth exceeds decay. Water is the most important factor limiting decay. A permanently high water table can be provided by high precipitation or by ground or surface water flow. Diversity in bedrock and water flow conditions is responsible for the large variety of peatland types. A second cause of slow decay rates are the low temperatures that occur at high latitudes and altitudes.

Peat accumulates with a rate of about 0.5 – 1 mm per year (or 5-10m over 10,000 years) with locally strong variation.

Peat can be formed from mosses, sedges, grasses, trees, shrubs, or reeds. In northern regions, mosses are the main peat-forming plants while trees are the main species in the tropics. Most peatlands which exist today formed in the last 10,000 years since the last ice age.

Peatlands can be found in all parts of the world, but their distribution is concentrated in specific zones. Peat formation is strongly influenced by climatic conditions and topography. This may be in areas in northern latitudes or high altitude where the temperature is high enough for plant growth but too low for vigorous microbial activity. Significant areas of peatlands are also found in tropical and sub-tropical latitudes where high plant growth rates combine with slow decomposition as a result of high rainfall and water-logged conditions. In some cases peatlands were formed during wetter climatic periods thousands of years ago, but peat may no longer accumulate due to recent climate changes.

Peatlands can be found in almost all geographic areas – from the Arctic to the Tropics. Suitable conditions for the formation of peatlands occur in many parts of a landscape – they can be found on watersheds and in river valleys, around lakes, along sea shores, in high mountains and even in the craters of volcanoes.

**Peatlands are closely linked with the economy and welfare of society**

Peatlands are important to human beings due to their unique role in environmental regulation, aesthetic values, and the wide range of goods and services they provide. Humans have directly utilised peatlands for thousands of years, leading to varying degrees of impact. In many areas of the world, peatlands are beautiful landscapes with a unique biodiversity. They are deeply integrated into socioeconomic processes and have become a historical arena of conflicts and contradictions in land use. Inappropriate or short-sighted exploitation of the functions and services from peatlands have often negatively affected the livelihood of local communities and created broader threats to society through increasing floods, water shortages and air pollution from fires.

**Table 1.1: Peatland Uses & Functions**

| | |
|---|---|
| Agriculture | For centuries, peatlands in Europe, North America and Asia have been used for grazing and for growing crops. Large areas of tropical peatlands have been cleared and drained for food crops and cash crops such as oil palm and other plantations in recent years. However large-scale drainage of peatlands for agriculture has often generated major problems of subsidence, fire, flooding, and deterioration in soil quality. |
| Forestry | Many peatlands are exploited for timber harvesting. In northern and eastern Europe and Southeast Asia, peatlands have been drained for plantation forestry, whereas in North America and Asia some timber extraction takes place from un-drained peatlands. The peat swamp forests of Southeast Asia used to be an important source of valuable timber species such as Ramin (Gonostylus bancanus), but over-exploitation and illegal trade have led to trade restrictions under CITES. |
| Peat Extraction | Peat has been extracted for fuel, both for domestic as well as industrial use, particularly in Europe but also in South America. Peat extraction for the production of growing substrates and gardening is a multi-million dollar industry in North America and Europe. For instance, the Netherlands import 150 million Euros worth of peat every year as a substrate for horticulture. |
| Subsistence use | Peatlands contribute importantly to the livelihood of local communities. In the tropics this includes the harvesting of non-timber forest products such as rattans, fish, Jelutung latex (a raw material for chewing gum), medicinal plants and honey. In parts of Europe and America the collection of berries and |

| | |
|---|---|
| | mushrooms is important for some rural populations. All over the world we can find indigenous people whose livelihoods and cultures are sustained by peatlands. |
| Water regulation | Peatlands consist of about 90% water and act as vast water reservoirs - contributing to environmental security of human populations and ecosystems downstream. They play an important role in the provision of drinking water, both in areas where catchments are largely covered by peatlands, and in drier regions where peatlands provide limited but constant availability of water. |
| Biodiversity | Peatlands constitute habitats for unique flora and fauna which contribute significantly to the gene pool. They contain many specialised organisms that are adapted to the unique conditions. The tropical peat swamp forests of Southeast Asia, for example, feature some of the highest freshwater biodiversity of any habitat in the world and are home to the largest remaining populations of orang utan. |
| Research, education and recreation | Peatland ecosystems play an important role as archives. They record their own history and that of their wide surroundings in the accumulated peat and enable the reconstruction of long-term human and environmental history. Because of their beauty and often interesting cultural heritage, many peatlands are important for tourism. |
| Carbon storage | Peatlands are some of the most important carbon stores in the world. They contain nearly 30 percent of all carbon on the land, while only covering 3 percent of the land area. Peatlands in many regions are still actively sequestering carbon. However, peatland exploitation and degradation can lead to the release of carbon. The annual carbon dioxide emission from peatlands in Southeast Asia by drainage alone is at least 650 million tonnes, with an average of 1.4 billion tonnes released by peatland fires. This represents a major portion of global carbon emissions and causes significant social and economic impacts in the ASEAN region. |
| Each of the uses and functions described above is elaborated in more detail in the different chapters of the Assessment. | |

**Peatlands and Climate Change**
Peatlands play an important role in climate regulation. Over the past 10,000 years peatlands have absorbed an estimated 1.2 trillion tonnes of carbon dioxide to have a net cooling effect on the earth. Peatlands are now the world's largest terrestrial long-term sink of atmospheric carbon storing twice as much carbon as the biomass of the world's forests. However in the last 100 years clearance, drainage and degradation of peatlands have turned them from a net store to a source of carbon emissions. This combined with large-scale emissions from use of fossil fuels and forest clearance has been responsible for significant global increases in the concentration of carbon dioxide and other greenhouse gasses – the root cause of global climate change. The current predictions by the Intergovernmental Panel for Climate Change (IPCC) for significant changes in global temperature and rainfall regimes have significant implications for peatland ecosystems. In many cases the changes are expected to have a negative impact on peatlands and exacerbate the rate of degradation and release of stored carbon.

**Peatlands and global environment conventions**
In the global arena of international environment conventions, peatlands are growing issue within the deliberations of the UN Framework Convention on Climate Change (UNFCCC) the Convention on Biological Diversity (CBD), the Convention to Combat Desertification (UNCCD) and Ramsar Convention on Wetlands. The UNFCCC (See Box below) is primarily concerned with the implications of peatland loss and its impact on the global GHG emissions as well as possible mitigation and adaptation options. The CBD and the Ramsar Convention have focused on the importance of peatlands for biodiversity conservation and the potential for sustainable use of biological resources. The Parties to the UNCCD have raised concerns about the degradation of peatland in the dryland regions and the loss of associated ecosystem services such as water supply. However since peatlands are one single ecosystem, it is important that their management is addressed in an integrated manner. The challenge will be to find new management methods that simultaneously generate benefits for biodiversity and climate change as well as addressing the important needs of local communities.

**Box 1.2: Peatlands and Environmental Conventions**

United Nations Framework Convention on Climate Change (UNFCCC)

In recent years there has been increasing reference to peatland in the deliberations of the UNFCCC although there have not yet been specific decisions relating to peatlands. Peatlands and other organic soils are now assessed separately in the national assessments of greenhouse gas emissions by Annex 1 Parties. The relevance of peatlands to climate change adaptation and mitigation as well as reducing emissions from deforestation in developing countries has been recognised by some of the parties to the convention.

Convention on Biological Diversity (CBD)

The CBD, through its decision on Biodiversity and Climate Change at COP VII, has supported action to minimise the degradation as well as promote the restoration of peatlands for their significance as carbon stores and/or ability to sequester carbon. The CBD also welcomed the current Assessment on Peatlands Biodiversity and Climate Change and has incorporated peatland related issues into its Programme of Work on Inland Water Biodiversity.

Ramsar Convention on Wetlands

The Ramsar Convention on Wetlands has recognised the need for increased attention to be paid to peatland conservation and wise use, as well as addressing the climate-related functions of peatlands. In 2002, it established a Coordinating Committee to monitor progress on implementation of its Guidelines for Global Action on Peatlands (CC-GAP), to develop an implementation plan for further action, and to identify priority actions for the promotion of the wise use of peatlands. The Resolution on Climate Change and Wetlands in 2002 gave specific recognition to the need to protect and restore peatlands in recognition of their role in carbon storage.

**Wise Use approach concerning peatlands**

Conflicts between different groups arise because some significant peatland functions can only be provided by intact peatlands, while other uses lead to total transformation. To address this issue, the International Mire Conservation Group and the International Peat Society, together with other partners, have been working to promote the wise use of peatlands since 1997. The principal objective of the Wise Use process is to protect peatlands in a manner which respects the positions of all stakeholders, contributing to sustainable life for humankind. This effort has brought together those who exploit peatlands through agriculture, forestry, peat extraction and other uses with those who wish to promote non-extractive benefits such as biodiversity, freshwater, climate stability, and beauty.

## 1.2 Purpose of the Assessment

The Assessment on Peatlands, Biodiversity and Climate Change aims to provide a synthesis of knowledge of the important functions and roles of peatland ecosystems in relation to biodiversity conservation and sustainable use and climate change mitigation and adaptation. One of the most pertinent reasons for the preparation of the assessment is because peatlands are very often inadequately recognized as specific and valuable ecosystems in relation to either climate change or biodiversity. The assessment aims to bring together diverse knowledge on peatlands features, functions and services from different sources through a multidisciplinary international task force of peatland, biodiversity and climate change experts.

**Why do we need an assessment?**

The assessment aims to contribute to the international decision-making processes related to global problems such as biodiversity conservation, climate change, desertification, pollution, poverty and health. It will enable the identification of appropriate management and adaptation strategies for peatlands which will bring both biodiversity and climate benefits. It is intended to provide information to feed into the deliberations of the global environment conventions as well as contribute to deliberations at regional and national levels. It also provides recommendations on the development and planning of peatland use that could be used as an information source in policy making, and the drafting of laws and regulations. For some countries with significant areas of peatland, this assessment could be used to provide guidance and reference in the development of sustainable strategies for peatland management; and in helping to foster understanding about the need for stakeholder interaction related to peatland management.

**Recognition of the Assessment process**

In February 2004, the Seventh Conference of Parties of the Convention of Biological Diversity formally recognised the preparation of the Assessment through decision VII/15 on Biodiversity and Climate Change. This decision *"encouraged the involvement of parties in this assessment and in preparations for the considerations of its findings by SBSTTA prior to the ninth CBD Conference of Parties in 2008"*. This decision formally links the assessment within the decision making process of the Convention on Biological Diversity. In July 2007, CBD SBSTTA considered and welcomed the results of the assessment and recommendnede further consideration by CBD COP IX in May 2008. CBD SBSTTA also mandate the Executive Secretary of the CBD to formally convey the outcome of the Assesment to the UNFCCC COP 13 in December 2007.

## 1.3 Outline of the Assessment

The Assessment report contains a number of key synthesis chapters (2–7). These provide basic facts in relation to the following questions:

Chapter 2: What are peatlands?
Chapter 3: What is the relationship between people and peatlands?
Chapter 4: How have peatlands responded to climate changes in the past?
Chapter 5: What is their importance for the maintenance of biodiversity?
Chapter 6: How is their role in carbon storage and sequestration?
Chapter 7: What is role of peatlands in the flux of greenhouse gasses?

These information are synthesized and applied in the Chapters 8 and 9 on:

- What are the possible impacts of climate change on peatlands (carbon storage, GHG, biodiversity) and peatland responses to future climate change?
- How can we manage peatlands in an integrate manner to generate benefits for biodiversity and climate change?

## 1.4 Process of preparation of the Assessment

The overall preparation of the assessment has been overseen the Global Environment Centre and Wetlands International who are the joint implementers of the UNEP-GEF supported project on Integrated management of peatlands for biodiversity and climate change. Guidance was also provided by the project steering committee comprising representatives from UNEP, GEF-STAP, IMCG and the participating countries.

The assessment was initiated just prior to CBD COP7 in February 2004, when a small expert meeting prepared the concept paper for the assessment. Following the expression of support for the process by the CBD Conference of Parties a request for expressions of interest was circulated to all parties to the CBD as well as a broad range of peatland and climate change experts and organizations. Based on the feedback received, a number key experts from a range of disciplines and regions were identified. A first coordination meeting held in October 2004 in Wageningen, the Netherlands to discuss in detail the possible topics, contents and author teams. An initial outline of the Assessment was then circulated to a range of experts related to peatlands, biodiversity and climate change as well as policy development and management to elicit further expressions of interest in involvement as contributing authors and reviewers. The drafting of the different chapters was initiated in 2005. Initial drafts were prepared by key authors and then circulated to contributing authors to get specific inputs. A series of meetings of Lead Authors were organised in June, October and November of 2006 to review and refine the chapters and address areas of overlap and synergy between the various chapters. Drafts were then circulated, reviewed and refined and the overall assessment finalised. Key findings of the Assessment were presented to the SBSTTA meeting of CBD in July 2007. A meeting in October 2007 finalised the content and design/layout of an Executive Summary to highlight the key findings from the overall assessment.

## 1.5 Scope and limitations

The scope and objective of the assessment report as mentioned above is rather specific and its main aim is to focus on the assessment of two very important issues of climate change and biodiversity in relation to peatlands. In order to undertake a manageable process it was necessary to restrict the inclusion of some other related topics. In particular, two important topics which were identified for inclusion in the initial scoping could not be included in the final assessment. These were an assessment of the function of peatlands in relation to water resources and the social and economic implications of peatland management and development. These issues are only addressed briefly in the current assessment and it is proposed that these are subjects of separate future assessment reports.

The assessment faced some constraint in gathering and assessment information on peatlands from different regional and scientific disciplines. The global knowledge on peatlands cross-cuts a number of scientific and social scientific disciplines and geographic areas. This knowledge is highly dispersed among publications in various languages and scientific schools, as well as being found amongst indigenous populations that have traditionally managed the peatlands. Despite the large body of knowledge, there are also still significant gaps. The strongest levels of inputs for the assessment came from experts from Europe, Asia and a lesser extent north America – regions which together contain the majority of the worlds peatlands and where there has been a relatively long history of peatland studies. A lower level of input was received from Africa, Latin America and the pacific region – which have smaller areas of documented peatlands and less detailed studies. It is hoped that in future coverage of information from these regions can be enhanced. Nevertheless, the Assessment tries to be as globally relevant as possible by including examples from different regions.

