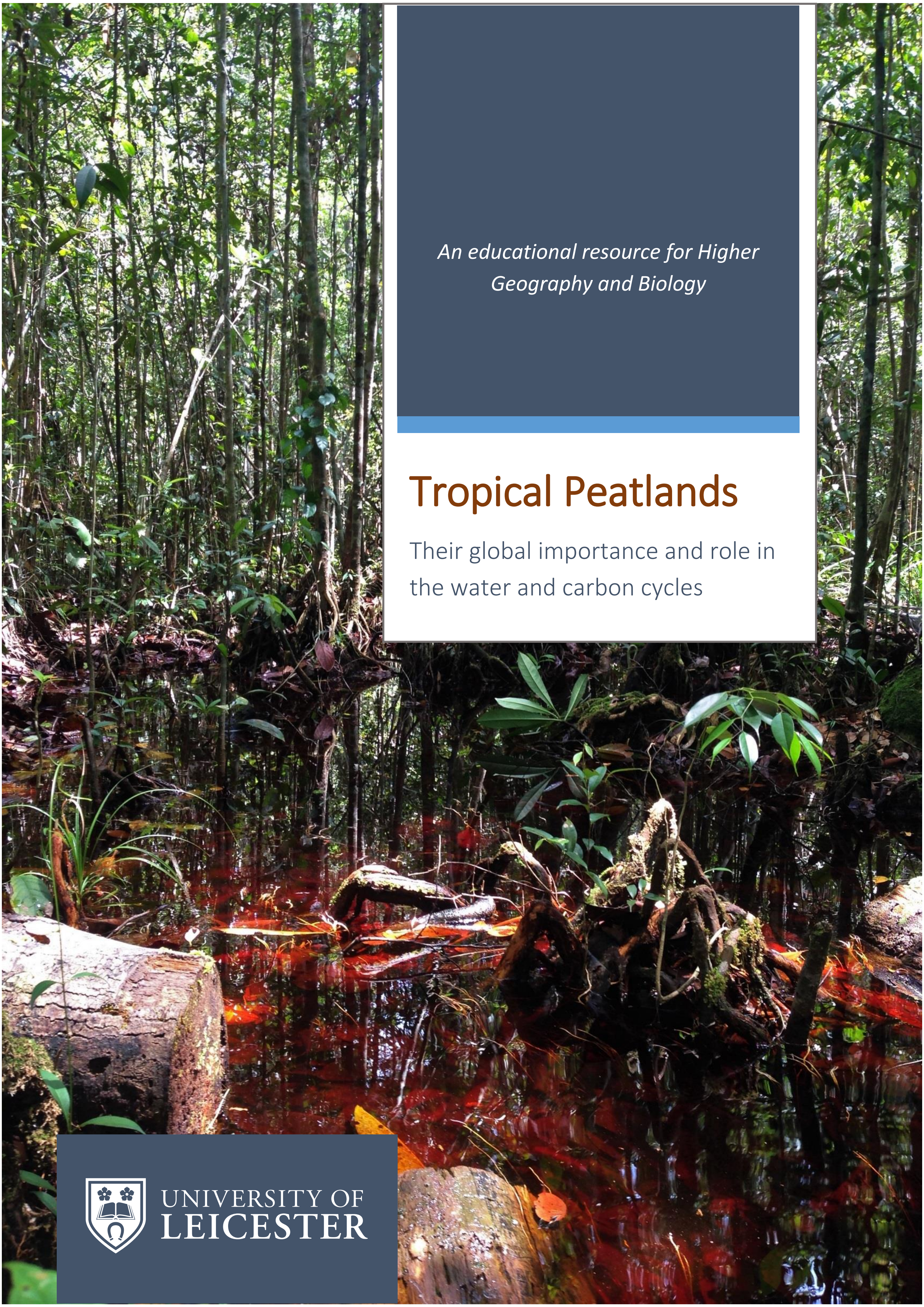

*An educational resource for Higher Geography and Biology*

# Tropical Peatlands

## Their global importance and role in the water and carbon cycles

UNIVERSITY OF LEICESTER

# Tropical Peatlands

An educational resource for Higher Geography and Biology

# CONTENTS

## INTRODUCTION TO THIS RESOURCE

The resource is aimed towards supporting teachers in Geography AS and A-levels, as well as other higher-level high school Geography courses. The table below indicates the relevance of this resource to the specifications of four main A-level boards in the UK. However, it is expected to be relevant to other high school curricula as well. It is open-access and free to share.

This resource was created by Dr. Sara Thornton, with substantial input and writing contributed by Professor Susan Page, writing contributed by Dr. Sophie Green, Sarah Cook and Laura Wright. It is based on recent research on tropical peatlands, their importance in the carbon and water cycles, the ecosystem services they provide, the threats they face and efforts on peatlands restoration.

You can contact Sara Thornton using the following email: s.thornton.p@gmail.com.

The creation of this resource was funded by the University of Leicester Research Impact Development Fund.

| Resource relevance to four main exam board specifications in the UK | | |
|---|---|---|
| **Exam board** | Specification Section | Relevant sections |
| **EdExcel** | Enquiry question 3: How are the carbon and water cycles linked to the global climate systems? | Key ideas: 6.7, 6.8, 6.9 |
| **Eduqas** | Section A, 2.1: Water and Carbon Cycles | 2.1.7, 2.1.8, 2.1.9 and 2.1.10 |
| **OCR** | Topic 1.2.: Earth's Life Support Systems | 2. How do the water and carbon cycles operate in contrasting locations? (Key ideas 2.a) |
| | | 3. How much change occurs over time in the water and carbon cycles (Key ideas 3.a.) |
| | | 4. To what extent are the water and carbon cycles linked? (Key ideas 4.a. and 4.b.) |
| **AQA** | 3.1. Physical Geography | 3.1.1 Water and carbon cycles and in particular 3.1.1.6 (Case study of a tropical rainforest setting) |

Front cover photo is the Sebangau peat-swamp forest (Indonesia), taken by Sara Thornton/CIMTROP/BNF.

# 1. PEATLANDS: HOW THEY ARE FORMED AND WHERE THEY ARE FOUND

## 1.1. WHAT IS PEAT?

Peat (Figure 1) is dead organic matter that has accumulated over thousands of years. It is formed when organic material (e.g. plants, leaves, trees) do not fully decompose due to the absence of oxygen in a waterlogged area (i.e. **aerobic** decomposition is limited), and therefore the partially decomposed organic material accumulates over time. The conditions needed for peat to form are therefore: permanent water saturation, low oxygen levels and often a high acidity, although peat can also form in contact with groundwater (e.g. in river valleys) that has a near neutral or even slightly alkaline pH.

Peat consists of 40-60% (dry mass) of dead organic material (vegetation).

**Figure 1: A northern peat bog undergoing peat extraction. Owing to its high carbon content, peat is used as a fuel source in a number of countries. Photo from Wikimedia Commons.**

## 1.2. WHAT ARE PEATLANDS AND WHERE ARE THEY FOUND?

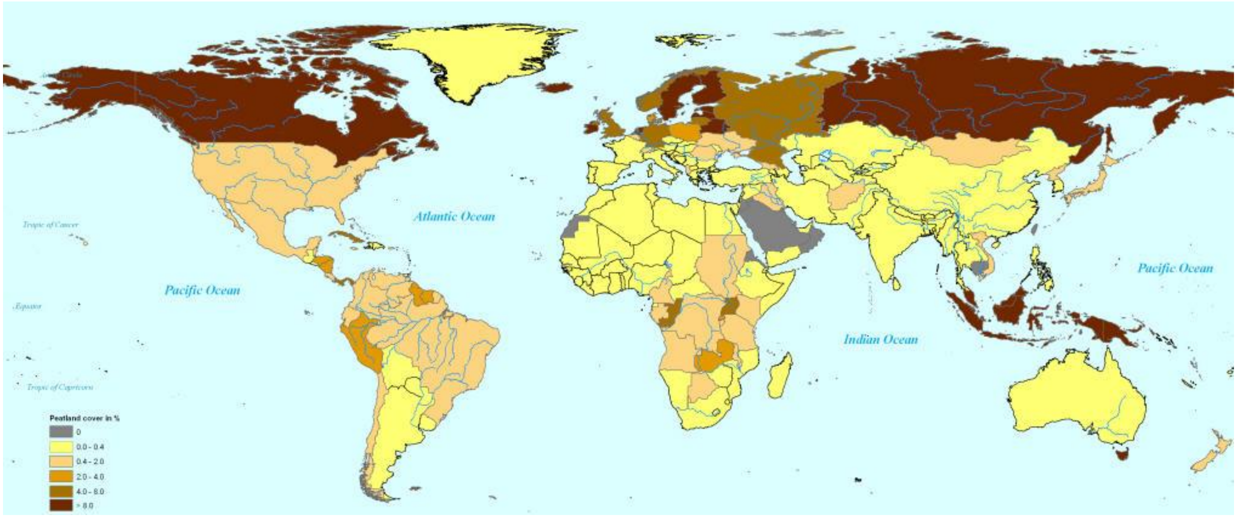


**Figure 2: Map illustrating the amount (% peatland cover) of peatland found in each country, brown colour indicating more than 8% land cover. Figure from Wetlands International.**

Landscapes that have accumulated layers of peat on the land surface are referred to as peatlands. Peatlands cover over 40,000 km$^2$, or 3% of the Earth's land surface but contain twice as much carbon as the world's forests (Figure 2). They represent half of the global wetlands. Damaged peatlands are responsible for more than 7% of the world's carbon dioxide ($CO_2$) emissions, and contribute towards climate change, but in an intact condition, they usually function as a long-term carbon sink (i.e. storing carbon over millennial timescales).

Peatlands are found in at least 175 countries. There are at least 7 principle global types of peatlands:

1. **Blanket mires**: these are rain-fed, generally between 1 and 3 metres deep. They are found mainly in Ireland and the UK.
2. **Raised mires:** these are rain-fed, potentially deep peatlands. They are found mainly in Northern Europe and North America.
3. **Fens:** these are groundwater-fed, often quite shallow peatlands found in basins and river floodplains. They occur in Europe and North America and can be quite extensive, e.g. the Norfolk Broad fens of eastern England.
4. **String mires:** these are flat or concave peatlands with a string-like pattern of hummocks. These are found primarily in northern Scandinavia.
5. **Tundra mires:** these are peatlands with a shallow peat layer, about 50cm thick. They form in permafrost areas in Alaska, Canada and the former USSR.
6. **Palsa mires:** these are a type of peatland typified by high mounds, each with a permanently frozen core, with wet depressions between the mounds. They are found mainly in the former USSR, Canada and Scandinavia.

7. **Peat swamps:** These are forested peatlands (both rain-fed and groundwater-fed) commonly found in high rainfall regions in Southeast Asia, central Africa and the Amazon basin.

By area, northern peatlands are the most extensive. They cover around 3,500,000 km$^2$ of northern Canada, the UK uplands, and the countries bordering the Baltic Sea, northern Russia and northern Asia. In the humid tropics, there are also significant peat deposits located in Southeast Asia, Africa and Central and South America (covering 580,000 km$^2$). The country with the greatest extent of peatland in the tropics is Indonesia, with 200,000 km$^2$.

## 1.3. THE DEPTH AND LAYERS OF PEAT

In northern peatlands, it can take at least 1000 years for peat to accumulate to a depth of 1 m, but because some peatlands have been accumulating over thousands of years they have achieved depths of 5 or even 10 m. In temperate regions peat soils tend to be between 1.5-2.3m deep. In the tropics, higher plant productivity has resulted in even deeper deposits—exceeding 15 m in some locations!

*Did you know?*
*Excitingly, a very large peatland area has recently been discovered in the Congo Basin in central Africa (see Case Study 2), making the Democratic Republic of Congo and the Republic of Congo, with 145,000 km$^2$ of peatland between them, the second and third most important countries (following Indonesia) in the world for tropical peat carbon stocks!*

Peatlands consist of two layers:

1. **Acrotelm**: The upper **aerobic** layer (Figure 3). In this layer the rate of organic decay is generally higher than in the lower layer. It has high permeability to water near to the surface, but becomes more impermeable with depth as the peat becomes more consolidated and decomposed (humified). Water movement and fluctuations mean that conditions in the acrotelm remain largely aerobic and it is here that microbial activity is strongest. These properties mean that the acrotelm is critical to the normal development and functioning of a raised bog.