In the process of preparing the Assessment report, efforts have been taken to gather and accumulate as much available information from a wide a variety of different sources as possible. Information related to the links between climate change, biodiversity and peatland have been concisely elaborated in the hope that readers would be aware of the need for a more integrated approach between different sectors to address common issues

## 1.6 Acknowledgements

The preparation of this assessment report has been undertaken as part of the project on Integrated Management of Peatlands for Biodiversity and Climate Change. This 4 year (2003-2007) project was developed and implemented by Wetlands International and the Global Environment Centre together with a range of other partners at national (China, Indonesia and the Russian Federation), Regional (ASEAN) and international levels supported by UNEP-GEF, the Dutch (DGIS) and Canadian (CIDA) governments. Additional support was received from The Asia Pacific Network for Global Change Research (APN) and other agencies.

The preparation of the assessment has involved contributions from many agencies and individuals. The lead and contributing authors are listed at the beginning of every chapter. Many others have contributed information or attended meetings. Profesor Dicky Clymo and Dr Lindsay Stringer assisted with the editing of the executive summary and Main assessment respectively. Dr Andrey Sirin acted as the scientific editor and stimulated and supported the lead authors of each chapter. Design activities have been supported by Regina Cheah.

# Chapter 2: What are peatlands?

***Lead author: Hans Joosten***


**Summary points**

1. **A peatland is an area with a layer of dead organic material (peat) at the surface.**
2. **The major characteristics of natural peatlands are the formation and storage of peat, the permanent water logging, and the continuous (upward) growth of the surface.**
3. **These characteristics determine the specific goods and services that peatlands provide. Of global importance is the long-term storage of 550 Gtonnes of Carbon as peat.**
4. **Peatland distribution and peat formation and storage are primarily a function of climate.**
5. **Covering 4 million km$^2$, peatlands are found in almost every country, but primarily in the boreal, subarctic and tropical zones. Their inventory status is (very) insufficient.**
6. **As a result of climatic and biogeographic differences, a large diversity of peatland types exists.**
7. **In peatlands "plants", "water", and "peat" are mutually interdependent, making peatlands vulnerable to a wide range of human interference.**
8. **As a result of long development, peatlands reach a high level of internal coherence and autonomy.**
9. **In northern regions and highlands, peatlands and permafrost are mutually dependent.**
10. **Peatlands deserve more attention as ecosystems with special characteristics and values,**


## 2.1 Introduction

**A peatland is an area with a naturally accumulated layer of dead organic material (peat) at the surface.**
In most natural ecosystems the production of plant material is counterbalanced by its decomposition by bacteria and fungi. In those wetlands where the water level is stable and near the surface, the dead plant remains do not fully decay but accumulate as *peat*. A wetland in which peat is actively accumulating is called a *mire* (fig. 2.1, Joosten & Clarke 2002). Where peat accumulation has continued for thousands of years, the land may be covered with layers of peat that are meters thick.

A **wetland** is an area that is inundated or saturated by water at a frequency and for a duration sufficient to support emergent plants adapted for life in saturated soil conditions. The Ramsar Convention also includes all open fresh waters (of unlimited depth) and marine waters ("up to a depth of six metres at low tide") in its "wetland" concept.

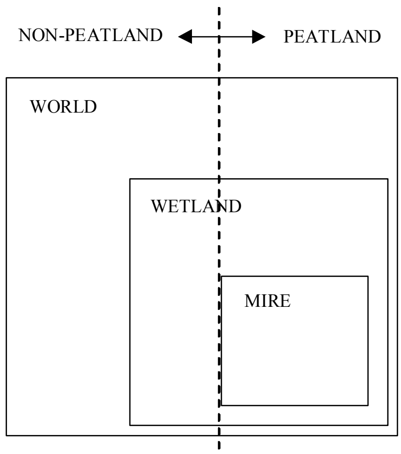



*Figure 2.1: The relation between "peatland", "wetland", and "mire" (adapted from Joosten & Clarke 2002).*

**Peat** is dead organic material that has been formed on the spot and has not been transported after its formation.

A **peatland** is an area with a naturally accumulated peat layer at the surface.

A **mire** is a peatland where peat is being formed.

Wetlands can occur both with and without peat and, therefore, may or may not be peatlands. A mire is always a peatland. Peatlands where peat accumulation has stopped, e.g. as a result of drainage, are no longer mires. When drainage has been particularly severe, they are no longer wetlands (fig. 2.1, Joosten & Clarke 2002).

**Peatlands are highly diverse and the peatland character of various ecosystem types is often not recognized.**
Peatlands are often unrecognized and overlooked. This is especially the case for mangroves, salt marshes, paddies/rice fields, boreal paludified forests, cloud forests, elfin woodlands, tropical swamp forests, highland sedge fens (pastures), spring mires, páramos, dambos, and cryosols, all of which may form peat and may have a peat soil (Joosten 2004). Peatlands may constitute almost 20 wetland

categories in the Ramsar Convention Classification System, over 40 habitat types of the EU Habitat Directive, and over 60 types of Endangered Natural Habitats of the Bern Convention.

Dramatic examples of overlooked peatlands are the high-altitude peatlands in Central and North-East Asia, e.g. in Mongolia, China, and Kyrgyzstan. These highland sedge fens (often on deep peat) are not recognized as peatlands by land users and decision makers, and are often overlooked even by specialists and experts. The peatlands are mainly used as pastures and are managed as meadows, yet they regulate river water flow by storing large amounts of ice and water (Minayeva et al. 2005). Local people are often not aware of the key hydrological functions of these highland peatlands.

In the Arctic regions, peatlands are called tundra and people do not care if vegetation grows on peat or mineral soil, whereas these different ecosystems need different management.

## 2.2 Peatland characteristics

**The major characteristics of natural peatlands are permanent water logging, the formation and storage of peat, and the continuous upward growth of the surface. These characteristics determine the specific goods, services, and functions associated with peatlands.**

Of global importance is the long-term storage of carbon and water within peatlands. Worldwide, peatlands contain 550 Gtonnes of carbon (see chapter 6) and 10% of the global fresh water in their peat (cf. Ball 2000). Carbon storage is made possible by the permanent water logging of the peat body. Water-logging and the continuous upward growth of the surface further determine the special and extreme site conditions to which peatland organisms are exposed. These conditions typically include

- A scarcity of oxygen and the presence of toxic ions such as $Fe^{2+}$, $Mn^{2+}$, $S^{2-}$ in the root layer (Hook & Crawford 1978, Sikora & Keeney 1983)
- Continuously rising water levels that can suffocate perennial plants (Van Breemen 1995, Grosse-Brauckmann 1990, Malmer et al. 1994)
- Spongy soil that makes trees fall over easily or drown under their own weight (Joosten & Clarke 2002)
- A scarcity of nutrients. This is the result of peat accumulation (by which nutrients are fixed in the peat), a limited nutrient supply (as in rainwater-fed mires) and chemical precipitation (as in groundwater-fed peatlands, where phosphates are bound by calcium and iron, Boyer & Wheeler 1989). The scarcity of ions in the water further complicates osmoregulation (an organism's control of the balance between water and ions) in submersed organs and organisms (Burmeister 1990)
- A generally cooler and rougher climate than the surrounding mineral soils, with stronger temperature fluctuations (Joosten & Clarke 2002)
- Acidity caused by organic acids and cation exchange (Ross 1995, Van Breemen 1995)
- The presence of toxic organic substances produced during decomposition (Verhoeven & Liefveld 1997, Salampak et al. 2000)
- The humus rich water, which can complicate orientation and recognition in aquatic animals.

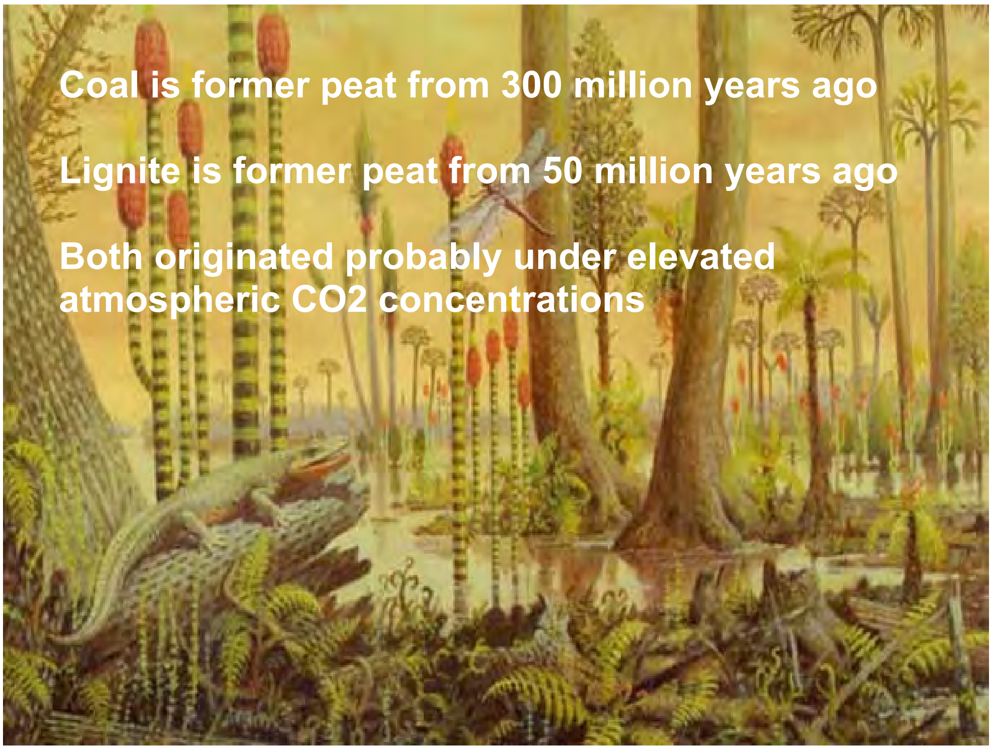
As a result of these extreme conditions, natural peatlands are in general species-poor compared with mineral soils in the same biographic region. However, many peatland species are strongly specialised and not found in other habitats, highlighting the biodiversity value of peatland areas (see chapter 5).

## 2.3 Peat formation

**The accumulation of peat implies an imbalance in the production and the decay of dead organic (plant) material.**

Such imbalance may be caused by both the production side and the decay side of the process. A high production rate is stimulated by ample availability of plant nutrients ($CO_2$, P, K, N), water, and warmth. A high $CO_2$ concentration in the atmosphere has probably been responsible for the enormous accumulation of peat in the Carboniferous and Tertiary periods that has been passed on to us as coal and lignite (Lyons & Alpern 1989, Cobb & Cecil 1993, Demchuk et al. 1995). While NPK-fertilization and higher temperatures may lead to higher production, decay rates generally are even higher. This therefore frustrates peat accumulation (Clymo 1983).

Differences in the chemical and structural composition of the plant material mean that some plant species and plant parts may produce peat, whereas others do not (Koppisch 2001). The most important reason for peat accumulation, however, is retarded decay due to the abundance of water (Clymo 1983, Koppisch 2001).




**Water is the single most important factor enabling peat accumulation.**
Water-logging is a prerequisite for the creation and preservation of peat. The large heat capacity of water and the large energy demand for vaporization induce lower than ambient temperatures, whereas the limited diffusion rate of gases in water leads to a low availability of oxygen (Ball 2000, Denny 1993). The resulting relatively cold and anaerobic conditions inhibit the activities of decomposing organisms (Moore 1993, Freeman et al. 2001).

**Peat accumulation only takes place when the water level is just under, at, or just over the surface over the long-term.**
When water levels are too low, plant remains decay too rapidly to allow accumulation. Water levels that are too high obstruct the production of plant material because the submersed plant parts are suffocated through lack of oxygen and carbon dioxide (Ivanov 1981, Ingram & Bragg 1984, Alexandrov 1988, Sjörs 1990, Lamers et al. 1999). Peat accumulation therefore only takes place in the range of water "availability" (both in space, with regard to water levels, and time, with regard to seasons), in which the decay of organic material is inhibited more than its production. In areas with deeper and fluctuating water levels a larger part of the organic material decays. This leads to less peat accumulation and more strongly humified peat. Activities that substantially lower or raise the water level in peatlands negatively affect their peat accumulation capacity and their associated functions (Ivanov 1981).

**In different parts of the world, different plant groups and plant parts are the main peat formers.**
Mosses (Bryophytes) determine peat growth in cold (e.g. boreal and subarctic) and wet-and-cool (e.g. oceanic) places (table 2.1). A lack of water-conducting organs enables peat formation by mosses only where water loss by evapotranspiration is restricted. In these areas, where most peatlands are concentrated, peatland science came into being. Therefore moss growth is the central model of peatland development, to the extent that the same words refer to tiny Bryophyte plants and to the extensive peatlands of e.g. Flanders Moss, Lille Vild Mose, and Katin Moch (Prager et al. 2006). This north/west European bias has hampered the recognition of peatlands that are not dominated by mosses.

In more temperate and continental parts of the world, the drier climate forces peat formation to "go underground". There, peat is formed from the downward growing rhizomes and rootlets of grasses (Poaceae) and sedges (Cyperaceae). Peat accumulates in the first 10–20 cm below the surface, as new root material is injected into the older peat soil matrix. In tropical lowlands peat is forms even further under the surface by the roots of tall forest trees (Prager et al. 2006).

Table 2.1: Characteristic peat forming plants in different parts of the Earth (Prager et al. 2006).

| Climatic zones and sections | Dominant peat formers (physiognomy) | Dominant peat formers (taxonomy) | Dominant peat forming plant parts |
|---|---|---|---|
| rctic / Boreal/ Oceanic | Mosses | Sphagnaceae, Hypnales | Stems, branches, leaves |
| Temperate / Subtropic | Reeds | Poaceae, Cyperaceae, Equisetaceae | Rhizomes, rootlets |
| Tropic | Trees | Angiospermae/ Dicotyledoneae | Roots |

**In natural peatlands peat typically accumulates with a long-term rate of 0.5 -1 mm and 10 – 40 tonnes C per km$^2$ per year, with locally strong variation (see chapter 6).**
These general rates may be slower under less favourable climatic or hydrological conditions, such as in the Arctic tundra, or faster, particularly in the tropics (Lavoie et al. 2005, Prager et al. 2006). The peatlands existing today largely originated from the end of the Late-Glacial and in the first part of the Holocene (Halsey et al. 1998, Campbell et al. 2000, MacDonald et al. 2006).

## 2.4 Peatland distribution

**Peat formation is primarily a function of climate. Peatland distribution is therefore concentrated in specific climatic regions.**
Climate determines the amount of water available in the landscape via the amount of net precipitation, while temperature affects both the production and decay of organic material. Accumulation and maintenance of peat is only possible when the balance between production and decay is positive. Peatlands are therefore especially abundant in cold (i.e. boreal and sub-arctic) and wet (i.e. oceanic and humid tropical) regions (fig.1.1). In areas where the precipitation/evaporation balance is less favourable for accumulation, peatlands are only found where landscape features enable water to collect. The scarcity of peatlands in the southern hemisphere is due to the absence of land in the relevant climatic zones. In mountains the zonation in altitude reflects the zonation in latitude (fig. 2.2).

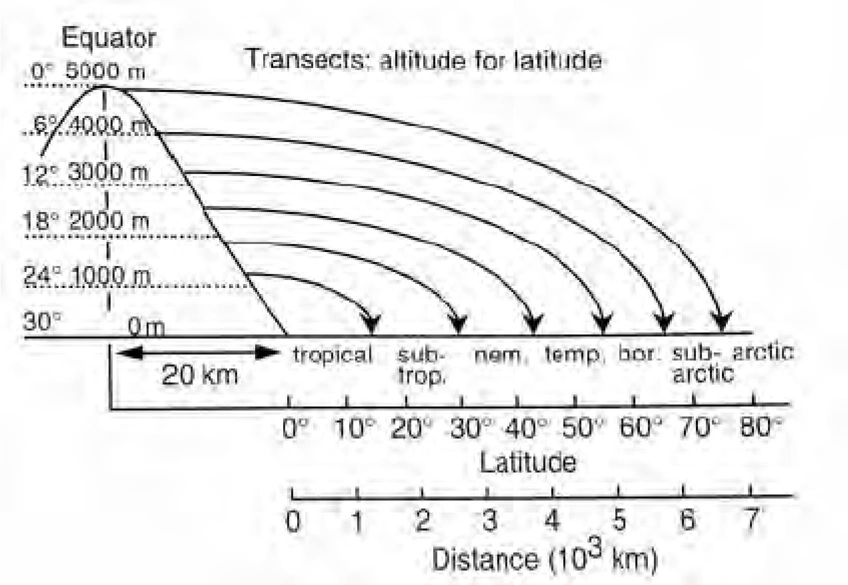



*Figure 2.2: Altitude for latitude: in mountains the climate across vast latitudinal distances is represented over short elevational distances (from Körner 2003).*

**Peatlands prevail on flat surfaces.**
As water-logging requires a flat surface, large peatlands prevail on extensive flat land areas, such as western Siberia, the Hudson Bay Lowlands (Canada), the Southeast Asian coastal plains, and the Amazon Basin (see fig. 1.1). In areas with abundant water supplies and limited water loss, peatlands may also occur on slopes. It is these conditions that can produce blanket bogs and hill slope peatlands.

**Approximately 4 million km$^2$ of the Earth (some 3% of the land area) is covered with peatland (with >30 cm of peat). Peatlands are found in almost every country of the world.**
Peatlands (with >30 cm of peat) cover approximately 4 million km$^2$ (Joosten & Clarke 2002, Lappalainen 1996, cf. Rubec 1996, Zoltai & Martikainen 1996). Peatlands with less than 30 cm of peat

may cover an additional 5 - 10 million km$^2$ (Tjuremnov 1949, Vompersky et al. 1996) and are largely situated in the permafrost regions (Vompersky et al. 1996). Countries with the most extensive peatland area include Russia, Canada, the USA and Indonesia. Together, these countries hold over 60 % of the global peatland area (Joosten & Clarke 2002). No peatlands are as yet known in Libya, Somalia, Saudi-Arabia, Yemen, Oman, Jordan, and Turkmenistan (fig. 2.3, IMCG Global Peatland Database: www.imcg.net/gpd/gpd.htm). The distribution of peatlands across the continents is shown in table 2.2.

Table 2.2: Distribution of peatlands (> 30 cm of peat) over the continents (after Joosten & Clarke 2002).

| Continents | Total area in $10^6$ km$^2$ | % of global land area | Peatlands in km$^2$ | % of land area | % of global peatland area |
|---|---|---|---|---|---|
| Africa | 30.37 | 20.3 | 58,534 | 1.9 | 1.4 |
| Antarctica | 13.72 | 9.2 | 1 | 0.0 | 0.0 |
| Asia | 43.81 | 29.3 | 1,523,287 | 3.5 | 36.7 |
| Australasia (Oceania) | 9.01 | 6.0 | 8,009 | 0.1 | 0.2 |
| Europe | 10.40 | 7.0 | 514,882 | 5.0 | 12.4 |
| North America | 24.49 | 16.4 | 1,884,493 | 7.7 | 45.3 |
| South America | 17.84 | 11.9 | 166,253 | 0.9 | 4.0 |
| Total | 149.64 | 100.0 | 4,155,459 | 2.8 | 100.0 |

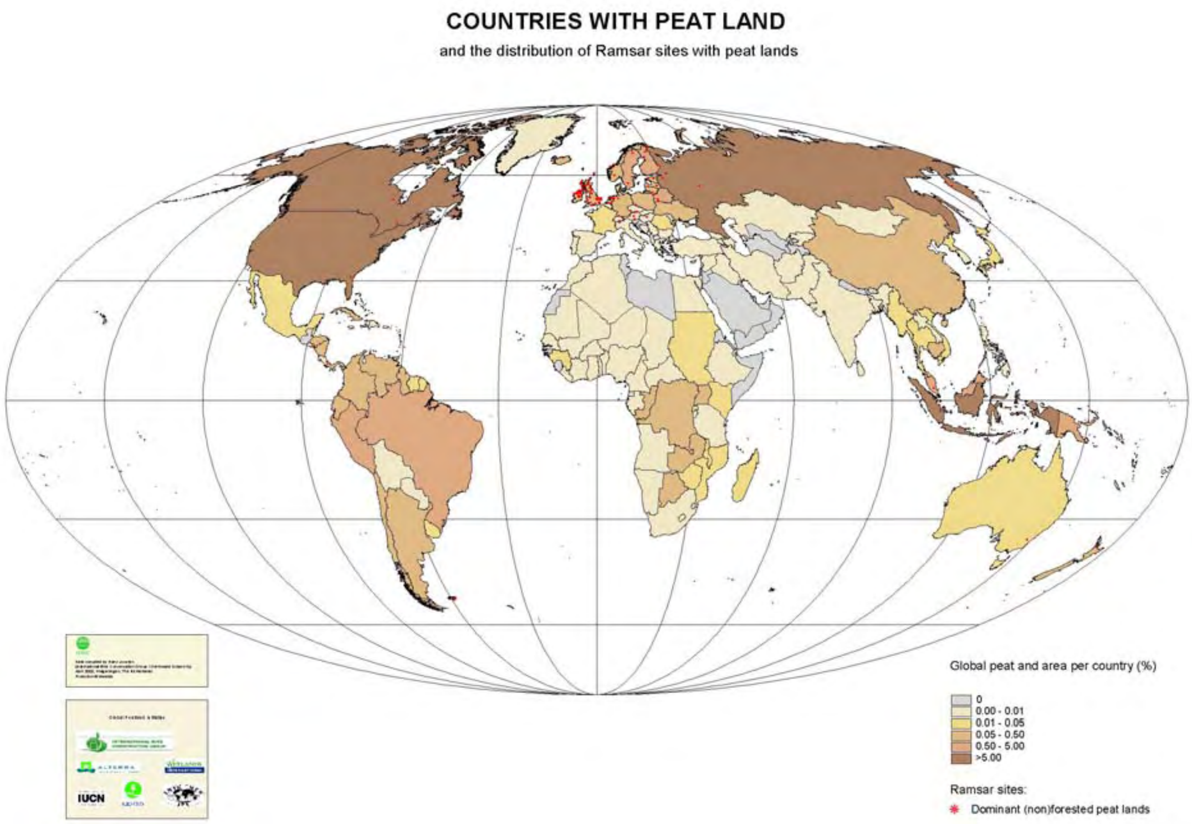



*Figure 2.3: Percentage of the area covered with peatland per country (after Van Engelen & Huting 2002).*

**The general inventory status of peatlands is (largely) inadequate.**

For some regions almost nothing is known about peatlands. This is the case, for example, for large parts of Africa and South America and for the mountain areas of central Asia. Major problems preventing a consistent global overview include a lack of awareness and capacity, typological differences between countries and disciplines, different inventory scales and the use of outdated data.

**Eighty per cent of the global peatland area is still pristine (i.e. not severely modified by human activities). Sixty per cent of the global peatland area still actively accumulates peat.**
The pristine peatlands are concentrated in the (sub)arctic and boreal zones; the modified peatlands in the temperate and (sub)tropic zones (Joosten & Clarke 2002). However, part of the pristine area no longer accumulates peat because of climatic changes. This especially concerns permafrost peatlands and peatlands in the tropics (Vitt and Halsey 1994, Oechel et al. 1993, 1995, Malmer & Wallén 1996, Vompersky et al. 1998, Sieffermann et al. 1988).

**Globally, natural peatlands are destroyed at a rate of 4,000 $km^2$ per year; the global peat volume decreases with 20 $km^3$ per year.**
These losses (Immirzi & Maltby 1992, Joosten & Clarke 2002) largely occurred (and occur) in the temperate and tropical zones. Fifty per cent of natural peatland loss has been attributable to agriculture, 30% to forestry and 10% to peat extraction (Joosten & Clarke 2002).

## 2.5 Peatland ecology and peatland types

**In peatlands *plants*, *water*, and *peat* are very closely connected and mutually interdependent (fig. 2.4). These interdependencies make peatlands vulnerable to a wide range of human interference.**
Plants determine the type of peat that will form as well as its hydraulic properties. The water (hydrology) determines which plants will grow, whether peat will be stored and how much decomposition will take place. The peat structure determines how the water will flow and fluctuate. These close interrelations imply that when any one component changes, the others will change too (Ivanov 1981, Davis et al. 2000). These changes do not necessarily all happen at once, but in the longer run, they inevitably occur. As changes take place in the different components, the mire services may change (fig. 2.5).

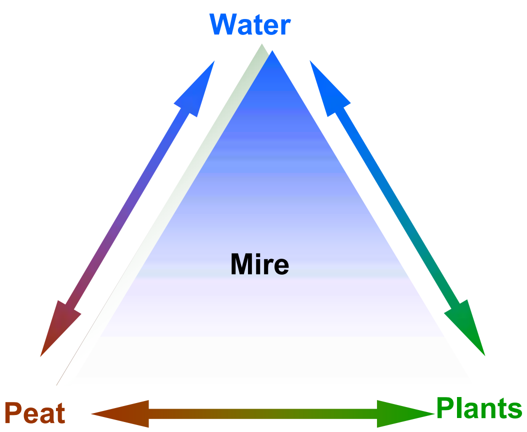



*Figure 2.4: The interrelations between plants, water, and peat in a mire.*

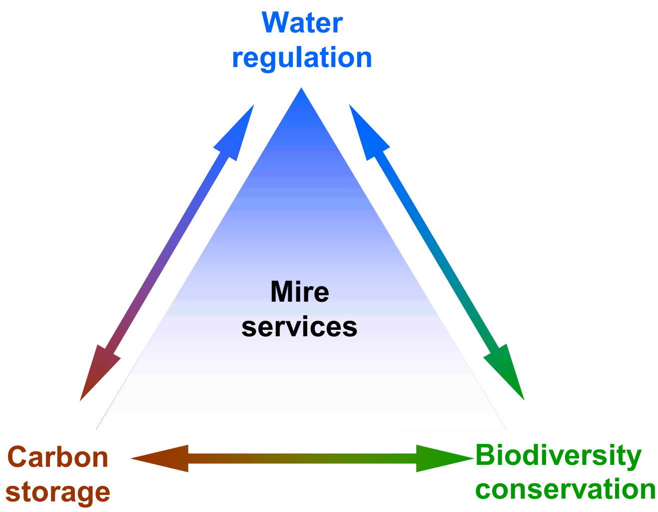



*Figure 2.5: Important services of mires and peatlands.*

**Water flow connects the larger catchment area with the peatland and various parts of a peatland with each other.**
A change in the water flow of the catchment or of part of the peatland may therefore influence every part of a peatland (Kulczyński 1949, Ivanov 1981, Wassen & Joosten 1996, Glaser et al. 1997, Couwenberg & Joosten 1999, Edom 2001b). Such interconnections may function over many kilometres (Schot 1992, Van Walsum & Joosten 1994, Glaser et al. 1997, Wetzel 2000).

**Globally, peatlands are highly diverse, especially with respect to species and community composition (see chapter 5). They have, however, much in common with respect to their ecohydrological functioning.**
A classical distinction is between *bogs* – which lay higher than their surroundings ("high mires") and are only fed by precipitation – and *fens* in landscape depressions ("low mires") – which are also fed by

water that has been in contact with mineral soil or bedrock (Fig. 2.6). Bogs prevail in wet climates whereas fens are ubiquitous.