2. **Catotelm**: The lower layer beneath the acrotelm which has a lower rate of decay. This layer is very much thicker and contains the bulk of the peat where individual plant stems have collapsed under the weight of vegetation above them to produce an **amorphous**, chocolate-coloured mass. By contrast with the acrotelm, catotelm peat is typically well consolidated and often strongly **humified**. It is permanently saturated with water. Water movement through this amorphous peat is very slow, typically less than a meter a day. This is where most of the rain water and carbon is stored.

The boundary between these two layers is defined as being the lowest level of the water table. An intact peat bog is fully saturated with water for most of the year. The water level will drop below the peat surface during dry periods, but during wet periods, the peat becomes saturated and water will simply run off and reach streams quite quickly.

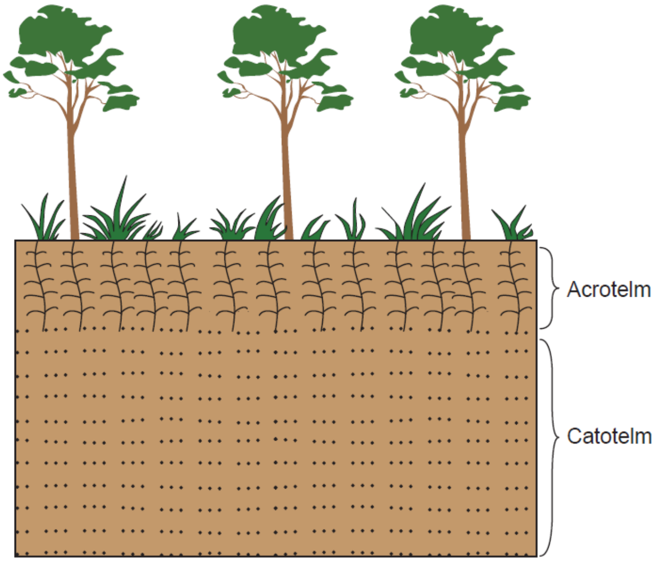


**Figure 3: The Acrotelm and Catotelm layers in a tropical peatland**

*Vocabulary*

***Aerobic:*** *relating to, involving, or requiring free oxygen.*

***Amorphous:*** *without a clearly defined shape or form.*

***Humified:*** *convert (plant remains) into humus.*

*Review question*

Discuss what peat is, where peatlands and found and how they are formed.

## 2. TROPICAL PEAT-SWAMP FORESTS

In the tropics, we find peatlands that are covered by tropical forests (Figure 4). These are called tropical peat-swamp forests, and are found in Central and South America, Central Africa and Southeast Asia.

Figure 4: Tropical peat-swamp forest in Indonesian Borneo. Photograph by Sara Thornton/CIMTROP/BNF.

Peatlands, including tropical peatlands, typically form between two rivers, or stream channels. This leads to the formation of their characteristic dome shape, with freshwater swamp forests at their margins, as Figure 5 illustrates.

For nutrients and water supply, peat domes are entirely dependent on precipitation: they are '**ombrotrophic**' in nature. Also, because of the lack of mineral input, along with the leaching of organic compounds from the organic materials into the water, this makes the surrounding water in the peat-swamp very acidic. The pH is usually less than 4 (pH is a measure of acidity: to compare, the pH of tomato juice is around 4, with lemon juice around 2. Pure water has a pH of 7).

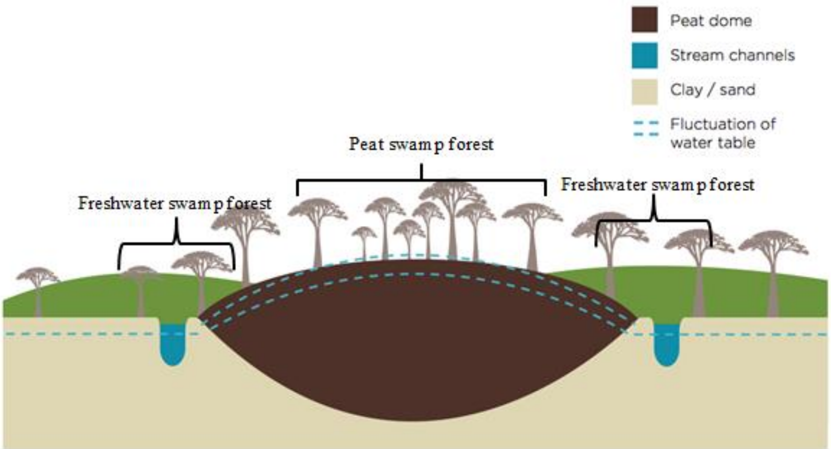


Figure 5: Representation of a highly developed inland peat dome, with peat swamp forest and freshwater swamp forests at margins. Figure from Page *et al.* (2011a).

As this resource will explain in greater extent, peatlands are vital for carbon storage. The table below shows the estimated carbon storage in tropical peatlands, including recent carbon stock estimates of the newly discovered Congo peatland (see Chapter 8 discussing this peatland discovery). As shown in the table, the peatlands of Southeast Asia store the most amount of carbon, followed by Africa and South America. The three case studies presented in this resource will therefore be focusing on these regions (Chapters 7, 8 and 9).

Table 1.: Estimated carbon storage in tropical peatland, on a regional scale, incorporating carbon stock estimates from the newly discovered Congo peatland and updated carbon stock estimates for Southeast Asia accounting for carbon stock losses of 0.5 Gt C $yr^{-1}$ since original data collection. Data from Page *et al.*, 2011b; Dargie *et al.,* 2017. Table from Sarah Cook.

| Carbon storage (GtC) | | | | | | |
|---|---|---|---|---|---|---|
| Region | Minimum | Best | Maximum | % (Best estimate) | Revised best estimate | % (Revised best estimate) |
| Africa | 3.54 | 6.93 | 8.13 | 7.82 | 34.40 | 32.76 |
| Southeast Asia | 66.34 | 68.52 | 69.85 | 77.34 | 57.02[2] | 54.30 |
| Asia (other) | 0.30 | 0.43 | 0.50 | 0.49 | 0.43 | 0.41 |
| Central America | 2.89 | 3.05 | 0.12 | 3.44 | 3.05 | 2.90 |
| Pacific | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| South America | 8.60 | 9.67 | 10.23 | 10.91 | 9.67 | 9.21 |
| TOTAL | 81.9 | 88.6 | 88.9 | 100 | 105 | 100 |

## 2.1. THE DEVELOPMENT OF TROPICAL PEATLANDS

A typical developmental process for the formation of a sub-coastal peat dome in Southeast Asia (Figure 6) might involve the following stages:

1. It begins with a flat area of land between two rivers.
2. This area of land experiences frequent flooding when the river channels overflow.
3. The flooding leaves behind a strip of alluvium, supporting a transitional freshwater swamp forest.
4. As flooding continues the river levees start to build up, eventually creating a shallow basin, with poor drainage. Under high rainfall conditions, any organic matter input into the basin, will be submerged and only undergo partial decomposition, leading to the accumulation of peat.
5. This area, in time, supports the development of a peat swamp forest (PSF), further increasing the input of organic matter.

6. Overtime this will cause the peat to become thicker, increasing hydraulic resistance, creating a hydraulic gradient.
7. Consequently, the watertable tends to be higher at the peat swamp centre and lower at the fringes, creating differential decomposition rates, and leading to the formation of a distinct convex dome shaped surface.

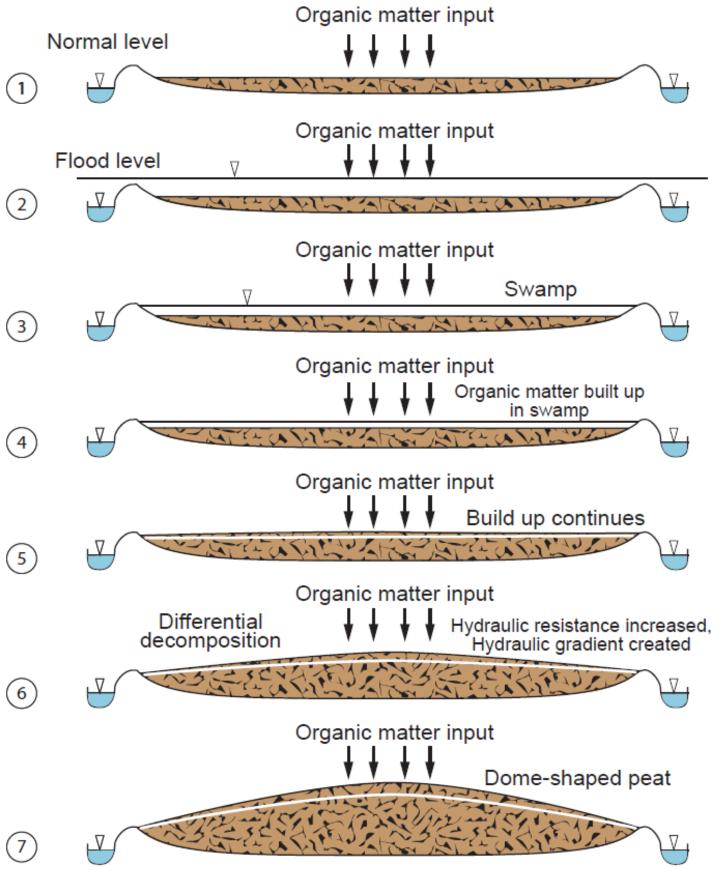


**Figure 6: Basic schematic diagram outlining the development of a peat dome. Diagram adapted from Rais, 2011.**

In coastal settings, peat swamps have developed over marine sediments inland from mangrove swamps. Over time, organic material begins to accumulate, and the mangrove vegetation is replaced by swamp forest as the ecosystem becomes increasingly ombrotrophic.

The current estimate of the total area of undeveloped tropical peatland is in the range 300,000 – 450,000 km$^2$. In Southeast Asia, tropical peat swamp forest resources and natural functions are being damaged severely by land development, legal and illegal logging and fire; they may soon be destroyed forever with potentially devastating environmental consequences regionally and globally.

In the coming teaching resource, I will outline the reasons why tropical peat-swamp forests are important: for their role in the water and carbon cycles, as well as their importance to livelihoods of communities living by these forests. Chapter 3 now starts with the role of tropical peatlands in the water cycle.

*Helpful links*

1. *Watch this video about the 'Natural Functions of Peatlands' to increase your understanding of how a natural peatland works:* *http://www.youtube.com/watch?v=zpP17-mc5I4 [6.22 min]*

2. *Watch this video about 'Peatland development' to increase your understanding of how a peatland is formed. This video focuses on temperate peatlands, but is relevant to the process of formation of tropical peatlands as well:* *https://www.youtube.com/watch?v=Hu7yCrSzC1A [4.16 min]*

***Vocabulary***

***Alluvium:*** *a deposit of clay, silt, and sand left by flowing floodwater in a river valley or delta, typically producing fertile soil.*

***Hydraulic resistance:*** *The resistance to the movement of a body in a liquid due to the friction forces that are generated between the body and the liquid.*

***Hydraulic gradient:*** *The difference in height of a liquid at two points in the open air, divided by the distance travelled by that liquid flowing under pressure.*

***Ombrotrophic:*** *dependent on atmospheric moisture for its nutrients.*

*Review question*

Discuss what tropical peat-swamp forests are, why they are unique and how they develop over time.

# 3. TROPICAL PEATLANDS AND THE WATER CYCLE

## 3.1. RECAP: THE WATER CYCLE

The water cycle (Figure 7) describes the continuous movement of water on, above and below the Earth's surface. Water is continuously transferred between the atmosphere and the oceans. This is known as the global hydrological cycle and this system is a closed system (there are no inputs or outputs).

The major reservoirs of water on Earth includes ice, fresh water, saline water and atmospheric water. Water moves between these reservoirs, such as from the ocean to atmospheric water, through physical processes of:

1. Evaporation
2. Condensation
3. Precipitation
4. Infiltration
5. Surface runoff
6. Subsurface flow

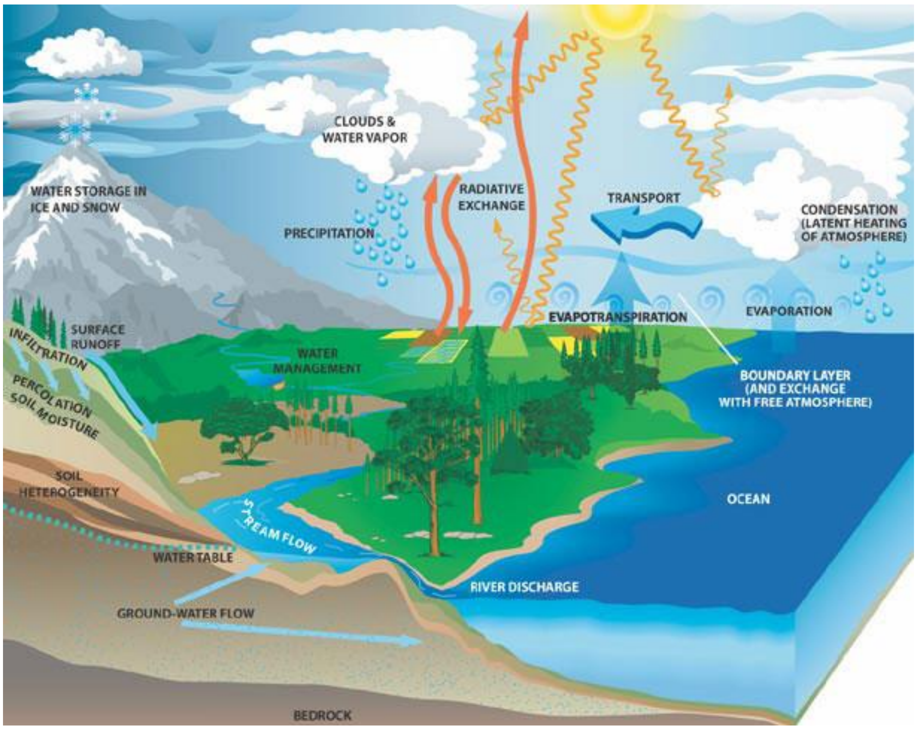


Figure 7: The water cycle. Figure by Sagar Purnima, available from Wikimedia Commons.

In doing so, water goes through different forms: liquid, solid (ice) and vapour. Moving through these forms involves the exchange of energy. This also leads to temperature changes. For example, when water evaporates, it takes up energy from its surrounding and cools the environment. When it condenses, it releases energy and warms the environment. These heat exchanges influence climate.

The water cycle is essential for the maintenance of most life and ecosystems on the planet.

*Helpful links:*

*To brush up on the water cycle, take a look at the following videos and links:*

1. *'The Water Cycle': https://www.youtube.com/watch?v=al-do-HGuIk [6.46 min]*
2. *'The Drainage Basin Hydrological Cycle': http://www.alevelgeography.com/drainage-basin-hydrological-system/*
3. *'Topic 5 – The Water Cycle and Water Insecurity': http://www.physicsandmathstutor.com/geography-revision/a-level-edexcel/water-cycle-and-insecurity/*

## 3.2. PEATLANDS AND THE WATER CYCLE

Tropical peatlands play important roles regionally and locally in the water cycle, climate and landscape stabilisation. They are the source areas of many rivers, are important for water storage and supply and are crucial for mitigation of droughts and floods. Peatlands globally contain 10% of all freshwater.

**Figure 8: The Sebangau Tropical Peatland River in Indonesian Borneo. Photograph by Sara Thornton/CIMTROP/BNF.**

Peatland hydrology, and particularly the position of the water table relative to the peat surface, plays a critical role in peatland functioning and carbon cycling. These systems are wet (the water table is usually within 20-40 cm of the peatland surface, and surface inundation in some peatlands is common) but considerable uncertainty exists over their hydrological budget. In natural peat-swamp forests the surface layer of peat, the **acrotelm**, may be flooded for nine months of the year; slowing down aerobic decomposition and thereby favouring the formation of peat. During the dry season the water level falls and there is an increase in the **oxic** peat profile (i.e. the amount of peat exposed to the air), leading to $CO_2$-releasing decomposition. This will be further explored in Chapter 4.

Water level decrease can be due to climatic variability or the drainage of peatlands (which is done for palm oil or timber plantations to lower the water table, or in logging operations where canals are built in the landscape to transport timber out of the area). Eventually, a lower water level can cause decreased peat accumulation and eventual collapse of the peat structure, furthermore causing the peat-swamp forest to shift from a net **carbon sink** (i.e. absorbs carbon from the atmosphere) to a net **carbon source**. Drainage of peatlands will be further explored in Chapter 6. Rehabilitating the natural peatland hydrology, e.g. by blocking drainage channels, is one peatland conservation action that is being taken aimed at slowing down peat degradation. A range of conservation actions will be further explored in Chapter 10.

Continuous water saturation is needed for the peat dome structure to be maintained. Only then does the peatland have the **anoxic** conditions which inhibit the decomposition of the plant-derived organic material for the peat to accumulate and not degrade. However, these conditions may not always be maintained over time, especially in tropical climates. This is because in these areas, there are high **evapotranspiration** rates and sometimes very distinct dry seasons. Also, the dome shape of the peat naturally (by gravity) leads to water running off the dome (but this isn't necessarily the case as will be described with the self-regulation of the hydrology later). This leads to dome peatlands naturally draining into the surrounding river (as illustrated in Figure 9).

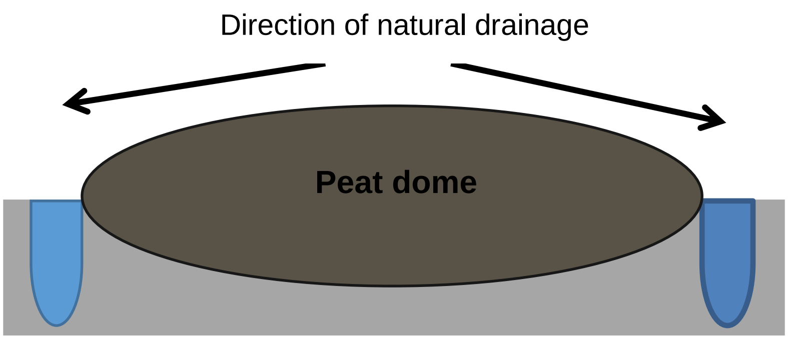


**Figure 9: Diagram to show the natural drainage system within tropical peatlands. Figure from Sarah Cook.**

To counter this, peatlands have several hydrological self-regulating mechanisms to sustain near-permanent waterlogged conditions. These include:

1. Depressions between hummocks and spreading buttress roots which greatly reduces the speed at which water moves across the peat surface.
2. Tip-up-pools (Figure 10) are where storm events have caused trees to become uprooted, creating a cavity in the peat. This cavity can become filled with water and leaf litter.

Figure 10: Tip-up pool in an Indonesian Peatland. Photograph by Sara Thornton/CIMTROP/BNF.

Considering a tropical peatland ecosystem, as illustrated by Figure 11: during the dry season, the water table is at the lowest point. The peatland will therefore experience **oxic conditions** within the top surface layer of the peat (upper 40 cm). Under these conditions, aerobic decomposition will occur leading to any organic matter on the peat surface to be decomposed by microbes in the soil. The heterotrophic respiration by the microbes breaks down the organic matter and releases it in the form of $CO_2$, $N_2O$ and $CH_4$.

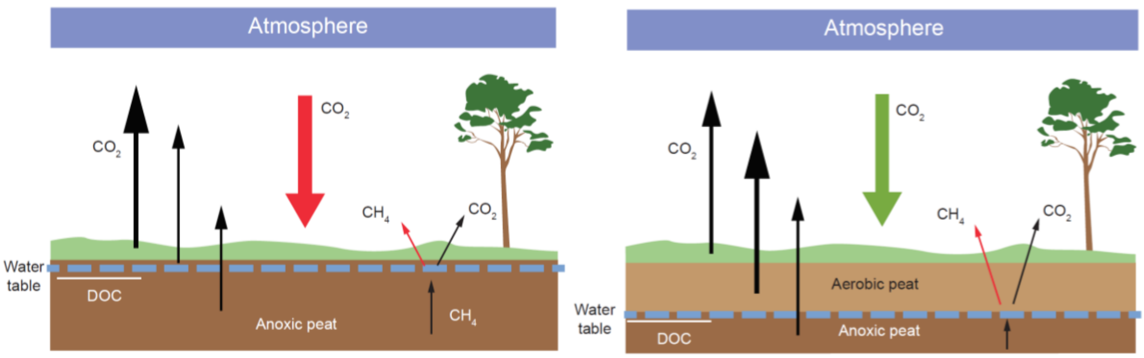


Figure 11: Carbon dynamics in an intact peatland with a high and low water table. Diagram adapted from David Wilson (2008)

***Vocabulary***

***Acrotelm:*** *is one of two distinct layers in undisturbed peat bogs. It overlies the catotelm. The boundary between the two layers is defined by the transition from peat containing living plants (acrotelm) to peat containing dead plant material (catotelm).*

***Oxic:*** *(of a process or environment) in which oxygen is involved or present.*

***Anoxic:*** *a total depletion in the level of oxygen*

***Carbon sink:*** *a carbon store that absorbs more carbon than it releases.*

***Carbon source:*** *A carbon store that* ***releases more carbon than it absorbs.***

***Review questions***

Discuss what the role of tropical peatlands are in the local and global water cycle.

# 4. PEATLANDS, THE CARBON CYCLE AND CLIMATE CHANGE

## 4.1. RECAP: THE CARBON CYCLE

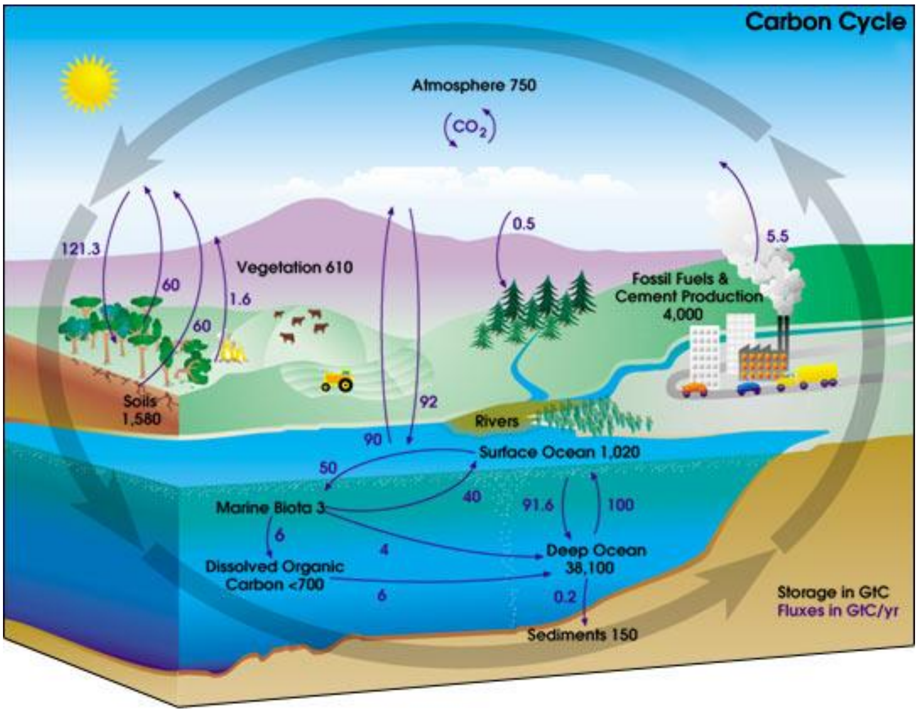


Figure 12: The carbon cycle, Diagram available from Wikimedia Commons.