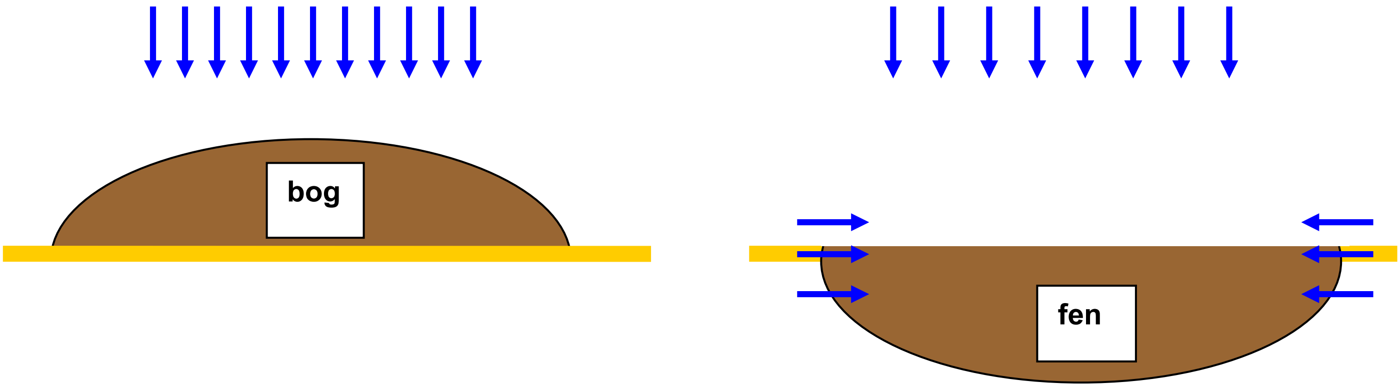



*Figure 2.6: The classical difference between "bog" and "fen" peatlands. Shaded = peat.*

**Acidity and nutrient availability particularly determine plant diversity in natural peatlands.**
Precipitation water is poor in nutrients and somewhat acidic. Through contact with the mineral soil/bedrock the chemical properties of the water may change. As a result, peatlands in different hydro-geological settings receive water inputs of different quality (Joosten & Clarke 2002).

On the basis of acidity (base saturation) and nutrient availability (trophic conditions) different "ecological peatland types" are distinguished (table 2.3, fig.2.7). The mesotrophic buffered (slightly acid and calcareous) peatland types are particularly threatened worldwide. Rare and threatened peatland plants mostly occur under carbonate-rich/subneutral and oligo-/mesotrophic conditions (mostly with P limitation, Wassen et al. 2005). The dependence of local peatland conditions on the quality of the incoming groundwater necessitates a thorough assessment of the relationship between the hydrology and the surroundings.

Table 2.3: Ecological mire types and their pH characterization after Sjörs (1950). The pH trajectories are largely determined by chemical buffer processes and therefore probably have a worldwide validity.

| **Peatland type** | **pH range** |
|---|---|
| bog | 3.7 – 4.2 |
| extremely poor fen | 3.8 – 5.0 |
| transitional poor fen | 4.8 – 5.7 |
| intermediate fen | 5.2 – 6.4 |
| transitional rich fen | 5.8 – 7.0 |
| extremely rich fen | 7.0 – 8.4 |

**The functions and functioning of peatlands are strongly dependent on their hydrological and genetic features (including their position in the landscape and the conditions of peat formation).**
Classically a distinction is made between *terrestrialization*, when peat develops in open water, and *paludification*, when peat accumulates directly over a formerly dry mineral soil (Fig. 2.8). In *terrestrialization peatlands* peat formation takes place in floating mats (e.g. *Papyrus* islands) or under water on the bottom of the lake (e.g. many *Phragmites* stands). Peatlands may also form on formerly dry soils when the water level in the catchment rises slowly due to external reasons (*water rise peatlands*). *Flood peatlands* are periodically flooded by rivers, lakes or seas. Without externally induced water level rise (due to climate change, changes in land use, rising sea levels, rising river beds, beaver dams, the origin of stagnating layers in the soil, etc.) all these *horizontal* peatlands only accumulate peat for a limited time.

**Of special importance for carbon sequestration and water regulation are *sloping peatlands.* These have an inclining surface plane and mainly horizontal water movement.**
In sloping peatlands the laterally flowing water is retarded by vegetation and peat. As a result, vegetation growth and peat accumulation cause a continuous rise of the water table in the peatland and often also in the catchment area. In this way these peatlands maintain their peat sequestration capacity autonomously. Sloping peatlands are subdivided into percolation, surface flow, and acrotelm peatlands. These are discussed in more detail below.

**Percolation peatlands are found in areas with a large water supply that is very evenly distributed over the year.**
Percolation peatlands are characterized by weakly decomposed or coarse peats (due to roots!) that are highly permeable. Consequently, the water flows via a considerable part of the peat body (Wassen

& Joosten 1996). Percolation peatlands are normally groundwater-fed because only large catchment areas can guarantee a large and continuous water supply in most climates. Groundwater-fed percolation mires are characteristic of the temperate zones. In steadily humid climates such as in the Kolchis lowlands (Georgia) ombrogenous *Sphagnum*-dominated percolation peatlands (percolation bogs) exist (Haberl et al. 2006).

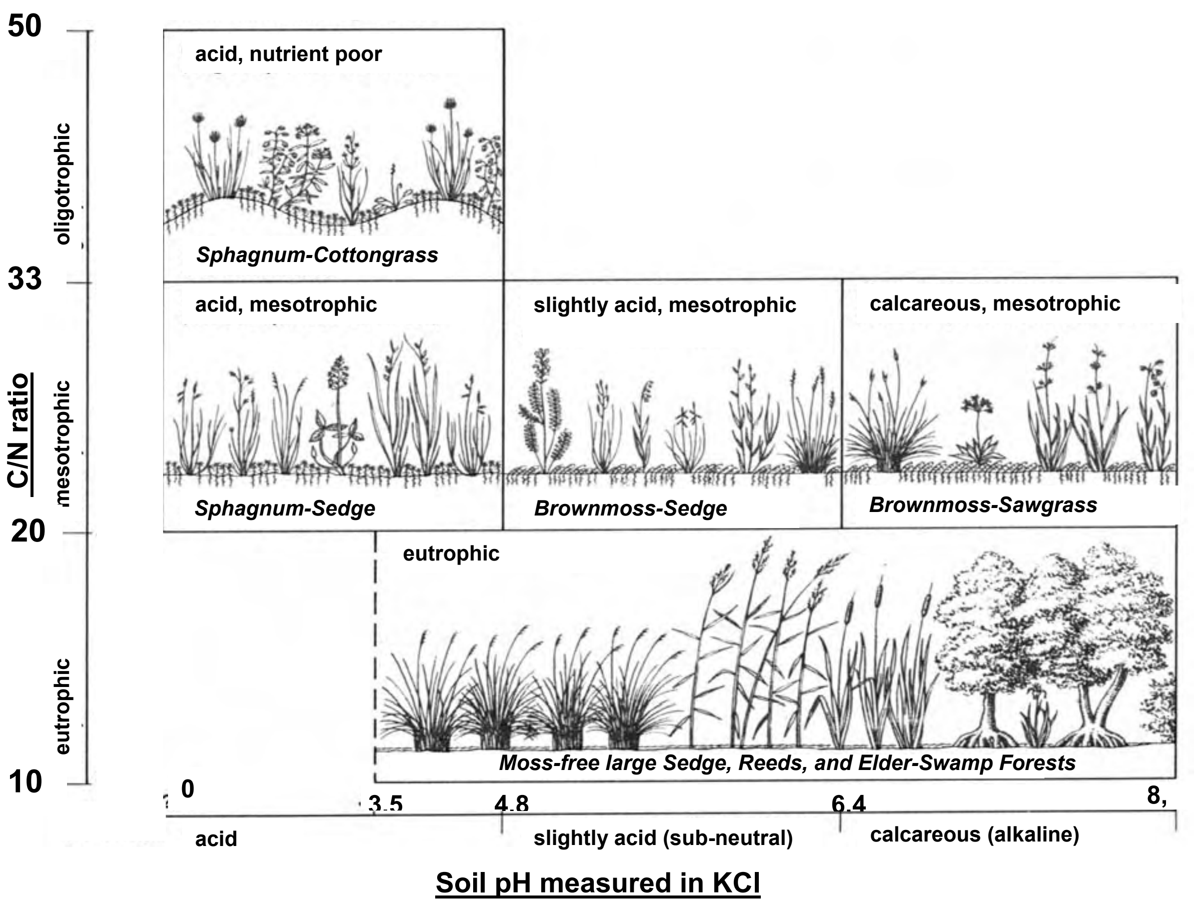



*Figure 2.7: Ecological mire types for Central-Europe with their characteristic ranges of soil pH (measured in KCl) and N/C ratio (Kjeldahl nitrogen determination). After Succow & Joosten (2001).*

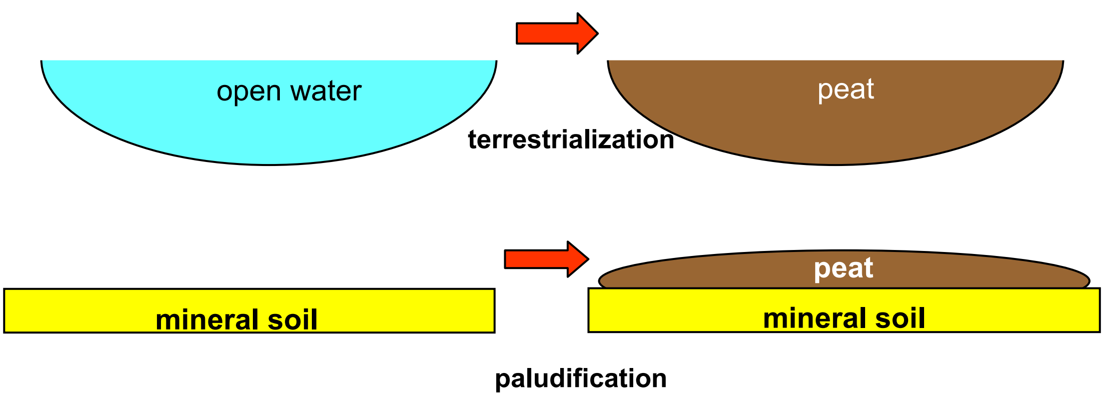



*Figure 2.8: The difference between terrestrialization and paludification.*

**Surface flow peatlands are found in areas with an almost constant water supply but with short periods of net water losses.**

In the short periods of water deficit, oxygen penetrates the peat. The resulting stronger decomposition and compaction make the peat less permeable, forcing the water to overflow the mire surface. Because of the low hydraulic conductivity of their peats and the large water supply, surface flow peatlands can occur on, and with, steep slopes. Three subtypes of natural surface flow peatlands can be distinguished: *Blanket bogs* – these are solely fed by rainwater and only occur under very oceanic conditions. *Hill slope peatlands* – these are additionally fed by (near-) surface run-off from the surrounding mineral slopes. S*pring peatlands* – these are largely fed by artesian groundwater; their peats often include carbonates and silicates that have precipitated from or washed in with the groundwater.

**Acrotelm peatlands occupy an intermediate but very special position.**
The plant material they produce is very resistant to decay and so the top decimetres of the peatland are little decomposed, open and permeable. Water flow is largely confined to these top layers. The distinct gradient in hydraulic conductivity in the top layers, combined with its large storage capacity, constitutes a very efficient water-level regulation device, the so-called *acrotelm*. Globally, the *Sphagnum*-dominated *raised bog* is the most important acrotelm peatland type. The global distribution of raised bogs, far beyond the area where percolation and surface flow peatlands may exist, illustrates the effectiveness of the acrotelm regulation mechanism (Joosten 1993). Also many tropical swamp peatlands may be assigned to this type (Joosten submitted).

**As a result of water, vegetation, and peat interacting over an extensive period of time ("self-organisation"), sloping peatlands develop high levels of internal coherence and autonomy, reflected in their typical shapes and sophisticated surface patterns.**
Peatlands are not merely a type of land cover. Many sloping peatlands develop high levels of internal coherence, self-regulation, and autonomy and almost organismatic properties (Ivanov 1981, Joosten 1993). This is expressed in the development of sophisticated patterning, such as those in string mires/aapa fens, plateau bogs, concentric bogs (fig. 2.9), and eccentric bogs (Glaser 1999, Couwenberg 2005, Couwenberg & Joosten 1999, 2005).The presence of such patterns has large consequences for biodiversity, water flow, and greenhouse gas emissions.

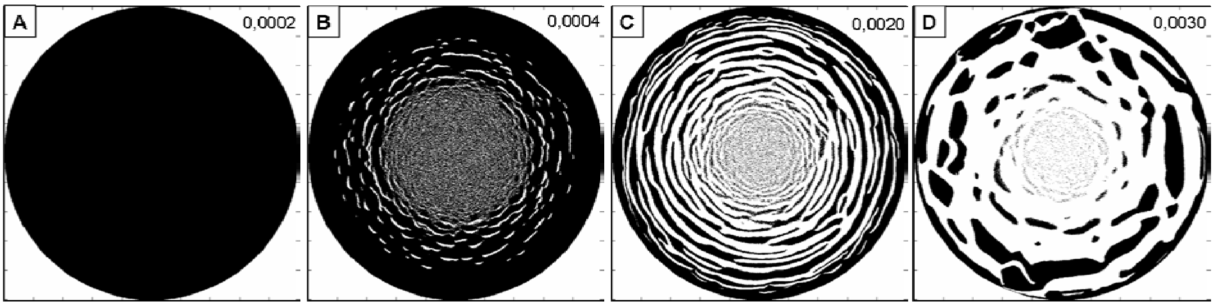


*Figure 2.9: Bogs change their surface patterns but not their overall functioning consequent on climate change. The sequence shows the effect of increasing precipation (from Couwenberg & Joosten 2005).*

**Self-regulation of raised bogs**
To guarantee continuous water logging of the peat deposit under conditions of strongly varying water supply and losses, a raised bog has several regulatory mechanisms:
- Sphagnum plants turn white under dry conditions so that more sunlight is reflected
- The acrotelm, the uppermost part of the peatland with a typical vertical decrease in water conductivity, stops water outflow under dry conditions
- The peatland surface moves up and down with water supply and losses ("Mooratmung")
- Peat moss species become less permeable with little water supply and more permeable with larger water supply
- Less permeable and less evaporating hummock vegetation expands under drier conditions; more permeable and more evaporating hollow vegetation under wet conditions
- The extent and large-scale arrangement of these vegetation types change with changing hydrological conditions (fig. 2.9, Ivanov 1981, Joosten 1993, Couwenberg & Joosten 2005).

These self-regulation mechanisms make bogs less sensitive to climate change than many other ecosystems.

**External mechanisms, specifically ice formation and permafrost may contribute to the configuration of peatland macro- and micro-patterns.**
Ice formation in the arctic, subarctic and boreal zones give rise to specific morphological peatland types (Tarnocai & Zoltai 1988, Zoltai & Pollet 1093, Zoltai et al. 1988). These include *polygon mires* in areas with continuous permafrost (Minke et al. 2007) and *palsa* (frost mound), and *peat plateau mires*

in areas of discontinuous permafrost. The relationship between peatlands and permafrost is reciprocal: specific peatland types are created by permafrost, whereas peatlands cause the development of permafrost in the zone of discontinuous permafrost.

**Peatlands are ecosystems with extraordinary characteristics for biodiversity conservation, water regulation, and carbon storage/sequestration and deserve more attention.**

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# Chapter 3: Peatlands and people

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**Summary points:**

1. **Peatlands and people are connected by a long history of cultural development; the livelihoods of substantial parts of rural populations in both developed and developing economies still significantly depend on peatlands.**
2. **From the tropics to the arctic the environmental security and livelihoods of indigenous cultures and local communities depend on peatland ecosystem services and the steady supply of natural peatland resources.**
3. **The value of peatlands as an ecosystem providing crucial ecological, hydrological and other services has generally been disregarded.**
4. **People have usually treated peatlands as wastelands, using them in many destructive ways, without taking the long-term environmental and related socio-economic impacts into account.**
5. **The main human impacts on peatlands include drainage for agriculture, cattle ranching and forestry, peat extraction, infrastructure developments, pollution and fires.**
6. **Deterioration of peatlands has resulted in significant economic losses and social detriment, and has contributed to tensions between key stakeholders at local, regional and international levels.**
7. **Lack of awareness and insufficient knowledge of peatland ecology and hydrology has been a major root cause of peatland deterioration.**
8. **The key economic, cultural and environmental role of peatlands in many human societies calls for a "wise use" approach that minimises irreversible damage and sustains their capacity to deliver ecosystem services and resources for future generations.**

## 3.1 Human – peatland interactions

**Peatlands and people are connected by a long history of cultural development.**
Peatlands have always been part of human history. Since pre-history, hunter/gatherers and traditional farmers have exploited peatlands by harvesting plants, game and fish, forage, fuel and other useful products. Bog bodies, tools, ornaments, weapons, and other archaeological remains found in abundance in peatlands testify to the long and intimate relationship between people and peatlands during the whole Holocene (Joosten in press). Historical accounts describe people who lived in and depended almost entirely on wetlands, from the "half amphibious" Fen Slodgers in the English Fenlands (Wheeler 1896) to the wetland peoples of recent times, such as the Marsh-Arabs (Ma'dan) of Southern Iraq (Thesinger 1964) and the Kolepom people in Irian Jaya (Serpenti 1977). Large-scale human modification of peatlands for agriculture started with the origin of rice cultivation in China about 6000 years BC (Glover & Higham 1996). The Minyans drained and subsequently cultivated the Kopais basin in Greece 3,500 years ago (Knauss *et al.* 1984). Some centuries later, the Babylonians established municipal reedbeds and harvested bulrushes for construction purposes (Boulé 1994). Peat bogs were also a primary source of bog iron, used since the Iron Age.

**Generally peatlands are considered as wastelands that are of no use unless they are drained, logged or excavated.**
In the past, peat landscapes were both feared and respected as wilderness areas and often linked to traditional culture, rituals and worship. Moreover, until modern times their ecosystem services and their very peat-land character, being unobtrusive and sub-surface, have generally remained unnoticed. This has resulted in a lack of appreciation of the needs for cautious development. As peatlands are "too wet to plough and too dry to fish" most people avoided them. Their limited accessibility protected them against large-scale human interventions and has often turned them into political, cultural, and language borders.

**Interactions between human and peatland can create far-reaching environmental and economic impacts.**
Whereas many peatland development activities are considered on basis of short to medium term economic interests the environmental, social and economic impacts can be far reaching and may span many generations. In many cases this is related to the gradual nature of the impacts of changes in peat hydrology and the related soil sub-subsidence and carbon emissions, which places the burden of impacts on future generations.

The history of peat development in the Netherlands provides a clear example (see box). It will be of interest to consider how future generations will look upon the current peatland degradation and related greenhouse gas emissions in the light of climate change impacts that they may experience, or perhaps the new opportunities that will emerge.

**Interest in peatland resources may fluctuate and re-emerge suddenly in times of crisis or opportunity.**
Whereas the use of peatlands for agriculture and as fuel resource has significantly declined over the last decades, in situations of economic crisis, peatland may suddenly become of interest again. For example the use of peat as fuel intensified in Ireland during World War II when the supplies of coal from Great Britain almost ceased. Currently, interest in peat as fuel is increasing in parts of the world with limited access to other fuels.

Large scale development of SE Asian peatlands started only in the 1960s as a result of population pressures, geopolitical interests and access to loans for large scale land-use development projects. Many peatlands were the subject of official and spontaneous transmigration schemes (Silvius et al 1984). Timber extraction of peat swamp forests has been a major – albeit ecologically unsustainable – cash earner, providing temporary employment, local income, jobs and business opportunities.

Over the last few decades the tropical lowland peat swamp forests of Malaysia and Indonesia have been the target of rapid and large-scale developments of oil palm and pulpwood plantations, driven by both local and global demands for these resources. Global policy changes in 2006/2007 demanding increased use of biofuels in transport and energy sectors has augmented these pressures, despite the fact that palm oil produced on peat actually leads to higher $CO_2$ emissions than burning of fossil fuels (Hooijer et al. 2006).

In the Netherlands, extensive drainage of peatlands for agriculture began in the 8th century, providing excellent yields of cereals. The availability of cheap energy from peat contributed substantially to the development of Holland as a major trade area in the 17th century. However, subsidence of the peat surface was inevitable (despite water control efforts using polder technology), eventually leading to the end of peatland-based arable agriculture. Peatland use changed since then towards dairy production (Borger 1992).

Over the last 50 years, the main developments on peatland in the Netherlands have been urban expansion and nature conservation. Large parts of the country are now lying below sea level, requiring major investments in flood protection both along the coast and along rivers.

This history illustrates the far-reaching impacts peatland drainage, mining and agriculture can have both on the environment and on human society. The changes made to the natural environment, especially the increased vulnerability to flooding, were irreversible. To cope with these impacts, trade profits and the increased availability of labour due to declining agriculture triggered technological developments, water management and the search for new sources of income (Gerbens-Leenes & Schilstra 2004).

Dutch water management skills have become a major export product. Peatlands are becoming a key part of the ecological networks of the Netherlands and provide opportunities for nature tourism and recreation.

## 3.2 Benefits of peatlands

**Peatlands are of considerable value to human societies due to the wide range of goods and services they provide.**
Peatlands help maintaining food and other resources and have functional significance far beyond their actual geographical extent. The benefits provided are:

a. **Regulation functions (ecosystem services)**
b. **Production functions**
c. **Carrier functions**

**d. Information functions**

The following sections provide a brief overview of these benefits.

### 3.2.1 Regulation functions (ecosystem services)

**Peatlands play a significant role in regulating the global climate, being one of the major sinks of atmospheric carbon and a source of greenhouse gases including carbon dioxide, methane and nitrous oxide.**

Peat accumulation involves the sequestration and storage of carbon from the atmosphere. The amount of carbon currently stored in peatlands equals approximately 75% of the total amount of atmospheric $CO_2$ (see chapter 6). Both pristine mires and re-wetted peatlands can emit methane. Almost all types of agricultural and forestry management of peatlands require drainage, which results in peat oxidation and the release of the stored carbon back into the atmosphere as $CO_2$. Human-induced fires in the degraded Indonesian peatlands may release amounts of carbon equivalent to 40 % of the global annual emissions from fossil fuels (Page et al. 2002). Peatlands used for agriculture are important sources of nitrous oxide. Thus the way in which people manage peatlands plays a significant role in managing climate change.

**Peatlands regulate local climates. The specific mesoclimate of peatlands influences regional and local climates through evapotranspiration and the associated alteration of heat and moisture conditions.**

The influence on micro and mesoclimate is larger in warmer or drier climates and smaller when the regional climate is colder or more humid. Consequently, in areas with extensive peatlands, the regional climate is cooler and more humid (Edom 2001). Drainage of mires in the boreal zone leads to a reduction in minimum temperatures and a shortening of the yearly frost- free period; a process that is reversed by subsequent afforestation (Yiyong & Zhaoli 1994, Solantie 1999). Similarly, the large-scale conversion and drainage of the Ruwenzori mountain peatlands at the Uganda/Rwanda border may have resulted in increased local temperatures and increased occurrences of malaria at higher altitudes.

**Peatlands play an important role in catchment hydrology with respect to water storage, water quality, the support of groundwater levels and flood and drought mitigation.**

Peatlands often form major components of local and regional hydrological systems. Peatland has the ability to purify water by removing pollutants (Joosten & Clarke 2002). Large peatland bodies may regulate the surface- and groundwater regime and mitigate droughts and floods. For example, tropical peat swamp forests serve as overflow areas in flooding periods, while in the dry season the stored water is slowly released (Klepper 1992). Riparian peatlands such as in the floodplain of the Pripyat River in Belarus store floodwaters, resulting in a downstream reduction of velocity and volume of peak discharges (Belakurov et al. 1998). Coastal peat swamps act as a buffer between salt- and freshwater systems, preventing saline intrusion into coastal lands. Scenario studies of the Air Hitam Laut river basin (Sumatra) demonstrate that reclamation of upstream peatland areas will dramatically reduce water flow to downstream and coastal areas, which can lead to increasing droughts, salt water intrusion and acidification of potential acid sulphate soils downstream (Silvius 2005; Wösten et al 2006).

**The water storage and retention function of peatlands is locally important for the supply of drinking water and for the irrigation of agricultural lands.**

In regions where catchment areas are largely covered by peatlands, as well as in drier regions where peatlands indicate a rare but steady availability of water, they can play an important role in maintaining water supplies for drinking and irrigation water. For example, much drinking water in Scotland is derived from peat-dominated catchments. Where or when other water resources are rare (e.g. in the dry season), mires and peatlands can be important as sources of water, for example, in the Andes, KwaZulu-Natal, Sarawak, Kalimantan, and Sumatra (Hooijer 2003, Silvius et al 1984). In the Sarawak coastal peatlands, some 25 Public Works Department supplies rely on stream water draining from the peat swamps, providing 70,000 people with high quality potable water (Rieley & Page 1997). Such water resources can also be important for the irrigation of agricultural areas.

### 3.2.2 Production functions

**The capacity of peatlands for agricultural production is – without intensive management (drainage, fertilization) – generally low.**

In their natural state, peatlands have only marginal agricultural capability (Melling 1999, Rieley & Page

1997), thus restricting their use. Important characteristics that inhibit agriculture are the very high groundwater table, the low bulk density and bearing capacity, the high acidity, the low availability of nutrients, and their subsidence upon drainage. Conventional agriculture involves drainage, fertilizing, tilling, compaction and subsidence, which eventually cut short the sustainability of peatland agriculture (Succow & Joosten 2001).

Approximately 14% of European peatlands are currently used for agriculture, mainly as meadows and pastures. Also in North America, extensive areas of peatlands are cultivated for agriculture, as pastures and for sugar cane, rice, vegetables, and grass sods. The commercial production of cranberries on peatlands in North America is a major business enterprise with a production of 6 million barrels. Large-scale cultivation in SE Asia is largely for estate crops (mainly palm oil, coconut and some sago) and rice. Sarawak is now the world's largest exporter of sago, exporting annually about 25,000 to 40,000 tonnes of sago products. Indonesia and Malaysia are the world's largest palm oil exporters, each covering 43% of the global production (Ref…).

**Much of the small-scale but widespread agricultural encroachment in tropical peatlands is linked to severe poverty. Large-scale encroachment is mainly linked to palm oil development.**

Agricultural development of tropical peatlands in South-east Asia only started a few decades ago. On shallow peat these developments have lead to the disappearance of the shallow peat layers as a result of drainage and ensuing oxidation. The agricultural successes are mainly due to the qualities of the surfacing sub-soil. As a result of continuous land hunger, however, even the deeper peatland areas have become the target of agricultural development. Only few commercial crops grow well on peatlands, including pine apple and oil palm. More recently the dryland species *Aloe vera* has been introduced in Indonesia to the desiccated peatlands and is falsely propagated as a "sustainable" crop. New commercial and sustainable crops may include the indigenous Jelutung tree (*Dyera* sp., also known as the chewing gum tree, as it produces the latex that is used in chewing gum), which can grow under non-drained conditions. Interesting commercial potential for local communities is the development of fishponds in closed drainage canals. In addition, many tropical black-water fish species are of interest to the aquarium industry. New development opportunities are very much needed as poverty levels in Indonesian peatlands are generally 2 to 4 times higher than in other areas.

Table 3.1: Peatland used for agriculture in selected countries (After Joosten & Clarke 2002; Hooijer et al 2006; JRC 2003)

| | Peatland used for agriculture ($km^2$) | % of total peatland |
|---|---|---|
| Europe | 124 490 | 14 |
| Russia | 70 400 | 12 |
| Germany | 12 000 | 85 |
| Poland | 7 620 | 70 |
| Belarus | 9 631 | 40 |
| Hungary | 975 | 98 |
| Netherlands | 2000 | 85 |
| USA | 21 000 | 10 |
| Indonesia | 60 000 | 25 |
| Malaysia | 11 000 | 45 |

Recent poverty induced agricultural encroachment has left over 80% of South Africa's coastal peat swamp forests denuded of its original vegetation. Communities have nowhere else to go and after the soil nutrients have been depleted, they move on to the next patch of remaining peat swamp forest (pers.obs.).

Agricultural development is also taking place in the high mountain peatlands of the Andean Paramos at over 3000 m altitude. Also in these "high mountain water towers" agriculture goes hand in hand with drainage and fires and the practices are clearly not sustainable. The resulting decreasing water retention capacity may jeopardise the water supply to agricultural communities and cities downstream (Bermudes et al, 2000, Hofstede et al, 2002).