Basic Steps of the Carbon Cycle:

1. Carbon enters the atmosphere as $CO_2$ from respiration and combustion.
2. $CO_2$ is absorbed by producers to make carbohydrates in photosynthesis.
3. Animals feed on the plants, passing the carbon compounds along the food chain. Most of the carbon they consume is exhaled as $CO_2$ formed during respiration. The animals and plants eventually die.
4. The dead organisms are eaten by decomposers and the carbon in their bodies is returned to the atmosphere as $CO_2$. In some conditions decomposition is slowed down or blocked. The plant and animal material may then accumulate as an organic sediment (e.g. peat) or over long geological time periods may be converted into organic-rich sedimentary rocks (e.g. coal, lignite). .

The components of the carbon cycle fall under two kinds of processes:

- **Stores:** The main stores of carbon are the lithosphere (e.g. rocks and soil), hydrosphere (e.g. oceans), cryosphere (e.g. snow and ice), atmosphere, and biosphere (e.g. plants).

- **Transfers (*flows/fluxes*):** These are the processes involved in transferring carbon between the stores. For example, the process of photosynthesis takes carbon out of the atmosphere in the form of $CO_2$ and converts it into carbohydrates, such as glucose within plants. Transfers are the inputs and outputs that affect the magnitude of the stores at any one time.

The main transfers (flows/ fluxes) operating in the carbon cycle are the following:

1. **Photosynthesis:** process whereby plants use the light energy from the sun to produce carbohydrates in the form of glucose.
2. **Respiration:** chemical process happening in all cells in both plants and animals. Glucose is converted into energy (used for growth, repair, movement, control of body temperature). Carbon is then exhaled and returned to the atmosphere.
3. **Decomposition:** during this process carbon from plant/animal bodies is returned back to the atmosphere as $CO_2$.
4. **Combustion:** when organic materials (containing carbon) are burned in the presence of oxygen (e.g. coal in a power station), producing energy, $CO_2$ and water..
5. **Burial & compaction:** organic matter buried by sediments becomes compacted. Over millions of years these organic sediments containing carbon may form hydrocarbons e.g. coal and oil.
6. **Carbon sequestration:** the transfer of carbon from the atmosphere to plants, soils, rock formations and oceans.
7. **Carbon capture & storage:** a recent term used to describe the technological 'capturing' of carbon emitted from power stations.
8. **Weathering:** involves the breakdown/ decay of carbon-containing rocks in their original place or close to the surface resulting in a flux of carbon to the atmosphere (as $CO_2$) or in solution (e.g. as calcium bicarbonate).

***Greenhouse gases: $CO_2$ and methane ($CH_4$):***

A critical role of the carbon cycle is the release of $CO_2$ and other gases e.g. methane, into the atmosphere. These so-called greenhouse gases (GHGs) absorb long-wave radiation from the Earth, thereby warming the lower atmosphere, enabling life to exist. However, recent anthropogenic activities e.g. burning fossil fuels and deforestation have increased the emission of GHGs, making the Earth's atmosphere more effective in trapping radiation and causing significant changes in our global climate system.

*Helpful links:*

*To brush up on the carbon cycle, take a look at the following link:*

1. *'Carbon and Nitrogen Cycle': https://www.slideshare.net/saramssantos/carbon-and-nitrogen-cycle-14932178*

## 4.2. PEATLANDS AND THE CARBON CYCLE

Peatlands are found across the world. They can have a variable but often considerable thickness and the peat has a high carbon content (typically 40–60% on a dry weight basis). As a result, the world's peat deposits are an important carbon store. While only covering around 3% of the Earth's land surface, they contain about 650 Pg (billion tonnes) of carbon, which is more than the carbon stored in all the world's vegetation (550 Pg) and around three times the carbon stored in known oil reserves (220 Pg).

Figure 13: The canopy of the Sebangau peat-swamp forest in Indonesia. Photograph by Sara Thornton/CIMTROP/BNF.

Peatland plants absorb $CO_2$ from the atmosphere as they grow (through photosynthesis), and incorporate the carbon into their biomass (**gross primary production**, **GPP**). When they die and become incorporated into the peat, a variable fraction of this carbon avoids aerobic decomposition and is stored for millennia. Most peat carbon has accumulated over long time periods; over the last 8,000 to 10,000 years. The slow decay of the plant litter and peat making up the peatland produces both $CO_2$ (as a result of aerobic decomposition) and $CH_4$ (as a result of anaerobic decomposition). These are lost mainly in the free-phase (gaseous) form from the peatland surface, but they may be lost also in the dissolved form in water flowing out of the peatland. Peatland vegetation and the peat itself release carbon in the form of $CO_2$ and $CH_4$, from autotrophic (root respiration) and heterotrophic respiration (decomposition of organic matter via microbes). Together, this set of processes is referred to as **net ecosystem productivity** (NEP). The heterotrophic respiration and resulting $CO_2$ emissions are dependent on microbial dynamics and activity. This is controlled by temperature (higher temperatures tend to lead to higher microbial activity), changes and levels of the water table (e.g. anoxic and oxic conditions; oxic conditions are needed for more microbial activity) and the availability of labile organic matter (e.g. cellulose in leaves; this is consumed by microbes quickly which then respire $CO_2$).

Figure 14: Trees and vegetation in a tropical peat-swamp forest in Indonesia. Photograph by Sara Thornton/CIMTROP/BNF.

The difference between the amount of carbon sequestered, via GPP, and that lost, is often reabsorbed by the surrounding peat-swamp forests, into the tree's biomass and accumulating organic matter. Consequently, under natural conditions these peatlands are effective **net carbon stores**. Their carbon storage capacity is dictated by their ability to maintain a positive net imbalance between a high GPP and low rates of organic matter decomposition. This, in turn, is dependent upon the prevalence and maintenance of anoxic and acidic conditions (as these inhibit decomposition).

- *Peatlands globally contain twice as much as all the carbon stored in the world's forests.*
- *Carbon storage in SE Asian peatlands is in the order of 58 Gt.*
- *The peat soils of tropical peat-swamp forests account for approximately 14-19% of the global peat carbon pool, and 5-6% of the global soil carbon pool! These are also likely to be under-estimates with recent findings of large peat areas in Congo and South America.*

GPP is also strongly controlled by the structure of the forest vegetation itself (density, height and stem diameter), which changes throughout the peat dome due to different environmental factors (e.g. tree height varies with peat depth as taller trees are unable to support themselves in deeper peat areas). Furthermore, heterotrophic $CO_2$ emissions depend on microbial dynamics which are controlled by temperature, water table fluctuations and the availability of **labile** organic matter.

The interdependence between the vegetation and peat dome structure makes these ecosystems extremely fragile and vulnerable to change, particularly hydrological change.

In addition to gaseous carbon flux, some carbon is naturally lost by leaching and drainage run-off, through the **fluvial** export of **dissolved (DOC) and particulate organic carbon (POC)**, see Figure 15. DOC and POC are waterborne forms of carbon which are leached from the surrounding organic matter. Once in the peatland drainage system of small streams and rivers, a considerable proportion of this organic carbon is thought to be liberated as $CO_2$ and released to the atmosphere.

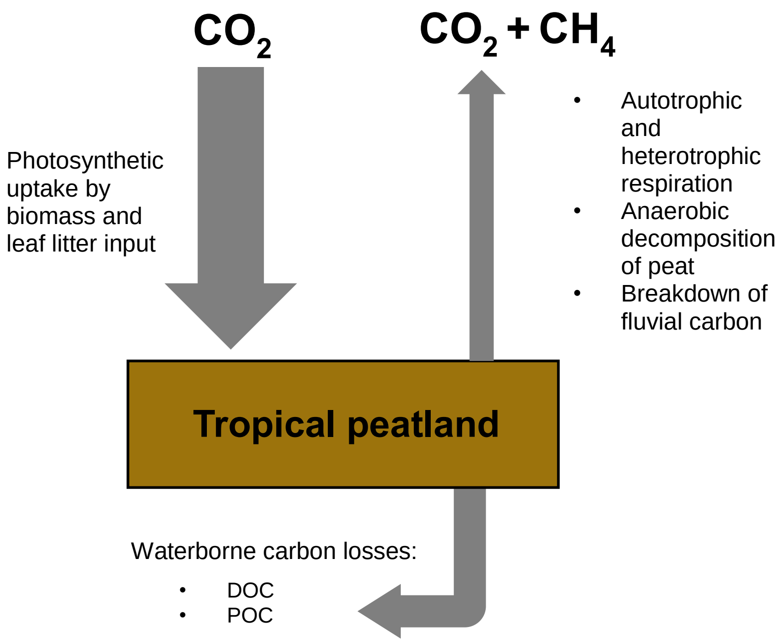


**Figure 15: Simplified schematic diagram to highlight the main carbon inputs and output pathways on an intact tropical PSF. Figure from Sarah Cook.**

Peatland carbon is, however, highly vulnerable to both environmental and climatic changes. As previously explained, when the water table is drawn down, oxidation of the peat leads to its decomposition and a rapid loss of stored carbon to the atmosphere, mainly in the form of the greenhouse gas $CO_2$. Peatland ecosystems can therefore change from a net **carbon sink to a net carbon source**.

Agriculture, forestry and, to a lesser extent, peat extraction have so far affected about 25% of the peatlands on Earth. While large parts of the enormous peatlands of North America and Russia are still relatively intact, those of many parts of Europe, Central and South-East Asia, Argentina and Chile have been significantly degraded, with some of the most rapid and extensive land use changes taking place recently in the peat swamp forests of Southeast Asia.

***To summarise:***
The carbon storage capacity of peatlands is determined by their ability to:

a) Maintain a positive net imbalance between high GPP and low rates of organic matter decomposition
    a. This is dependent on the maintenance of anoxic and acidic conditions which inhibit decomposition of organic matter.
    b. GPP is also strongly controlled by the structure of the forest vegetation (density, height and stem diameter). This changes throughout the peat dome in response to variable abiotic and biotic factors.
b) Heterotrophic $CO_2$ emissions are dependent on microbial dynamics (which are controlled by temperature, water table fluctuations and the availability of labile organic matter).

## 4.3. METHANE AND NITROUS OXIDE

Peatlands not only play a role in carbon cycles, but also methane and nitrogen cycles. While healthy peatlands have a net storage of carbon, they produce the GHGs methane and nitrous oxide. Methane is particularly a powerful GHG: **every unit of methane has 24.5 times the global warming effect of a unit of $CO_2$.**

Peatlands are currently contributing 3-5% to the total global methane emissions.

Peatlands have always been emitting methane naturally, and these emissions should be considered part of the natural baseline. Overall, methane emissions from tropical peatland are very low irrespective of whether it is natural peat swamp forest or drained and degraded or used for agriculture. The vast majority of healthy peat bogs absorb and store enough carbon from the atmosphere via the photosynthetic activity of bog plants, that they provide a **net climate benefit.**

For nitrous oxide ($N_2O$), emissions from natural tropical peatlands are low but evidence is emerging that suggests that these increase following land use change and fire. For example, there is evidence that those used for agriculture are releasing significant amounts of this potent greenhouse gas.

## *Vocabulary*

***Gross primary productivity:*** *the rate at which photosynthesis or chemosynthesis occurs.*

***Net ecosystem productivity:*** *the difference between gross primary production and total ecosystem respiration, represents the total amount of organic carbon in an ecosystem available for storage, export as organic carbon, or nonbiological oxidation to carbon dioxide through fire or ultraviolet oxidation.*

***Labile:*** *liable to change; easily altered or decomposed.*

***Fluvial:*** *of or found in a river.*

***Dissolved organic carbon:*** *the organic matter that is able to pass through a filter of 0.45μm.*

***Particulate organic carbon:*** *the carbon that is too large and is filtered out of a sample, and remains on the top of the filter (see DOC definition above)*

## *Review questions*

Discuss what the role of tropical peatlands are in the local and global carbon cycle.

## 5. PEATLANDS MATTER

Peatlands are important to us all. The importance of the environment to global systems and human life can be described under the term **ecosystem services.** This is a contentious term that is debated in academia, but is currently popular in international and UK policy. Ecosystem services can be categorised in four different groups: regulating, provisioning, supporting and cultural ecosystem services. The role of tropical peatlands in the water and carbon cycles are an example of regulating services.

Other ecosystem services which tropical peatlands are vital for are illustrated in the table below.

| *Regulating Ecosystem Services* | *Provisioning Ecosystem Services* | *Supporting Ecosystem Services* | *Cultural Ecosystem Services* |
|---|---|---|---|
| Regulating global climate | Drinking water | Peat formation | Social-amenity and historical functions |
| Regulating regional and local climates | Wild plants for food/medicines | Biodiversity | Recreation and aesthetic functions |
| Regulating catchment hydrology | Fish | Nutrient cycling | Symbolisations, spirituality and existence functions |
| Regulating catchment hydrochemistry | Soil | | Education |
| Regulating soil conditions | Fuel | | |
| Erosion protection | Fibre | | |
| Water purification | Wood | | |
| Water regulation | | | |
| Carbon storage | | | |

Peat-swamp forests in the tropics represent a high biodiversity ecosystem with thousands of species and are rich in endemic and endangered flora and fauna. It has been found that 45% of mammals and 33% of birds recorded in tropical peat-swamp forests have an IUCN Red List status of near threatened, vulnerable or endangered. For example, the peatland forests of Southeast Asia are of vital importance for the survival of several charismatic megafauna such as the orangutan (Sumatran and Bornean, *Pongo spp*.), Sumatran Tiger (*Panthera tigris sumatrae*), Sumatran Rhinoceros (*Dicerorhinus sumatrensis*), Storm's Stork (*Ciconia stormi*) and False Gharial (*Tomistoma schlegelii*). They are also home to endangered felids (i.e. from the cat family) such as the flat-headed cat (*Prionailurus planiceps*), Sunda clouded leopard (*Neofelis diardi*), and marbled cat (*Pardofelis marmorata*). Peat-swamp forests in Borneo provide habitat for eight other primate species, including the Southern Bornean Gibbon (*Hylobates agilis albibarbis*) and Red Langur (*Presbytis rubicund*). For both the gibbons and orangutans, the Sebangau peat-swamp forest in Central Kalimantan (Southern Borneo) represents one of the largest remaining continuous populations worldwide, and is therefore a vital area for the conservation of these primates.

The conditions of peat-swamp forests globally are also thought to favour evolution of specialised fish species, and each patch of peat swamp could contain its own endemic species (Figure 16).

**Figure 16: Peatlands in Indonesia are important habitats for fish. This in turn provides a vital resource for the local communities who have a high dependency on fish and fishing for their livelihoods. Provision of fish is one example of an ecosystem service provided by tropical peatlands. Photograph by Sara Thornton/CIMTROP/BNF.**

Tropical peat-swamp forests also support a great variety of plant and tree species, many of which are also facing threats of extinction. While these may be less charismatic than apes or large mammals; they are vital for the conservation of these forests and their biodiversity.

Tropical peat-swamp forests have greater floral diversity than any other peatland in the world. Due to the specific hydrology and structure of the peat, trees have adapted to fluctuating water levels and unstable ground – with pneumatophores, stilt roots and buttresses (see photos below; stilt roots can provide structural support for the trees to deal with the unstable, wet peat soil; buttress roots can help with the same issue of unstable soil by helping to stop the uprooting of large trees; pneumatophores are “breathing roots” which, as might be evident, help in getting oxygen into the roots which are under the swamp water) (Figure 17). Peat-swamp forests require these adaptations at the same time.

**Figure 17: Top right showing pneumatophores (photograph from Wikimedia Commons), Top left showing stilt roots (photograph by Cesar Paes Barreto) and bottom photo showing buttress root (photograph by Marco Schmidt)**

What makes peat-swamp forests additionally distinctive, is that as the peat characteristics determine the tree species found (depending on the depth of the peat, water level etc.), there is no single peat swamp forest vegetation type; each peat-swamp forest will differ from another with regards to species composition and ecology. There is a continuous and distinct change in forest structure and tree species composition across the peat dome; from riverine forest, to mixed swamp forest, to low pole forest. In addition, there is considerable regional variation in tree species composition – e.g. in northern Borneo, the dominant peat swamp tree species on deep peat is *Shorea albida*, (Figure 18) but this species does not occur in peat swamps elsewhere in the region. This highlights the need for protection of multiple sites to protect the full range of biodiversity variation in this ecosystem.

**Figure 18: Dr. Sunitha Pangala standing by a *Shorea albida* at the Mendaram peat dome in Brunei. Photograph from Sunitha Pangala.**

Peatlands provide poor agricultural land given the high water tables and low pH and nutrient content of the peat soil. Until recently, they have generally supported only low human population densities. Despite this, the world's peatlands do support millions of people who live in and depend on them for grazing livestock, catching fish, reed harvesting, farming specific crops and forestry.

In Southeast Asia, for example, peatlands and their rivers are vital sources of fish. Fish is one of the main sources of livelihood and dietary protein for many communities across Borneo, with fishing often supporting the poorest members of society. Peat-swamp forests are also an important source of plants used for medicine and other aspects of life in Borneo. For example, in the past the *ehang* (indigenous Dayak name) tree bark was boiled to produce a dye to colour fishing nets and clothes. Another tree called *kahui* (Dayak name) has strong wood that is used in construction. Efforts to improve the production in peatlands by conversion, drainage and fertilising the soils are often very unsustainable.  In the following chapter we will look at the threats which tropical peatlands face in greater detail. Peatland degradation not only has serious implications for the environment, climate and biodiversity, but also the human communities that depend on peatlands and their forest for their wellbeing and livelihoods.

***Helpful links:***

1. *Watch this video about 'Community Voices', which shows voices of farmers and fishermen living and working in peatland areas in Central Kalimantan, Indonesian Borneo, to increase your understanding of why peatlands matter: https://www.youtube.com/watch?v=CAjs565FgQQ [9:08 min]*
2. *Watch the following video to understand why peatlands matter, and why their degradation is concerning, 'Why peat matters': https://www.youtube.com/watch?v=1C7ecAoXav0 [2.22 minutes]*
3. *Find out more about peatlands' role in climate regulation and biodiversity (this has a focus on temperate peatlands): https://www.youtube.com/watch?v=ZcxZ9gvNfSU [14.25 minutes]*

***Vocabulary***

***Ecosystem services:*** *the benefits people obtain from ecosystems. There are four categories of ecosystem services—supporting, provisioning, regulating and cultural.*

***Review questions***

Discuss why tropical peatlands are important to a) local communities and b) the global community.

What are ecosystem services, and give examples of each of the category of ecosystem services for tropical peatlands.

# 6. THREATS FACING TROPICAL PEATLANDS

Around the world, peatlands are facing threats, predominantly through harvesting, conversion to other land uses and drainage. **Human exploitation has damaged or degraded 25% of the peatlands on earth.** This has direct implications for loss of ecosystem services and for climate change, and is therefore relevant to us all: globally, peatland degradation contributes to over 3,000 million tonnes of $CO_2$ emissions per year. This is equivalent to 11.5% of all global fossil fuel emissions (26,000 million tonnes $CO_2$).

Today, less than 6% of Southeast Asia's peat swamp forests remain in a near intact condition: 43,000 $km^2$ (27%) are under large scale plantations and a further 35,000 $km^2$ (24%) are used for small scale farming. In Southeast Asia alone, more than 2,000 million tonnes of $CO_2$ are emitted per year due to peatland loss, of which 90% comes from Indonesia. **This is equal to 8% of all global $CO_2$ emissions.**

The main threats that this resource focuses on are: drainage, land subsidence, fires and oil palm plantation expansion. These are very much related to each other as will be further described in the coming sections.

Figure 19: A degraded and burnt tropical peatland, showing a drainage canal. Photograph by Sara Thornton/CIMTROP/BNF.

## 6.1. DRAINAGE

Figure 20: A drainage canal in a tropical peatland in Indonesia. Photograph by Sara Thornton/CIMTROP/BNF.

One of the main threats to peatland ecosystems is the disturbance of their natural hydrological balance through the building of drainage canals (Figure 20) for the transportation of timber out of the forest or to lower water tables for agricultural purposes. As the water level drops, the peat layers become dry and are exposed to oxygen, which then catalyses their decomposition and increases their susceptibility to fire. Drainage therefore leads to an increased risk of dry-season drought and resulting fire. Peat oxidation following drainage leads to $CO_2$ emissions to the atmosphere in the range of 355-874 Mt $CO_2$ per year for all Southeast Asian peatlands. Since 1990, the decomposition of drained peat soils in Southeast Asia has been responsible for the emission of around 0.2 Pg of carbon per year. To put this number into perspective, this contributes 18% of current net global carbon emissions arising from land use and land cover change. The water cycle and carbon cycle of peatlands are therefore linked.

Large areas of peatland across the world are currently drained for agriculture, forestry, and, to a lesser extent, peat extraction. Unless responsibly managed, drainage, conversion to agricultural land and fertilisation of peat soils can turn peatlands into strong sources of greenhouse gases (GHGs) and, ultimately, into landscapes that are very difficult to manage owing to land surface lowering and an increased risk of flooding.

One example of large-scale peat drainage and its environmental consequences is the former Mega Rice Project (MRP) in Central Kalimantan (Figure 21). Here, a total of 4,600 km of canals were dug to drain the peatland under a project initiated in 1995 by President Suharto that aimed to convert over 10,000 $km^2$ of deep peatland into rice paddy fields. However, as anticipated by scientists at the time, the acidic land and over-drainage proved unviable for growing rice and the project was quickly abandoned. Due to the drainage caused by construction of large canals the peat became over dry during the dry season, and fires are now a near annual occurrence that have destroyed large areas of forest and also burnt down into the peat itself. Following the MRP failure, transmigrants who had been moved into the area to work the rice paddy fields were left with no means of income, and many became 'environmental refugees', turning instead towards illegal logging and gold mining. The MRP has been called one of the biggest environmental disasters of the 20th Century and conservation efforts are urgently required to protect the remaining patches of forest and to rehabilitate the peatland hydrology, both to conserve the remaining forest biodiversity and the carbon stored within the underlying peat.

**Figure 21: The former Mega Rice Project area in Indonesian Borneo. This drained peat landscape has been subject to regular fires resulting in loss of carbon to the atmosphere from combustion of the forest biomass and the underlying, drained peat. Photograph by Sara Thornton/CIMTROP/BNF.**

While carbon emissions arising from peatland drainage may dominate some environmental debates due to their potential for climatic warming, there are also additional, important local and regional implications of peatland drainage, including increased risks of flooding and fire with associated human health and socio-economic repercussions.

## 6.2. LAND SUBSIDENCE

Another serious problem associated with peatland drainage and the loss of soil organic matter, is the lowering of the land surface, called **subsidence**. This can happen to the peat soil following drainage because of compaction, consolidation and loss of volume. Peat soils are made up of about 10% accumulated organic material (carbon) and 90% water. Therefore, when the water is removed following drainage, the carbon in the peat soil is exposed to aerobic conditions, leading to the previously discussed decomposition of the peat (and the resulting $CO_2$ emissions). This process continues as long as drainage is occurring and until all of the peat above the drainage level is lost. This process is illustrated in Figure 22.