**Peatlands are used for forestry all over the world.**

Extensive commercial forestry operations have been established on peatlands in many nations. Exploitation of naturally forested peatland is practiced in northern boreal mires throughout Scandinavia and Canada. The dominant species are mostly coniferous (Black Spruce *Picea mariana*, Scotch Pine *Pinus sylvestris*). The growth of these commercially useful species is limited by waterlogging. Therefore, drainage has been used in many areas to provide greater economic returns. Afforestation of open mires is a more fundamental alteration of the peatland system. It involves major change to the physical and hydrological conditions due to ploughing and drainage, major structural alteration to the vegetation, and the introduction of non-native species. Afforestation is especially common in the blanket and raised mires in oceanic western Europe (British Isles, northern Scotland). Tropical peat forests include substantial quantities of commercial tree species and yield some of the most valuable tropical timbers. Ramin (*Gonystylus bancanus*) and Agathis (*Agathis dammara*), for example, contribute almost 10% of Indonesia's exports of forest products. Also in Malaysia, logging of peat swamp forest plays a very important role in the economy, especially in Sarawak which has major peat swamp forest reserves. More recently, large tracts of peat swamp forest in Sumatra have been granted in concession to pulp-and-paper companies, like APRIL and APP. The establishment of the pulp plantations (*Acacia sp.*) involves the deforestation of the original peat swamp forests, soil compaction and drainage.

**Peat as an energy source is only important for regional or domestic socio-economic reasons, because it is more expensive and emits more $CO_2$ per unit energy than other fossil fuels.**
The use of peat as an energy source has been established since at least two millennia. At present peat only contributes marginally to worldwide energy production, but at the local and regional scale, peat can still be an important energy source, particularly in Finland, Ireland, and Sweden. It also continues to be important in the Baltic States, Belarus, and Russia. In recent years technical developments have led to lower, more competitive peat prices.

As peat is more expensive and emits more $CO_2$ per unit energy than other fossil fuels, peat as an energy source is only interesting for regional or domestic socio-economic reasons. In Finland and Ireland employment in rural areas is the most important motive for peat energy, whereas in eastern countries, independence from Russian oil and gas imports and the lack of foreign currency are important driving factors.

**Peat is widely used as a growing medium in horticulture and as a soil conditioner.**
Peat substrates are used particularly in glasshouse horticulture for the cultivation of young plants, pot plants and for the growing of vegetable crops. It is also sold to amateur gardeners as a soil conditioner. In Europe, approximately 95% of all growing media for the professional and amateur markets are peat-based. The total global production amounts to a use of around 30 million tonne peat per annum, of which approximately one-third is used for agriculture and one-third for energy (Joosten & Clarke 2002). Although alternative materials are emerging, these may not yet available in sufficient quality and large enough quantities to replace peat.

> The IPCC Guidelines (IPCC 2006) provide a default for peat calorific value of 9.76 GJ/t peat and an emission factor of 28.9 kgC/GJ = 106 kg$CO_2$/GJ (compared to <100kg$CO_2$/GJ for various types of coal). Countries may adjust these values to national circumstances. There is not much room for adjustment, however, as the emission factor for peat is largely determined by chemical properties that cannot be altered (Couwenberg 2007, Joosten & Couwenberg 2007

**Peat is also extracted for small-scale uses.**
In addition to fuel and horticulture, there is a variety of other uses of peat that involve the extraction of smaller amounts. These include: raw materials for chemistry, bedding material, filter and absorbent material, peat textiles, building and insulation material, therapeutic uses (balneology), and peat as a flavour enhancer (e.g. in whiskey) (Joosten & Clarke 2002).

**Peatlands provide many plant species that are utilized for food, fodder, construction and medicine**.
One of the oldest and most widespread utilization of wild peatland plants is their use as straw and fodder for domestic animals. For example, in Poland 70% of the peatlands was used as hay meadows and pastures. A second important use, especially in the temperate and boreal zones of Eurasia, is the collection of wild edible berries and mushrooms. Cloudberries (*Rubus chamaemorus*) are an important dietary supplement for many Arctic residents as well as a source of cash income. In Finland, the estimated yield at the turn of the 20th century amounted 90 million kg. In the north, wild plants are used for a great variety of purposes (see box). Their use today is, however, declining, as is the knowledge required to find, identify, and gather such plants.

Tropical peat swamp forests provide a wide range of products, such as edible fruits, vegetables, medicinal and ritual plants, construction material (wood, rattans, bamboo), fibres and dyeing plants, firewood and traded products like rattans, timber and animals. Important timber species are Ramin (*Gonostylus bancanus*) and Meranti (*Shorea* sp.). Both timber and non-timber forest products (NTFPs) are, besides providing employment and contributing to state and federal revenues, central to the well-being and livelihood of local indigenous communities, such as Dayak and Iban. Socio-economic studies indicate that in Indonesia local community livelihoods may depend for over 80% on the peat swamp forest rather than on agriculture. NTFPs provide cash income to supplement daily expenses or are a ‘safety net’ in time of need. Moreover, they represent an essential part of subsistence culture and heritage. To the Dayak, the forest landscape is not only viewed as a collection of biodiversity, but also as a meaningful object for their social, economic, politic, and cultural lives (the concept of "*Petak Ayungku*"). The forest functions are a strong chain that binds all members of the Dayak communities of the past, present, and future. (Colfer and Byron, 2001)

**The use of wild plants among Nenets nomadic tundra communities**
Present patterns of plant use still follow the old tradition of a reindeer-herding culture. Few plants are used as food, whereas medicinal plants and plants for other practical purposes are more important. The Nenets (Gyda Peninsula, northern Siberia) have names for all species of importance for the reindeer and themselves. All other species are just called "plant" (*namted*). Some 30 species of plants are used. Most important are *Betula nana* and *Salix* spp. for firewood. *Salix* and graminoids are collected for making covering mats used in the tipi (*chum*). *Cladonia arbuscula* is used for cleaning wounds, while *Ledum palustre* is used as tea, in washing water after childbirth, in cleaning rituals after burials, and as a ceremonial drug by the shamans. Another important medicinal plant is *Veratrum album* which is used against intestinal worms. Moxibustion with a fungus (possibly *Piptoporus betulinus*) is popular among the Nenets and the fungus is also used in tea as a healing drink. Peat mosses *Sphagnum* are among the most important plants. They are divided into "white", "red" and "brown" moss. The white moss is used for absorbing fluids, e.g. as nappies, in shoes or for cleaning tables. The red moss is used as bandages, whereas the brown moss indicates drinkable water in small ponds. Most popular is tea made from the leaves of *Comarum palustre*. Other popular food plants are the leaves of *Oxyria digyna* and *Rumex*, and roots of *Pedicularis*. Berries, especially *Rubus chamaemorus* (Cloudberry), are picked mostly by children. Thin *Betula pubescens* carvings are used in baby cradles and are often traded in the nomads' winter locations.

**Peatlands may also be significant for hunting and fishing.**
Fur-bearers such as coyote, racoon, mink and lynx, and game species such as grouse, ducks, geese and moose are often found in peatlands. In North America, black bears, hunted for food, fur, and traditional medicine (bladders), are also frequently found in peatlands. Wild reindeer (caribou in North America) are hunted for meat for local markets as well as for subsistence. An estimated 250,000 people in the Eurasian Arctic depend on reindeer as a major food source. Caribou meat and hides are marketed in Canada on a small scale, and in both Alaska and Canada caribou are hunted recreationally, generating income for guides, outfitters, and the service industry. For animal species that do not directly depend on peatlands, the habitat may contribute substantially to their continued presence in populated regions where few areas other than peatlands provide safe havens away from direct human disturbance.

Peatland waters harbour many fish species, which in some regions, in addition to providing an important protein source to local communities, can be an object of sports fishing, generating income in sales of fishing equipment and licences. Tropical black water fish diversity is extremely high. Black water species are attractive to sport fishing and the often very colourful species are attractive for the aquarium industry.

Peatlands and tundra with shallow peat are crucial habitats for reindeer throughout the circumpolar region. They serve as a refuge from predation and, more importantly, as a source of forage. Reindeer are very selective foragers. During spring and early summer, they depend greatly on peatland plant species such as early sprouts of cotton grass (*Eriophorum vaginatum*) or bogbean (*Menyanthes trifoliata*). This food source plays an important role in the growth of calves because of its high protein content. Later on, other species become also important such as herbs (*Eriphorum angustifolium, Equisetum fluviatile, Rubus chamaemors, Carex* sp.), willow (*Salix* spp.), deciduous trees and shrubs (*Vaccinium myrtillus*). Summer forage significantly affects the condition of reindeer and their survival over winter. Ground lichens (*Cladina* sp.*, Cetraria* sp. *and Cladonia sp.*) are a major winter food source.

### 3.2.3 Carrier functions

**Peatlands provide space for urban, industrial and infrastructural development.**
Peatlands are generally uninhabited which makes them attractive to a wide variety of land use options including building construction, waste disposal and even military exercises. Substantial peatlands are located in coastal areas, where over 50% of the world's population lives. Major cities like Amsterdam and St. Petersburg are largely built on peat. Their location near to coastlines makes it tempting to convert mires and peatlands to provide infrastructure for towns and harbours, as can currently be observed in Southeast-Asia. Being often related to low relief, peatlands provide suitable locations for water reservoirs.

Vast areas of peatlands in Western Siberia and Alaska (Prudhoe Bay) have been affected by expanding infrastructure for oil exploration, exploitation, and transport. In Georgia (Caucasia) new harbours and railroads are currently being constructed in protected mires that are of international importance for biodiversity conservation, in order to carry oil from Azerbaijan to the Black Sea (Krebs & Joosten 2006).

Peatlands in the UK, Ireland and the USA are increasingly targeted for wind and hydro-electric energy development. The production of such “green” energy may have negative environmental impacts on the peatlands, including significant greenhouse gas emissions, that should be taken into account.

### 3.2.4 Information functions

**Peatlands are major contributors to the natural diversity of the temperate, boreal and sub-arctic regions of both hemispheres, as well as in some tropical areas**.
The variety of peatland types provides a rich source of ecosystem diversity. Whereas their species diversity in general is low compared to mineral substrate habitats, they are important sources of genetic richness, as they contain specialized organisms including many rare or endangered species. Peatlands are also important refuge areas, with many relict species. For animal species that for their survival do not directly depend on them, peatlands may contribute substantially to their continued presence in populated regions where few areas other than peatlands provide safe havens away from human disturbance. For example, SE Asian tropical peat swamp forests are important for the survival of many species that have become rare in other habitats such as the Sumatran Rhino, Sumatran Tiger, Malayan Tapir, Storm’s Stork and White-winged Duck. See further Chapter 5.

**Peatlands contain important information on environmental and cultural history.**
Peatlands are valuable for education and research, since they contain important archives of cultural and environmental history reaching back more than 10,000 years. Fossils in the peat matrix, including pollen, plant remains, archaeological artefacts and even human sacrifices, reveal the ecological and cultural history of the peatland itself, its surroundings, and even more distant regions (Joosten & Clarke 2002, see also Chapter 4).

**Peatlands provide significant aesthetic, artistic, cultural, and spiritual values.**
Relatively few people lived or live entirely from and in peatlands. For many more people, peatlands are part of their traditions and have a special place within the ancestral land area, shared with the other members of their community and being part of their spiritual and aesthetic world, frequently occurring in folklore, literature, paintings, and other art (Joosten & Clarke 2002).

**The cultural and aesthetic values of natural and cultural peatlands offer high potential for ecotourism and recreation.**
The limited accessibility of mires and peatlands does not make them particularly suitable for mass recreation. Where facilities are available, however, large numbers of people may visit peatland reserves, e.g. the Everglades NP (USA), North York Moors NP (UK), and Spreewald Biosphere Reserve (Germany) (Joosten & Clarke 2002). In many other countries peatlands are an important part of the national park or protected area networks that attract tourists, such as in Canada, Finland, the Baltic countries, and the Netherlands. Many more mires are used for low- intensity recreation.
Such ecotourism can provide additional income, such as in the Tasek Bera Ramsar site in Peninsular Malaysia where local communities earn additional income by selling traditional handicrafts and guiding boat tours through the swamps (Santharamohana 2003). In Indonesia, Orangutan rehabilitation centres in some peat swamp forest reserves (e.g. Tanjung Putting, Central Kalimantan) attract local

> Tasik Bera, or Bera Lake, is the largest freshwater swamp in Peninsular Malaysia. It sustains the livelihoods of the Semelai, the indigenous people inhabiting the wetlands. The majority of Semelai (total population around 2000) live in Pos Iskandar, a settlement area with five main villages, where they cultivate hill rice, cassava, vegetables, fruit and rubber trees. Traditional Semelai homes are built from forest products such as bamboo (for flooring) and tree bark (for walls). Dependent on the lake and forests, the Semelai fish, hunt and trap wildlife (mainly wild boar and deer) to supplement their income. Wetland and forest products are used to make traps, spears, and canoes. They also practise the traditional collection of "minyak keruing", the resin from the Keruing tree, which is used for making torches, sealing boats and as an ingredient in perfume. Medicinal species, usually planted near the home, are used to fend off fever and other ailments. Their extensive knowledge of both the forest and lake habitats makes them a popular choice as guides among sport fisherman (Santharamohana 2003).

and international tourists. Much of the potential of peatlands as special and intriguing habitats remains unexplored, perhaps also because there is limited experience with the special facilities that could make them more accessible and attractive to visitors.