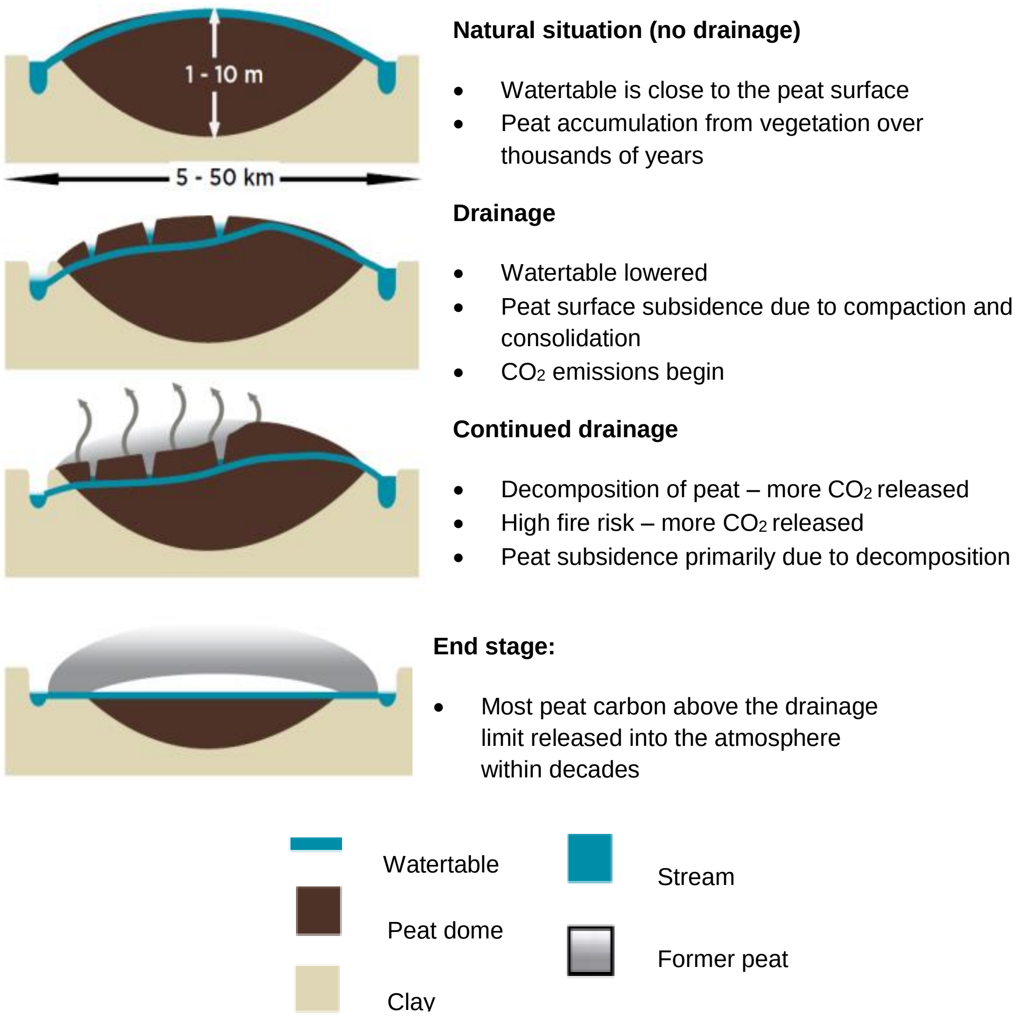


Figure 22: Process of drainage and land subsidence in a peatland. Diagram from Susan Page.

Across the world peatland subsidence has led to drainage problems (i.e. an increasing risk of seasonal or continuous flooding), salt intrusion in coastal peatlands and eventually to the loss of productive land. It has been estimated that drained peatlands in the temperate zone can lose 1 to 2 cm in height per year. In the tropics the rate of subsidence can be as high as 3 to 5 cm per year. This is due to the year-round high temperatures in these regions, driving higher rates of peat decomposition. As a result, and within only a few decades, ongoing subsidence will likely threaten the long-term agricultural and economic productivity of drained coastal tropical peatlands in, e.g. Southeast Asia, as they become progressively more vulnerable to riverine and coastal flooding.

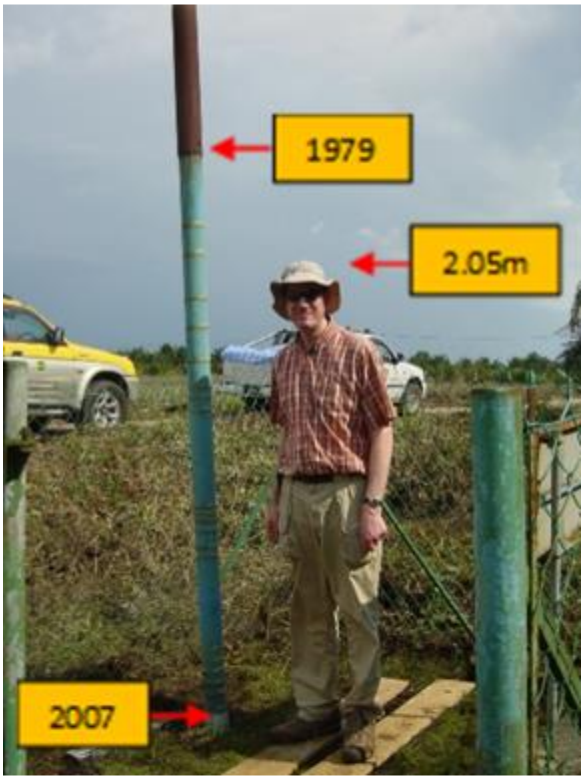


**Figure 23: Subsidence pole in a peatland in Johor, Peninsular Malaysia. The pole was inserted beside an oil palm plantation in 1978, and at the time of this photograph (2007), 2.3 m of subsidence had occurred. Image from Susan Page, University of Leicester.**

In addition to carbon storage, peatlands play an important role in protecting adjacent or downstream areas against floods after heavy rainfall and in ensuring a supply of clean water throughout the year. If subsidence occurs this capacity to produce and provide for local communities (human and non-human) is lost, and can, ultimately, cause ecosystem disruption. For example, within the Rajang River Delta along the coast of Sarawak, Borneo, the cover of industrial-scale oil palm plantations on peatland has increased from 6% to 47% between 2000 and 2014, with most of the remaining non-plantation peatland also affected by drainage. This has already and will increasingly result in the coastal lowlands being affected by subsidence and an increasing risk and duration of flooding. Flood models generated by Deltares (**https://www.youtube.com/watch?v=SRwrAczShUc**), show that a plantation flood risk estimated to be 29% in 2009, will increase to 42% in 25 years, 56% in 50 years, and 82% in 100 years. It is predicted that as flood conditions intensify in terms of frequency and impact, oil palm production may eventually have to be abandoned in most of the area.

## 6.3. FIRES

When peatlands are drained, they become highly vulnerable to peat fire. Dry peat ignites very easily and can burn for days or weeks, even smouldering underground. This makes tropical peatland fires incredibly difficult to extinguish, highly unpredictable and uncontrollable. The peat fires in Southeast Asia can burn thousands of square kilometres of peatland in one dry season. Fires are extremely rare in non-degraded and non-drained peatlands; but in drained peatlands, fires can last for weeks, sometimes even months, burning downwards into the thick layers of peat over large areas. The combination of rapid rates of peat oxidation and frequent fires mean that the Southeast Asian region has been identified as a global 'hot spot' for peatland greenhouse gas emissions.

**Figure 24: Burning tropical peatland, photograph from the Borneo Nature Foundation.**

Some of the most severe peat fire events from 1960 to the present day have occurred during years of low rainfall induced by El Niño–Southern Oscillation (ENSO) events. The fires of 1997-98 burned 97,000 -117,000 km$^2$ on Borneo and Sumatra, including 15,000 km$^2$ of tropical peat-swamp forest.

In 2015 Indonesia was once more hit with disastrous fires: a strong El Niño-related drought combined with forest disturbance and widespread peatland drainage made 2015 the worst fire season since 1997. Emissions from peat fire and decomposition were comparable to those in 1997 in magnitude, with the fires leading to a total carbon release of 227 ± 67 Tg C. To put this into perspective, the amount of $CO_2$ release every day during the 2015 fire season exceeded the daily fossil fuel emissions of the whole European Union (EU28) (data from Huijnen *et al*., 2016).

In Southeast Asia, peatland fires are almost entirely of anthropogenic origin and the large majority occur in the dry season. Slash and burn agricultural techniques have a long history in this region, and the livelihoods of small farmers generally still depend upon fire as the only affordable way to rapidly clear land. Therefore, the Indonesian government's attempts to ban the use of fire have been met with resistance from farmers. Large company-owned oil palm plantations and smallholders also use fire to clear land and landowners use fire to demonstrate use of land, as under Indonesian law unused land is considered available for occupation. Fires are also started through arson, from cooking fires, to create better access to valuable timber and to hunt animals, including fish. Fires are often used to resolve land disputes and in some cases to drive off settlers. The causes of fire are therefore numerous and multifaceted.

**Figure 25: The Sebangau peatland river in Indonesia, experiencing serious haze from peatland and forest fires in 2015. Photograph by Sara Thornton/CIMTROP/BNF.**

The implications of carbon emissions from peat fires and peat oxidation for climate change are serious; Indonesia is responsible for the third highest emissions of $CO_2$ worldwide. Furthermore, estimates show that the 1997 fires contributed the equivalent of 13-40% of global carbon emissions from fossil fuels that year, while the economic cost of the 2015 fires and associated air pollution (haze) has been provisionally estimated at USD 16.1 billion or about 1.8% of Indonesia's 2014 GDP. Income and property losses due to fires, along with smoke haze and associated public health impacts, floods, decreasing income from timber and non-timber forest products and fish, contribute to the impoverishment of local communities.

The smouldering nature of peat fires means that they burn slowly down into and below the ground, consuming the carbon-rich peat as a fuel source. The result is a dense, toxic smoke containing a cocktail of greenhouse gases, including $CO_2$ and methane, along with carbon monoxide, small particulates and aerosols that are extremely harmful to human health. During the peat fires of 1997-98, annual mean particulate matter concentrations reached 200 $\mu g\ m^{-3}$ near fire sources for more than 50 days across Southeast Asia (Southeast Sumatra and Southern Borneo), which exceeds the World Health Organization's 24-hr air quality target (50 $\mu g\ m^{-3}$).

For the 2015 fires, research has found that high particulate matter concentrations exposed 69 million people to unhealthy air quality conditions, with short-term exposure to this pollution potentially causing almost 12,000 excess mortalities. Particulate concentrations also achieved harmful levels: an AERONET (NASA) station in Palangkaraya, one of the most severely affected cities in Borneo, detected a six-fold increase in air-borne particles. Furthermore, in parts of southern Sumatra and southern Borneo, Indonesia's Pollutant Standards Index (PSI): which incorporates particulate matter, sulphur dioxide, nitrogen dioxide, carbon monoxide and ozone, soared above 2000. Any score above 350 is considered hazardous to human health.

As a result of frequent smoke from peat and forest fires, it has been estimated that ~ 30% of all children living in the locality of peatlands in Indonesia have respiratory diseases and growth inhibition. In addition, each fire event leads to thousands of hospitalizations, due to an increase in respiratory and cardiac conditions.

Following the fires in 2015, about 26,110 $km^2$ of peatland were burnt with significant negative consequences for tropical peat-swamp flora, fauna and human communities in the affected areas. The fires in 2015 were a catastrophe for the climate, environment, and humans alike.

## 6.4. OIL PALM PLANTATION EXPANSION

Palm oil is extracted from the fruit of the oil palm tree, *Elaeis guineensis*. Palm oil is used as a food oil, biofuel, and is found in everything from shampoo to doughnuts. It is now the most common vegetable oil in the world.

Oil palm has played a central role in the observed land-use changes within Indonesia and Malaysia over the last few decades, driven by global consumer needs for vegetable oil based products. Consequently, this form of conversion is responsible for 16% and 32% of total emissions from land-use change and peat oxidation in Indonesia and Malaysia, respectively.

In 2010, it was estimated that industrial plantations, dominated by oil palm, covered approximately 3.1 million ha (Mha) of peatland distributed across Peninsular Malaysia, Borneo and Sumatra. However, more recent figures show that this has now increased to 4.3 Mha, with 50 % of peat-swamp forests in this region now covered by 'managed land' (22.4 % smallholders; 27.4 % industrial). Following a 'business as usual' (BAU) approach it has been suggested that this could reach upwards of 6 to 9 Mha by 2020.

About 90% of the world's palm oil production occurs in Indonesia and Malaysia. Of these plantations, 20% are grown on peat soils, formerly covered by peat-swamp forests. Sumatra has the largest absolute extent of oil palm plantations on peat (1.3 Mha), followed by Kalimantan (730,750 ha), Sarawak (717,830 ha) and, and Peninsular Malaysia (275,680 ha). The highest oil palm development rates on peat are in Sarawak: the rate of change in the last temporal period of swamp forest in Sarawak was approximately 7% annually (59,620 ha) and nearly all of the loss of peat forest can be directly attributed to establishment of new oil palm plantations.

Peatlands are not very suitable for oil palm production: the soil has poor fertility and is too wet for the trees. Therefore, the peatlands have to be logged and drained for the oil palms to be planted. This causes the issues of peatland oxidation, degradation, subsidence and vulnerability to fire.

This also means that oil palm on peat is contributing to significant greenhouse gas emissions. Given that Indonesia has over 30,000 $km^2$ of oil palm plantations and a similar amount of smallholder plantations on peat, drainage for the production of palm oil is, using conservative estimates, causing emissions of 438 million tonnes of $CO_2$ per year. With harvests of 2-6 tonnes of palm oil per hectare, palm oil is causing $CO_2$ emissions 10 times the magnitude of fossil fuels. Between 2000 and 2009, palm cultivation in Indonesia was responsible for 2-9% of worldwide emissions from tropical land use.

Figure 26: Oil palm plantation in Sarawak, Malaysia. Photograph by Sarah Cook.

Palm oil production also takes a toll on biodiversity and human rights. Once the peat-swamp forests have been cleared, little of the biodiversity remains, while oil palm growers have been accused of using forced labour, seizing land from local populations and other human rights abuses.

There has been significant movement from Southeast Asian governments to address oil palm impacts, though there is still much to be done. In 2010, Indonesia established a moratorium on new concessions for oil palm, timber and logging operations on primary forests and peatlands. In addition, Indonesia has responded to worsening haze conditions by calling for a halt to clearance and drainage of peatlands, and for the restoration of those already drained. Malaysia has also begun to act to protect some of its forests, though its protections thus far have not been as strong as Indonesia's.

On the private-sector side, the Roundtable on Sustainable Palm Oil (RSPO) was formed to bring oil producers, non-governmental organizations (NGOs) and other stakeholders together to improve the sustainability of palm oil production. However, current RSPO standards fall short in important respects. For instance, while primary forests are protected under RSPO regulations, secondary, disturbed, or regenerating forests are left unprotected. Peatlands are also given limited protection under RSPO guidelines. So "RSPO-certified" does not necessarily mean "deforestation-free." Nevertheless, efforts to raise standards are to be welcomed as they have raised consumer awareness of the issues related to palm oil production and increased pressure on the industry to certify.

A further welcome move is the EU regulation (2014) that requires the source of vegetable oils in food products to be included on food packaging. This means that palm oil can't be labelled as only 'vegetable oil' with the source of the oil having to be specified (e.g. oil palm, rapeseed, coconut etc.). This allows consumers to make more targeted choices for their purchases and allows producers to see if there is a demand for sustainable palm oil and products with an RSPO or similar labels.

*Activity ideas:*

*Have students explore the questions:*

- *What are the benefits and disbenefits of palm oil production? Consider environmental, social and economic (dis)benefits.*
- *What is RSPO, and is it possible to have sustainable palm oil?*
- *Check your family's weekly shop: how much of it contains palm oil? How much is certified palm oil?*
- *What can you do as an individual to support the movement towards more sustainable palm oil in the world?*

*Helpful links:*

1. *'Palm oil production, peatland loss and CO2 emissions': https://www.youtube.com/watch?v=KsWHLGEVodk&t=20s [4.28 min]*
2. *'Peat Destruction, Soil Subsidence and Flooding in South East Asia': https://www.youtube.com/watch?v=FhLkBGYl_tw&t=39s [4.48 min]*
3. *'Indigenous and forest community leaders tour the EU to call for conflict-free palm oil' [article] : https://news.mongabay.com/2016/05/indigenous-forest-community-leaders-tour-eu-call-conflict-free-palm-oil/*
4. *'Study maps 187 land conflict as palm oil expands in Kalimantan' [article]: https://news.mongabay.com/2016/12/study-maps-187-land-conflicts-as-palm-oil-expands-in-kalimantan/*
5. *'Local land rights may be in danger from push for palm oil in Liberia' [article]: https://news.mongabay.com/2015/03/local-land-rights-may-be-in-danger-from-push-for-palm-oil-in-liberia/*
6. *'Palm oil companies ignoring community rights, new study shows' [article]: https://news.mongabay.com/2013/11/palm-oil-companies-ignoring-community-rights-new-study-shows/*

*Review question*

Discuss the main threats that tropical peatlands face, the causes of these threats and how they impact the water and carbon cycles of tropical peatland ecosystems.

# 7. CASE STUDY 1: SOUTHEAST ASIAN PEATLANDS AND INDONESIA

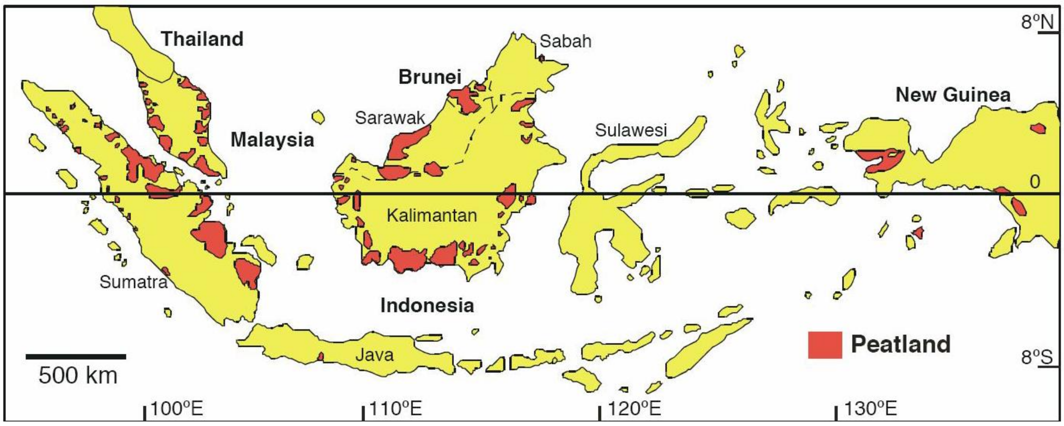


**Figure 27: Distribution of tropical peatlands found throughout Southeast Asia. Figure from Page *et al.* (2004).**

Peatlands make up 12% of the Southeast Asian land area (defined as Indonesia, Malaysia, Brunei and Papua New Guinea) (Figure 27). This equals some 270,000 $km^2$. Indonesia harbours 225,000 $km^2$, Malaysia 20,000 $km^2$ and Papua New Guinea 26,000 $km^2$.

Southeast Asian peatland forests are among the last vast tracts of rainforest in the area. Until recently, the tropical peat-swamp forest of Southeast Asia was a neglected ecosystem with low conservation priority. However, it is now clear that these forests contain high faunal and floral diversity, and unfortunately some of these species are facing the threat of extinction. A total 45% of mammals and 33% of birds recorded in TPSFs are classified as near threatened, vulnerable or (critically) endangered by the IUCN. Lastly, due to the unique characteristics of TPSFs such as the acidic water, the rivers and waters of these forests are important fish habitats containing various endemic stenotopic species (species that are only able to tolerate a restricted and specific range of habitats or ecological conditions). These areas are also of particular importance for the survival of the orangutan, Sumatran Tiger, Sumatran Rhinoceros, as well as less well-known rare species such as the White-winged Duck, Storm's Stork and False Gharial which have small populations that are mainly restricted to peat-swamp forests.

However, already over 90% of Southeast Asian peat-swamp forests have been affected by drainage, conversion or logging. Between 1985 and 2005, Southeast Asian peatlands were deforested at an average rate of 1.3% per year; the highest value is found in East Kalimantan (2.8%) and the lowest in Papua (0.5%). This is twice the rate of deforestation in other forest types in the region. Vast areas of peatland have been rapidly exploited for economic benefit; driving land conversion by deforestation, drainage and fire. Consequently, only 6% of peat-swamp forests in Peninsular Malaysia, Borneo and Sumatra are now considered pristine. The conversion of peat-swamp forests into other land uses significantly contributes to global anthropogenic greenhouse gas (GHG) emissions, with managed land cover types contributing 78 % of Southeast Asia's total peat oxidation emissions (146.2 Mt C $yr^{-1}$).

The tropical peat-swamp forests of Central Kalimantan are among the most extensive in Southeast Asia. Central Kalimantan holds about 13.5% of Indonesia's peatlands, with one fifth of the province covered in peatland. The Sebangau Forest in Central Kalimantan is home to the world's largest remaining contiguous orangutan and southern Bornean gibbon (*Hylobates albarbis)* population.

However, the Indonesian province of Central Kalimantan has seen major deforestation and forest degradation due to illegal and legal logging operations, plus land clearing and fire for small scale farming and plantations. With the rapid expansion of timber and palm oil plantations, Central Kalimantan is now the province with the highest rate of deforestation in Indonesia. This loss of forest has not only negatively affected biodiversity in the area but also the local human communities, many of whom depend on the forests for their livelihoods.

The largest and most disastrous example of peatland degradation is the MRP in Central Kalimantan. In the mid-nineties this large-scale reclamation project attempted to convert 1.5 million ha of peat-swamp forest into agricultural areas for rice production, despite many warnings of scientists and nature conservationists that this would not be possible. Thousands of people moved to the area, many as part of **transmigration schemes** (see box below). Rice production appeared to be possible on less than 2% of the total area. Income was derived mainly from logging in and around the MRP area. Many people moved away, but villagers that stayed in the peatlands were increasingly coping with floods because of soil subsidence. Today, the drained and logged-over areas are the scene of annual peat fires. Besides this visible form of degradation, more invisible subsidence and decomposition (oxidation) of the peat is taking place at a rapid rate.

*Transmigration in Indonesia*

*Transmigration was a scheme created by the Indonesian government to ease overpopulation in the capital of Java and overpopulated areas by moving people to the less populated areas of Indonesia such as Indonesian Borneo. The government provided land, money and fertiliser for those who moved and supported them to start farming in their new location. Transmigration led to a multitude of issues relating to indigenous rights (transmigrants were sometimes given land that was already used by indigenous communities with no formal land rights), land management and forest degradation due to increased populations and unsustainable practices.*

*Find out more:*

- *http://gcsegeographyhelp.blogspot.co.uk/2016/06/transmigration-in-indonesia.html*
- *https://geographyatmanor.wikispaces.com/Transmigration*
- *http://www.downtoearth-indonesia.org/old-site/ctrans.htm*

***Activity ideas:***

*Have students explore the questions:*

- *What was the Mega Rice Project? Why was it started and why did it fail?*
- *What are the social, environmental and economic consequences of the MRP?*
- *What is being done now to counter the peat degradation in the MRP?*

***Helpful links:***

1. *'Carbon Bomb: Indonesia's Failed Mega Rice Project':* *http://www.environmentandsociety.org/arcadia/carbon-bomb-indonesias-failed-mega-rice-project*
2. *'Indonesia blocks major artery in haze-causing Mega Rice canal network' [article]:* *https://news.mongabay.com/2017/07/indonesia-blocks-major-artery-in-haze-causing-mega-rice-canal-network/*

# 8. CASE STUDY 2: AFRICAN PEATLANDS AND THE CONGO BASIN

In the beginning of 2017, news came out that scientists had discovered the world's largest peatland in the remote swamps of Congo (Figure 28). Researchers mapped the Cuvette Centrale peatlands in the central Congo basin, and found they cover 145,500 $km^2$ – an area larger than England. The swamps could contain 30 billion tonnes of carbon that was previously not known to exist, and equal to three years' worth of the world's total fossil fuel emissions. These peatlands also store the equivalent of nearly 30% of the world's tropical peatland carbon.


**Figure 28: Tropical Peatland Scientists working in the Congo basin. Photograph by Simon Lewis.**

It is amazing that as recently as 2017 discoveries like the world's most extensive peatland complex can still be made!

These peatlands are not only globally important for their carbon storage, but are also refuges for endangered species such as lowland gorillas and forest elephants; animals that are threatened by developments in the surrounding landscapes.

This finding also places the Democratic Republic of Congo (DRC) and the Republic of Congo (RoC) as the second and third most important countries in the world for tropical peat carbon stocks. In the first place is Indonesia. The RoC is considering extending the area of protected swamp by expanding the Lac Tele Community Reserve by up to 50,000 $km^2$. Let's hope that happens for this vital area.

Because of their remote location, the peatlands in the Congo basin are relatively undisturbed, but they are also not currently protected by conservation plans. They potentially face threats from drainage for agriculture plantations, such as for oil palm, as is occurring in Indonesia.