## 3.3 Peatlands and livelihoods

**Many peatlands are of considerable value in supporting local communities for subsistence.** Human cultures can be substantially dependent on the productivity and/or the ecological and hydrological functions and values of peatlands. These includes e.g. the reindeer herding cultures of nomadic tribes that almost fully depend on arctic and sub-arctic peatland landscapes, central Asian nomads whose livestock mostly depends on pastures on peat soils, small scale subsistence farming communities in the peaty páramos of the high Andes, and the nomadic yak herding cultures on the Tibetan plateau.

| **Raised island culture of Kimaam Island** |
| --- |
| Pulau Kimaam is a 1,146,000 ha large deltaic island in South-east Irian Jaya. Swamps (both tidal and seasonal) cover 98% of the total area. During the wet season, the island is almost completely inundated. The inhabitants (10,200 in total) are highly adapted to this extreme swampy environment. They have developed a unique system of agriculture, which is the primary means of subsistence. Except for some sandy reefs along the coast, all agricultural ground, as well as the ground needed for dwelling houses has to be artificially obtained, except for some sandy reefs along the coast. For this purpose long and narrow islands, made of clay, drift grass and mud, are raised in the marsh to a certain level, depending on the crop to be grown. On these islands coconuts, papaya, root crops, fruit trees etc. are planted, and around the islands floating grass beds are cultivated which are used to regularly build up the continuously declining islands. The garden islands are fertilized by spreading alternate layers of drift-grass and clay. This intensive agricultural use is a practical necessity, since the environment would not allow of a system of shifting cultivation. In fact, the possibility of having intensive agriculture was the main reason for the natives to choose the swamp instead of cultivating on dry land. Their diet is supplemented with a wide variety of edible plants, eggs from magpie geese, and by fishing and hunting. The gardens are still in use even by people who moved to dry land in translocation schemes. (Serpenti 1970; Silvius 1989). |

More often, human communities depend on peatlands for only part of their subsistence. Examples are the Semelai in Peninsular Malaysia (Tasek Bera Ramsar site) or local people eking out a living on the coastal valley peats in Maputaland, South Africa. Other examples include the traditional agricultural systems in central and eastern Europe involving low intensity agricultural use of fens as pastures and hay meadows, the rattan gardens of the Dayak people in the peat swamp forests of Kalimantan, or the widespread subsistence fisheries of riverine communities in the black waters of SE Asia.

| **High altitude peatlands.** | |
| --- | --- |
| **Yak and sheep herding in Tibet.** High altitude peatlands often represent key resources for livestock production because in such particularly scarce and dry environments, peatlands provide relatively high biomass production and water resources. One example is the Ruoergai Plateau in Western China; a relatively flat plateau at 3300-3800m asl in the northeast part of the Qinghai-Tibetan Plateau. This area is rich in peat resources (total peat area of 490,000 ha) and has abundant water resources. Its rangelands rank among China's most productive areas for livestock production. Tibetan pastoralists have depended on the peatlands to support their herds and families for thousands of years. The population of the plateau at present is about 125,000 people, mostly Tibetan pastoralists with vast herds of sheep, yaks and horses. The livestock population of the plateau currently | **Peatlands in the Andean highlands.** The biomass-rich pastures of the *bofedales* (cushion peat bogs) in the Andean highlands, such as the 4000 m high Bolivian Tarija Altiplano, are a vital forage resource for livestock production, since the herbaceous vegetation of dry areas in this region has a very low productivity. The soils rich in organic matter and with adequate moisture for year-round growth are able to support quite high livestock densities. The perennial grasses *brama* (*Distichlis humilis*) and *bramilla* (*Muhlenbergia fastigiata*) grow quickly after rain and are important for grazing, as are other species such as *Chondrosum simplex*. Traditional alpaca herders (*Aymara*) have used theiTarija plateau for over 7,000 years by raising llamas and alpacas as a source of meat and wool. Pastoralism, combined with arable farming and seasonal migration, is also an important element of the |

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| comprises 800,000 yaks, 1,300,000 sheep and 50,000 horses. In recent decades, traditional nomadic pastoralism has been replaced by semi-nomadic and settled systems, that have a larger impact on the fragile grasslands and wetlands. Industrial and agricultural output is valued at US $ 15.6 million, of which animal husbandry comprises 50%. The annual per capita income is about US$ 85. (Yan Zhaoli, 2005; http://www.gefweb.org/wprogram/Jan99/undp/main2.doc; Wetlands International. 2005. ) | livelihoods of other altiplano people. Livestock is important within these livelihoods for minimizing risk. Local people consider livestock as an ambulant bank and as a buffer against adversity. Elsewhere in the Andes the peaty páramos are important to local communities and to some mega cities as water providers. Both traditional and intensive farmers depend on grazing areas in the páramos to feed the oxes needed to plough the steep slopes. (Hofstede et al, 2003) |

**Peatlands are often poverty traps**

Whereas peatlands are valuable in many respects, they are often also poverty traps for local people. Many indigenous people in peatlands are living isolated from the modern economic mainstream. While there is value in the traditional lifestyle, it may also come with hardships, in terms of lack of access to schooling, medical facilities and many other services and facilities that modern society regards as synonymous with wealth. Nevertheless, attempts to push these communities into modern life often creates more poverty and may be more related to interests in the natural resources of the land than in the livelihoods and development of these people.

In some cases the opposite has happened: people who have been unsuccessful in modern society are forced out and move into unoccupied and cheap land areas that are often peatlands. For example, in many transmigration projects in Indonesia poor farmers from Java and Madura were moved to large-scale agricultural development projects on peatlands in Sumatra and Kalimantan.

As a result of some of these projects, local indigenous communities lost access to valuable resources and land that had been developed over centuries through enrichment planting, sustainable agriculture and fisheries. For example, the traditional agriculture and rattan gardens of Dayak communities in Central Kalimantan were affected by the large-scale misguided development of the centrally (nationally) organised Mega Rice Project.

These projects were often designed to improve development opportunities. However, the lack of experience with large-scale peatland development in the tropics exacerbated rather than reduced poverty. Poverty in Indonesian peatlands is estimated to be 2 to 4 times higher than in other parts of Indonesia. It is made worse by the recurrent problems of over-drainage and fires. According to data from CARE-Indonesia, around 30% of the children under the age of 5 living in Indonesian peatlands suffer from respiratory diseases caused by the annual smog of peat fires during the dry season.

Also in western Europe, poverty in peatlands is often higher than elsewhere, but the relative poverty of farming communities is often hidden by agricultural subsidies.

**Indigenous communities that depend on wild peatlands are most vulnerable to peatland degradation.**

Peatlands include some of the last remaining wilderness and vast natural resource areas of the world, with huge undisturbed stretches in the sub-arctic zone. Development in such areas often ignores the special hydrological and ecological characteristics, central to the productivity of these peatland areas. While developments may bring economic prosperity to some stakeholders, the poorer and marginalized local people who subsist on the natural productivity of peatlands are often excluded from the planning and development process, and suffer most from negative environmental impacts. For these communities, the degradation and loss of their peatlands is tantamount to losing their way of life. Currently, the potential for subsistence livelihoods is decreasing in many peatlands

**Peatland conservation and restoration: a new service market for local livelihoods**

Developing carbon markets, both under the Clean Development Mechanism of the Kyoto protocol, as well as emerging voluntary markets, may in the near future provide a price for Reduced carbon Emissions from Deforestation and Degradation (REDD). With current certified emission carbon prices under the CDM (10-20 Euro/tonne and voluntary market prices of around 5 – 10 Euro/tonne) the value in avoiding emissions from peatlands would be billions of Euros. These values may also represent a potential new service market that can be catered for by the local people. To avoid further emissions from deforestation, drainage and fires, the degraded peatlands require management, restoration and protection measures that can only be provided by these people. Such new global enviro-economic mechanisms may thus provide a way out of poverty. Internationally, there is a call for emerging carbon markets to link their environmental payments in developing countries to poverty reduction schemes.

due to increasing population pressure as well as externally induced development. Under such circumstances, local communities may find no other solution than to over-exploit what is left of the natural resource base.

**Peatlands still play a key role in modern economies**
In many first world countries peatlands still play a key role in the economy. The economic value of peat as a substrate for modern horticulture in countries like the Netherlands and Germany is huge. This is one of the reasons why large areas of peatlands in western and central Europe remain a target of peat mining (Aerts, R.J., 2005). In countries in economic transition, such as Russia and eastern European countries, the demand for agricultural products is decreasing, making traditional agriculture and grazing on peatlands no longer economically viable. This leads to large scale abandonment of drained or extracted peatlands, with farmers and companies unable or unwilling to pay for restoration.

## 3.4 Impacts of human use on peatlands root causes

**The impact of humans on peatlands is increasingly negative and has locally resulted in the total annihilation of peatlands**
Whereas the relationship between people and peatlands in the past may often have been balanced and mutually enriching, recent developments have resulted in huge areas of peatlands being degraded as a result of drainage (oxidation), deforestation, fire and pollution.

Table 3.1: Present and former extent of mires in the non-tropical world (after Joosten & Clarke 2002)

| Continent | Original mire area (x1,000 $km^2$) | Present mire area (x1,000 $km^2$) | Loss of mire area (%) |
|---|---|---|---|
| Europe | 617 | 295 | 52 |
| Asia | 1,070 | 980 | 8 |
| Africa | 10 | 5 | 50 |
| North America | 1,415 | 1,350 | 5 |
| South America | 25 | 20 | 20 |

**Human exploitation has destroyed almost 25% of the mires on Earth: of this destruction, 50% is by agriculture, 30% by forestry, 10% by peat extraction, and 10% by infrastructure development.**

Compared to other continents, Europe has suffered the greatest losses in mires, both in absolute and relative terms. Peat formation has stopped in over 50% of the original mire area, of which possibly 10-20% does not even exist any more as peatland (Joosten 1997). In Western Europe, many countries have lost over 90% of their peatland heritage, with the Netherlands leading with almost 100% of its natural peatlands destroyed.

Asia and North America, including the vast extent of Siberian and sub-arctic peatlands, have incurred the least losses. Large-scale reclamation of tropical peat swamp forests in Southeast Asia which started only in the 1960s has destroyed over 120,000 $km^2$ of this habitat. Large areas have been left without peat soil as a result of oxidation and fires. Over 90% of peat swamp forests in South-east Asia have been impacted by deforestation, conversion, drainage and legal or illegal logging, to the extent that they are significantly degraded and have turned from being carbon sinks into net sources of carbon (Hooijer et al, 2006).

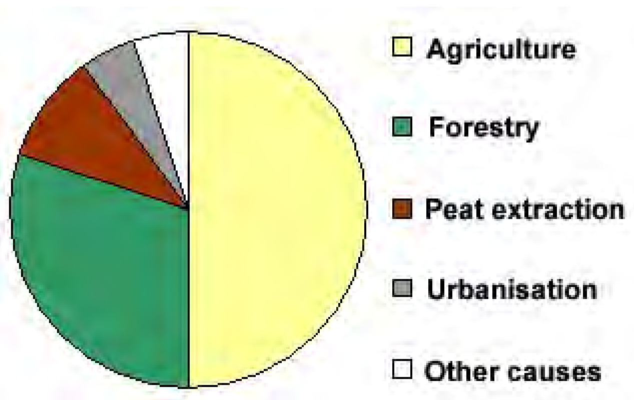


*Figure 3.1: The contribution of different human activities to peatland losses (after Joosten and Clarke 2002).*

On a global scale human exploitation may have destroyed 800,000 $km^2$ (20%) of mires on Earth: 50% of these losses are attributable to agriculture, 30% to forestry, 10% to peat extraction, and 10% to infrastructure development (Joosten & Clarke 2002).

As a result of continuing exploitation, the global mire resource is decreasing by approximately 1‰ per year, but in some regions (southern Africa, South-east Asia, Central Asia) the current annual losses of peatlands can be counted in whole percentages and may result in the annihilation of the natural peatland habitat in this century (Silvius and Giesen 1992; Hooijer et al, 2006). Peat swamp forest area decline in insular South-east Asia is twice that of other forest decline (Hooijer et al, 2006). Most mire and peatland losses in future are expected to result from drainage and infrastructure development.

**Unsustainable use of peatlands can have significant environmental and socio-economical side effects. These may be exacerbated by externalities and feedback mechanisms such as climate change (El Niño, sea level rise).**

Exploitation of peatlands may bring short-term benefits, but the loss of peatland ecosystem functions involves irreversible changes with large long-term impacts, both on-site and off-site. On-site changes result in habitat destruction with significant implications for local biodiversity, productivity and ecosystem services. Off-site effects may be felt at local, regional and global scales.

Also peat firs can have major collateral impacts, including losses of timber and other natural resources, regional public health problems as a result of the haze and major economic losses in transport and tourism sectors (Tacconi 2003).

Even though far fewer mires have been destroyed by peat extraction than by agriculture and forestry, this practice is in the short-term most damaging to bogs. Peat extraction is still ongoing today, particularly in Europe, and remains a serious local threat.

**Drainage of peat leads unavoidably to land surface subsidence and carbon emissions**

Most land-use practices on peatlands require drainage. This results invariably in subsidence of the peat body owing to physical collapse and compaction of the dehydrated peat, together with lowering as a result of loss of organic matter by oxidation. Subsidence may be as much as 500 mm in the first year of drainage and proceeds at rates of 10-100 mm in subsequent years depending on local conditions (Wösten et al, 1997). Consequently drainage and overall site hydrology are very difficult to manage, which results in technical management difficulties, declining water quality and smaller harvests. The exposure of peat layers to oxygen leads to oxidation of the organic material, while drying out of peatlands also leads to increased occurrence of fires. This results in huge emissions of $CO_2$ (see chapter 7).

> The largest recent example of disastrous drainage for agriculture is the Mega Rice Project in Kalimantan (Indonesia) where since 1995 over one million ha of peatlands were drained for rice production. Without taking the hydrological and hydromorphological properties of peatlands or their (un)suitability for rice cultivation into account, 4400 km of drainage canals were dug, leading to subsidence, desiccation, and huge carbon emissions as a result of peat oxidation and major fires. In 1997, immense, uncontrollable fires ravaged the area with enormous consequences for both the environment and human health. As a result of peat smog, thousands of people in Indonesia were hospitalized and half a million received out-patient treatment, causing a loss of millions of work and school days (Tacconi, 2003).

In many parts of the world, peatlands have developed on former mangrove soils with high pyrite contents. These Potential Acid Sulphate Soils (PAS Soils or sulphaquents) may become exposed after destruction of the peat layer, resulting in oxidation of the pyrite and the production of sulphuric acid. This leads to loss of nutrients and severe acidification of the land and water.

In the temperate and boreal zones drainage of pristine mires for forestry is declining. In some countries (e.g. Finland and Russia) current drainage activities are concentrated on maintaining ditches in already drained peatland forests. Partly in response to wildlife conservation arguments, large-scale commercial forestry is increasingly combined with management of wildlife and landscape values, for example by partial harvest management. This results in multi-purpose forests with improved aesthetic and recreational values and opportunities. In general, the area of agricultural peatlands in Europe is decreasing as a result of globalization (which makes agriculture on marginal lands in developed areas uneconomic).

However, the opposite trend is occurring in Southeast Asia where over the last decades millions of hectares of peatlands have been deforested and drained. Deforestation rates in peat swamp forests are currently double of those in other tropical rainforests (Hooijer et al 2006). Large areas have been converted to agriculture but in many areas these attempts have failed resulting in extensive areas of degraded idle land. More recently there has been a growing drive to develop pulp wood and oil palm plantations on peatlands.

The latter is augmented by recent European policies for increased use of agro-fuels for transport and energy generation. Europe is a major importer of palm oil, and this now stands to substantially increase, despite the fact that palm oil from peat may result in up to 10 times more carbon emission than is being sequestered in the crop. Currently about 20% of palm oil in South-east Asia is produced on peat, making it a product that negatively impacts on the global climate overall. Similarly, production of corn on peatlands in western Europe for bio-ethanol is increasing, despite the fact that the carbon balance of such production will be negative. Generally there is a lack of awareness amongst policy and decision makers of the significant climate change impacts of unsustainable (i.e. drained) uses of peatlands, creating the opportunity for adverse policies and development of perverse incentives.

**Changes to the physical and chemical properties of peat soil caused by drainage increase susceptibility to soil erosion and fire hazard.**
The changing land management practices in tropical peatlands have greatly increased the susceptibility to physical degradation (subsidence), chemical degradation (oxidation) and fire, with particularly extensive fires associated with ENSO-related droughts in Indonesia since 1982. Similar effects of peatland drainage have been observed in Europe, with large parts of Russia and major cities like Moscow being covered in peat smoke for months on end in some years. Huge fires were in the past also known from Western Europe.

Intensive grazing on temperate and highland peatlands leads to increased phosphate P-output to surface water (Tetzlaff & Wendland 2004). It creates compaction and the exposure of the peat soil results in oxidation and erosion.

**Peatland conversion for different kinds of uses often leads to fragmentation of the remaining natural or semi-natural peatlands.**
Large-scale conversion and intensive use of peatlands has in various parts of the world led to anthropogenic landscapes with 'islands' of remnant peatland habitats. Even when these fragments are protected for their wildlife and aesthetic values, their long-term sustainability is questionable, when their ecohydrological system has been destroyed (Charman 2002).

## 3.5 Conflicts and wise use

**The broad range of peatland values and functions underlines the variety in user groups of peatland systems.**
There are those people who wish to use peatlands for their production functions, and others who wish to preserve and manage these ecosystems for their regulating and non-material life-support functions. Conflicts may arise between these competing views of protection and production. For example:
- the drainage of peatlands may affect their flood control functions leading to damage of downstream valley farmlands, bridges and buildings;
- drainage of peatlands for agriculture may lead to loss of carbon storage and climate change mitigation functions;
- drainage and afforestation of peatlands impacts upon biodiversity and constrains their use for recreation, berry picking and hunting;
- strict nature conservation may impact upon the local socio-economic situation, especially in developing countries.

**The multiple functionality of peatlands leads to trade-offs between different stakeholder groups and consequent conflicts over use options.**
Conflicts between production versus conservation uses and values often result in "win-lose" situations with the more influential or powerful stakeholders "winning" and the less powerful "losing". An example is peat extraction without taking peatland conservation or after-use into account. There can also be "lose-lose" situations in which all stakeholders lose, for example, the Indonesian Mega Rice Project. This project was cancelled in 1998 after drainage of over one million ha of peatlands and without producing any economically viable agricultural crops.

**There are a number of reasons why peatlands continue to be lost, converted, or degraded.**
The individuals who benefit most from the conservation of peatlands are often local residents, and many of them are not involved in policy development and decision-making processes. Decisions concerning the fate of their wetlands are often made through processes that are unsympathetic to local needs or that lack transparency and accountability.

Many services delivered by peatlands (such as flood mitigation, climate regulation, and groundwater recharge) are not marketed (i.e. do not generate income to local communities) and accrue to society at large at local and global scales. Individuals often do not have incentives to maintain the services for the benefit of wider society. Furthermore, when an action results in the degradation of a service that harms other individuals, market mechanisms do not exist (nor, in many cases, could they exist) to ensure that these individuals are compensated for the damages they suffer.

Decision-makers at many levels are unaware of the existence of peatlands and their special management requirements. They fail to recognise the connection between peatland conditions and the provision of peatland ecosystem services. Decisions are generally not informed by assessments and evaluation of the total economic value of both the marketed and non-marketed services provided by peatlands.

The private benefits of peatland conversion are often exaggerated by subsidies such as those that encourage the drainage of peatlands for agriculture or the large-scale replacement of coastal wetlands by intensive aquaculture or infrastructure, including that for urban, industrial, and tourism development.

In some cases, the benefits of conversion exceed those of maintaining the peatland, such as in prime agricultural areas or on the borders of growing urban areas. As more and more peatlands are lost, however, the relative value of the conservation of the remaining areas increases, and these situations become increasingly rare.

**Economic and public health costs associated with damage to peatland ecosystem services can be substantial. Often significant investments are needed to restore or maintain non-marketed peatland ecosystem services.**

Non-marketed benefits are often high and sometimes more valuable than the marketed benefits. Some examples include:

- Flood control functions of the Muthurajawela Marsh, a 3,100-hectare coastal peatland in Sri Lanka, provides an estimated $5 million in annual benefits ($1,750 per hectare) through its role in local flood control (Mahanama, M. (2000).
- Economic and public health costs associated with damage to peatland ecosystem services can be substantial. The burning of 1.5 to 2.2 million hectares of Indonesia's peat swamp forests in 1997/98 came at a cost of an estimated $9.3 billion in increased health care, lost natural resources, lost production, and lost tourism revenues. It affected some 20 million people across the region (Tacconi 2003).
- Annual costs of replacing the life support services of the Martebo mire, Sweden, with human-made technology is calculated between $350,000 and $1million (Emerton & Bos 2004).

**The multifunctional benefits from the maintenance of peatlands as intact ecosystems may far exceed the economic returns from single sector conversions, such as agriculture, forestry or mining.**

Yet such conversions may continue because of a lack of awareness of the wider economic, social, ecological and environmental benefits. However, this finding would not hold true at all locations. For example, the value of conversion of an ecosystem in areas of prime agricultural land or in urban regions often exceeds the total economic value of the intact ecosystem. (Although even in dense urban areas, the total economic value of maintaining some "green space" can be greater than development of these sites, e.g. the "Green Heart" in the densely populated area in western Netherlands).

**Peatland conservation and restoration will in many areas not be feasible without sustainable development and poverty alleviation**

Considering the decline in incomes from agriculture, there is a pressing need to enhance alternative income opportunities for rural populations. It is important to ensure that their lands and resources are no longer degraded. Environmentally sound economic development is the basis for sustainable development that creates livelihood options and employment opportunities for current as well as future generations.

Sustainable livelihood strategies to generate income include income from carbon trading, water, biodiversity, green energy and tourism. Profitable land use options, such as, in tropical peatlands, oil palm, could under certain conditions be part of a wise use of deforested and degraded areas in order to prevent further

**Community Development.** Peat swamp forests in Indonesia are currently subject to relatively high population pressure from new immigrant communities that often combine their main agricultural livelihoods with use of forest and fishery resources. In many areas there are also still the villages of the original Dayak and Melayu communities. As a result of the many failed large-scale developments, both immigrant and native communities have a strongly reduced resource base left for pursuing further development. This creates the danger (and for them – in view of their poverty situation – often the necessity) of continuing or augmenting unsustainable practices. This vicious circle can only be broken by provision of alternative means of income generation.

unproductive degradation. Another strategy, particularly relevant to countries with no substantial agricultural subsidies, is the development of innovative financial instruments, e.g. Bio-rights that involve payments by the global community to local stakeholders for biodiversity conservation services, thus compensating for the opportunity costs of sustainable use of their natural resources. Bio-rights allow the public value of key biodiversity wetland/peatland areas to be transferred to local stakeholders as a direct economic benefit.

**Economic valuation provides an argument and a tool for promoting wise use approaches.** Evidence has been accumulating that in many cases natural peatland habitats generate marketed economic benefits that exceed those obtained from habitat conversion. Also, non-marketed ecosystem services do have economic value, but these often only become obvious when they are missed.

Mechanisms for monetarising ecosystem functions such as flood prevention, biodiversity conservation and carbon storage are generally underdeveloped. While some ecosystem functions are difficult to value as their precise contribution becomes known only when they cease to function, other functions are difficult to price as there are no equivalents to be put in their place. Consequently, weighting can only be partial and many values, benefits or disadvantages may escape monetary evaluation.

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| Significant investments may be needed to restore or maintain non-marketed ecosystem services. In the Netherlands loss and subsidence of peatlands has created a situation in which a large part of the country can maintain dry feet only at the costs of considerable investments in dikes and other water management structures. Whereas this may be economically feasible in such a small and highly developed country, this will not be the case in regions with lower population densities and economic productivity. |

Valuation studies of industrialized countries focus on recreational and existence values held by urban consumers (travel cost models, contingent valuation). In developing countries, ecosystem values related to production and subsistence are more important, although this is changing in regions characterised by rapid urbanisation and income growth.

A new but key issue for peatland valuation is climate change and the related emerging official (CDM) and voluntary carbon markets. With degraded peatlands now emitting more $CO_2$ than global deforestation (IPCC 2007 (Working Group 3 report)), avoiding emissions from peat swamp forests and peatlands in general is rapidly turning from a hypothetical value into a real commodity. The average annual emissions of 2000 million tonnes of $CO_2$ from Indonesian and Malaysian degraded peatlands represent a value of 10 to 40 billion Euros if compared to investments made elsewhere in innovative climate change mitigation solutions (such as capturing of carbon from power stations and/or storage of carbon in old oil or gas fields as being experimented in the Netherlands and Norway). The potential and relatively low costs of avoidance of these huge emissions from degraded peatlands also compares favourable to many conventional methods for decreasing emissions in transport and energy sectors. The additional spin-offs of combining peatland restoration (combating land degradation) with sustainable development, biodiversity conservation and poverty reduction creates a win-win option, and win for all agreements under the Rio conventions and other international agreements.

| Valuation of peatland ecosystem services | |
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| **Using replacement cost techniques to value the life support services.** The Martebo mire, on the island of Gotland, Sweden has been subject to extensive draining, and most of its ecosystem-derived goods and services have been lost. A study to assess the value of these lost life-support services calculated the value of replacing them with human-made technologies. The services (and their replacements) included peat accumulation, maintenance of water quality and quantity (installing pipelines, well-drilling, filtering, quality controls, purification plants, treatment of manure, pumps, dams), moderation of waterflow (pumps and water transport), waste processing and filtering (sewage plants), food production (increased agricultural production and | **Using mitigative or avertive expenditure techniques to value wetland flood attenuation.** Muthurajawela is a coastal peatland that covers an area of some 3,100 hectares, running alongside the Indian Ocean between 10-30 km north of Colombo, Sri Lanka's capital city. One of its most important functions is its role in local flood control. Muthurajawela buffers floodwaters from three rivers and discharges them slowly into the sea. The value of these services was calculated by looking at the flood control measures that would be necessary to mitigate or avert the effects of wetland loss. Consultation with civil engineers showed that this would involve constructing a drainage system and pumping station, deepening and widening the channels of water courses flowing between the marsh area and the sea, installing infrastructure to divert floodwaters into a retention area, and pumping water out to the sea. Cost estimates for this type of flood control measure were available for Mudu Ela, a nearby wetland that had |

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| import of foods), fisheries support (fish farming), as well as certain goods and services that could not be replaced. Replacement costs were calculated at market prices. The results of the study indicated that the annual cost of replacing the peatland's services was between $350,000 and $1million. | recently been converted to a housing scheme. Here, infrastructure had been installed to ensure that a total of 177 ha of land remains drained. Extrapolating the capital and maintenance costs from Mudu Ela to Muthurajawela gave an annual value for flood attenuation of more than $5 million, or $1,750 per hectare (Emerton & Bos, 2004) |

**Economic value of peat swamp forests of North Selangor, Malaysia.** Kumari's study (1995, 1996) of the peat swamp forests of in Peninsular Malaysia, analyzes the various benefits of moving from an existing unsustainable timber management system to sustained forest management overall. Kumari concludes that adopting more sustainable methods of timber extraction from peat swamp forest is preferable in economic terms. Although shifting to a sustainable harvesting system reduces the net benefits of timber harvesting, the case study suggests that this is more than offset by increased non-market benefits, primarily hydrological and carbon storage values. The study evaluates the total economic value (TEV) of four options (one "unsustainable", three "sustainable") for logging a peat swamp forest in North Selangor. All three sustainable options have higher net present values than the unsustainable option, for which a TEV of about US$4,000 (M$10,238) per hectare was calculated. Over 90% of TEV in all cases is made up of timber and carbon storage benefits. Economic values considered:

- direct use values associated with extraction of timber and Non-Timber-Forest Products (rattan and bamboo);
- indirect and direct use values associated with forest water regulation/purification services;
- direct use values associated with forest recreational benefits;
- indirect use values associated with forest carbon sequestration; and
- the existence and option values associated with wildlife conservation.

| **Summary Results** | | | | | |
|---|---|---|---|---|---|
| | | | **Change from Base Case to:** | | |
| **Forest Base Good/Service** | **Case (unsustainable traxcavator and canal) (M$/ha)** | **Percent of Total Economic Value (TEV)** | **Sustainable Traxcavator and Canal (M$/ha)** | **Sustainable Traxcavator and Winch (M$/ha)** | **Sustainable Winch and Tramline (M$/ha)** |
| Timber | 2,149 | 21.3 | -696 | -399 | -873 |
| Hydrological - Agricultural | 319 | 3.1 | 0 | 411 | 680 |
| Wildlife Conservation | 454 | 4.4 | 35 | 20 | 44 |
| Carbon Sequestration | 7,080 | 69.2 | 969 | 1,597 | 1,597 |
| Rattan | 22 | 0.2 | 88 | 172 | 192 |
| Bamboo | 98 | 1.0 | 0 | -20 | -20 |
| Recreation | 57 | 0.6 | 0 | 0 | 0 |
| Domestic Water | 30 | 0.3 | 0 | 0 | 0 |
| Fish | 29 | 0.3 | 0 | 0 | 0 |
| **TEV** | 10,238 | 100.0 | 396 | 1,782 | 1,620 |
| Source: Kumari (1995), Table 12. | | | | | |

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