Africa has now become the new frontier of industrial palm oil production. From 2016 to 2021, as much as 220,000 $km^2$ of land in west and central Africa could be converted to oil palm plantations. Following experiences from Indonesia and Malaysia, questions arise of whether it is possible to establish a sustainable palm oil industry that operates in a way that protects environmental and human rights, and provides local communities with genuine opportunities.

*Activity ideas:*

*Have students explore the questions:*

- *What does sustainable palm oil mean?*
- *Is sustainable palm oil possible?*
- *What are the environmental and human implications of palm oil? Consider a comparison between countries or regions.*
  - *Consider land right issues, local food needs, cultural and income needs.*
  - *What is Free Prior and Informed Consent?*

*Helpful links:*

1. *A comparison between palmoil industry in Liberia and Indonesia:* *http://rightsandresources.org/en/publication/view/industrial-oil-palm-development-liberias-path-to-sustained-economic-development-and-shared-prosperity-lessons-from-the-east/*
2. *Dargie et al. (2017), 'Age, extent and carbon storage of the central Congo Basin peatland complex' [article]:* *https://www.nature.com/nature/journal/v542/n7639/full/nature21048.html*

# 9. CASE STUDY 3: PERUVIAN PEATLANDS AND PALM SWAMPS

Peru has, following Indonesia, DRC and ROC, the next largest expanse of peatland in the tropics.

Peru's peat-swamps are also important for the *aguaje* fruit. They help to purify water and provide breeding habitat for fish. The *aguaje* fruit is produced by the *Mauritia flexuosa* palm, which grows throughout the Peruvian Amazon in swamps known as *aguajales*. Thousands of people depend on harvesting the fruit for their livelihoods.

Just like the peat-swamps in Indonesia and Africa, those in Peru face threats from development, agriculture and people harvesting *aguaje* fruit.

The harvesting of the *aguaje* fruit often involves chopping down the palms. The palms grow so tall that it is quicker and easier to chop the whole tree down rather than climbing up and cutting off the hanging clumps of *aguaje*.

**Figure 29: The Mauritia flexuosa palm at the site of Quistococha. Photograph from the UK Tropical Peatland Working Group.**

Cutting the palms, combined with logging of timber species in the swamps, can change a swamp's microclimate, drying it out and exacerbating the degradation of the peat. If the tree canopy cover is removed, more sun gets in and evaporation increases; this changes the air temperature, soil temperature and soil moisture.

In various parts of the Peruvian Amazon, palm peat-swamps have been cleared, drained and turned into rice paddies or oil palm plantations.

Just as for Congo's peatlands, Peru's peatlands are still a bit of a mystery. Their exact extent is unknown, although they are estimated to cover at least 50,000 square km: an area almost as large as Costa Rica. Also, not all palm swamps are peatlands, and researchers are not sure which ones have peat deposits or why – i.e. what are the precise environmental conditions that favour the initiation of peat formation? We therefore need more peat researchers in the field!

In 2015, researchers reported a large and previously unmapped peatland covering 35,000 square km in the upper Amazon basin in northeastern Peru. The Pastaza-Marañón swamp is the most carbon-dense landscape in Amazonia. It covers just 3% of the forested area in Peru but contains 3 billion tons of carbon: almost half as much as in all the country's above-ground forests. The Pastaza-Marañón is threatened by the expansion of commercial agriculture linked to new transport infrastructure. Cultivators have moved into the neighbouring region of Ucayali, where 89 $km^2$ of primary forest was cleared for an oil palm plantation. The Peruvian government also has plans for the first all-weather road into the peatland, linking it to the rest of Peru, as well as Brazil and Colombia.

*Activity ideas:*

*Have students explore the questions:*

- *What is aguaje fruit used for and why is it important?*
- *Can harvesting of the aguaje fruit be done in a sustainable way?*
- *What other aspects of livelihoods are dependent on peat-swamps? Consider a comparison of peat-swamps and their importance to local community livelihoods from different countries.*

*Helpful links:*

1. *Inside Peru's peatlands A scientist explains: https://www.youtube.com/watch?v=VD4YD_602Pk [4.50 min]*
2. *Draper et al. (2014), 'The distribution and amount of carbon in the largest peatland complex in Amazonia' [article]: http://iopscience.iop.org/article/10.1088/1748-9326/9/12/124017*

## 10. THE WAY FORWARD: BY DR. SOPHIE GREEN AND PROF. SUSAN PAGE

Fundamental changes in the management of northern and tropical peatlands are required if their large carbon stocks are to be managed responsibly while also ensuring land use, biodiversity and livelihoods can be maintained or protected (Figure 30).

Figure 30: A family of fishers check their catch on the Sebangau peatland river in Indonesia. Photograph by Sara Thornton/CIMTROP/BNF.

In South-East Asia, Europe and North America, it is encouraging that researchers and those managing peatlands are beginning to collaborate in the search for long-term, more responsible land management solutions and for interim measures to mitigate ongoing rates of peat loss under existing land uses. Research and practical knowledge on approaches to and consequences of the removal of active drainage and rewetting of northern peatlands is moving forwards rapidly, but is at a less advanced stage in the tropics, even though this is where knowledge and solutions are most urgently needed.

In Southeast Asia, the continued conversion of peatlands to agricultural use, and degradation by repeated wildfires along with an increased risk of flooding, will ultimately lead to a loss of economic returns, increased poverty for communities living in and around peatlands, and pressure on remaining natural resources. But encouragingly, these issues are now being recognized by the plantation industry and a number of large and experienced oil palm and pulpwood companies have halted further development on peat, implemented zero burning and fire control policies, and begun to introduce more rigorous water management requirements in existing plantations. As a further strong step in the direction of responsible peatland management, the President of Indonesia has established in the aftermath of the 2015 fires a national Peatland Restoration Agency. Mandated to plan and implement the restoration of approximately 20,000 $km^2$ of degraded peatland, the agency is also co-ordinating research on alternative, more sustainable economic activities for cultivated peatlands, including methods to cultivate crops under wet(ter) conditions.

The 'responsible' use of organic soils will inevitably involve a gradient of land use options. There is no universal solution, but in essence there needs to be a prevention of further degradation, which may involve ceasing or reducing the intensity of artificial drainage. At one end of the spectrum, responsible use of cultivated peatlands will require a more efficient use of a finite resource; whilst high water table agriculture represents the ideal end-point, more research is needed to develop economically viable crops. At the other end of the spectrum, the protection of peat carbon stocks and biodiversity may require the cessation of all drainage and restoration of near-natural hydrological regimes and plant communities (Figure 31).

**Figure 31: A dam blocking a drainage canal in a tropical peat-swamp forest in Indonesia. Photograph by Sara Thornton.**

In support of more responsible peatland uses, there are a small but growing number of good examples demonstrating opportunities for changes in peatland management. These include paludiculture (i.e. a combination of rewetting and wetland crop cultivation) and diversifying income sources through mechanisms such as payments for ecosystem services, climate change mitigation funding and tourism development.

In Indonesia, a small number of pilot projects are being undertaken to ‘retire’ and rewet plantation blocks that adjoin intact forest by blocking drainage canals and replanting with native tree species in an effort to increase the hydrological resilience of the peat swamp forest, to protect biodiversity and to reduce fire risk.

Peatlands across the globe have served as long-term carbon sinks. Nevertheless, without adequate safeguards, predicted climatic changes towards drier conditions and longer fire seasons combined with ongoing human disturbances will inevitably lead to increased rates of carbon loss and hence faster rates of carbon flux to the atmosphere. In Southeast Asia, as in other parts of the world, measures to protect intact peatlands and to manage degraded peatlands more responsibly are vitally important if we are to ensure the continued role of peatlands in climate change mitigation.

## 10.1. PEATLAND RESTORATION: CANAL BLOCKING

One of the main approaches to restoring a peatland, is to restore its hydrological functioning through blocking drainage canals. One example of peatland restoration using this method is taking place in the MRP in southern Borneo (see section 6.1 and 7). This is an area that experienced deforestation through plans to convert 17,000 $km^2$ of peat swamp forest to rice paddy fields. With the failure of the project (with rice being unable to grow in acidic peat soils) most of the former MRP area is now left in a highly degraded condition.

Comparing the drained and degraded peatland of the MRP to the nearby Sebangau Forest (a relatively undisturbed tropical peat-swamp forest), it is clear that the restoration of the peatland hydrological functions is the key pre-requisite to establishing a positive or neutral peatland carbon balance, as well as providing suitable conditions for revitalisation of the forest vegetation.

In the Sebangau Forest, canal blocking has been undertaken on small scale. This involves damming of narrow, shallow canals previously used to transport timber out of the peatland area (which now only leads to further drainage of the peatland), in order to raise water levels (Figure 32). Over a 5 week period following the installation of dams in Sebangau, there was an increase in the water levels in the blocked channels of an average of 8 cm. While these results are preliminary, they suggest that blocking canals can have a positive impact on the water levels and hence hydrological recovery of the forest.

However, efforts to block the much wider and deeper canals in the former MRP has illustrated the complications associated with damming operations. While dams initially led to an increase in the adjacent peat groundwater table which decreased subsidence and $CO_2$ emissions, there was still an issue of the canals "eating" themselves into the peatland; thereby creating extra runoff as well as increased subsidence of peat near canals. Dam breakage, by people, is also one of the biggest causes of dam failure. Researchers therefore concluded that there has to be improved canal blocking strategies to allow for the restoration of tropical peatlands, which will require better understanding and research into the effects of changes in hydrology and damming on the topography of peatlands. This will also require understanding why people break the dams, and working alongside local communities to find canal blocking strategies that work for them. While it is clear that the opportunity exists for restoration projects to reinstate the hydrological function which is a prerequisite for the return of the biological diversity of tropical peatlands; more work is indeed needed to identify the most effective methods for doing so.

**Figure 32: Building a dam in a drainage canal in Sebangau peat-swamp forest in Indonesia. Photo by BNF.**

In particular, more research is needed regarding methods to approach the restoration of large areas of degraded tropical peatland. The longer an area of peatland has been drained, the more challenging it is to restore to its original state. In these cases, a 'new natural state' will be achieved through restoration; different from the original state and perhaps not a functioning peatland habitat type but at least the worst effects of degradation could be mitigated (fully functioning would imply peat formation which is unlikely even in the medium term). It is furthermore expected that climate change will have serious impacts on wetlands through changes in hydrological regimes with increasing global variability. This will have consequences on the effectiveness of restoration projects to restore ecosystems, additionally highlighting the need for adaptive management and conservation in peatland restoration. Lastly, restoration ultimately represents a commitment of land and resources that is indefinitely long-term. It therefore requires careful deliberation and planning which is why it is vital to involve all stakeholders, such as local communities, when making decisions regarding the implementation, planning and monitoring of a restoration project. Once an ecosystem is self-sustaining (and thereby restoration is achieved), the restored ecosystem will, just as an undamaged ecosystem, require continued management to deal with impacts of human activities and climate change. This therefore highlights the importance of incorporating the local communities in ecosystem restoration projects, as then there is a greater likelihood that these communities will continue managing the ecosystem once restoration is complete. To do so requires an understanding and incorporation of the social and economic needs and wants of local communities.

*Review question*

Choose one case study of a tropical peatland, explain what threats the area is facing and discuss what needs to be done to conserve the forest and local livelihoods.

## 11. MORE HELPFUL LINKS FOR FURTHER INFORMATION

1. ‘Why peatlands matter’: http://www.cifor.org/publications/pdf_files/brief/6453-brief.pdf
2. ‘For peat’s sake: the facts’: http://www.cifor.org/publications/pdf_files/posters/6448-infographic.pdf
3. For information on CIFOR’s work on peatlands: https://www.cifor.org/?s=peatlands&submit=%EF%80%82
4. 'Can We Find the World’s Remaining Peatlands in Time to Save Them?’ [article]: http://e360.yale.edu/features/can-we-discover-worlds-remaining-peatlands-in-time-to-save-them

*Example exam-style questions*

1. Discuss the role of tropical peatlands in the carbon and water cycles.
2. Humans are affecting the carbon cycle more than physical factors - discuss in reference to named ecosystems.
3. Assess the extent to which humans are altering the water cycle in one tropical environment.
4. Assess the extent to which humans are altering the carbon cycle in one tropical environment.

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