THE UNIVERSITY OF WARWICK

Summer School Lecture 2026

Peatlands: Microbes Carbon Playground

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Environmental Scientist

Human-ecosystem interactions

- Biogeochemical cycling and the critical role of freshwater ecosystems in the global carbon cycle.
- Carbon cycling emissions from freshwater ecosystems and the impact of nutrients and anthropogenic drivers on modifying aquatic carbon dynamics across inland waters.
- Tropical peatlands
- Borneo, India and Cambodia

Peatland ecosystems

What are peatlands?

Carbon rich wetlands that cover 3% of the earth's surface and 12% of UK land area.

Peatlands are carbon-rich ecosystems that possess the ability to store and sequester more carbon than any other terrestrial ecosystem.

Through the process of peat accumulation, these ecosystems surpass even the global above-ground carbon stock found in forest ecosystems.

Peat is partially decomposed dead organic mater (mainly of plant origin i.e. fallen leaves)

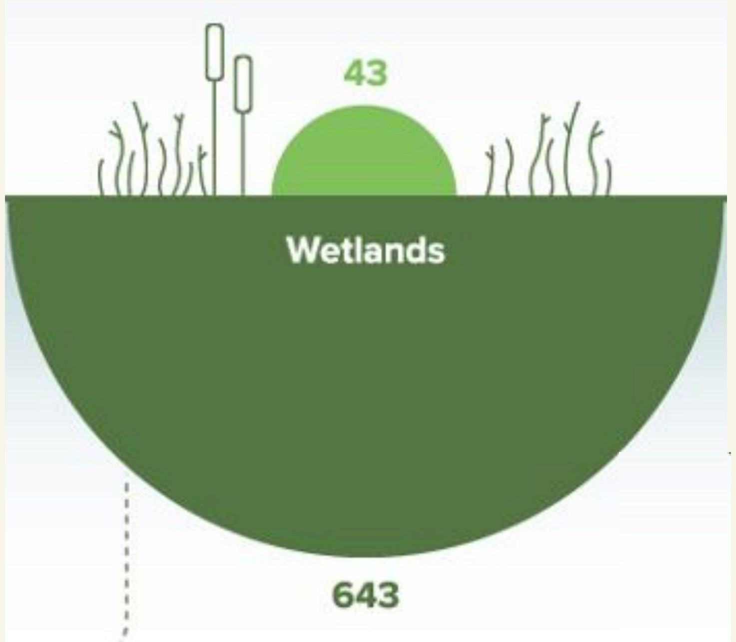
Formed in areas which are:

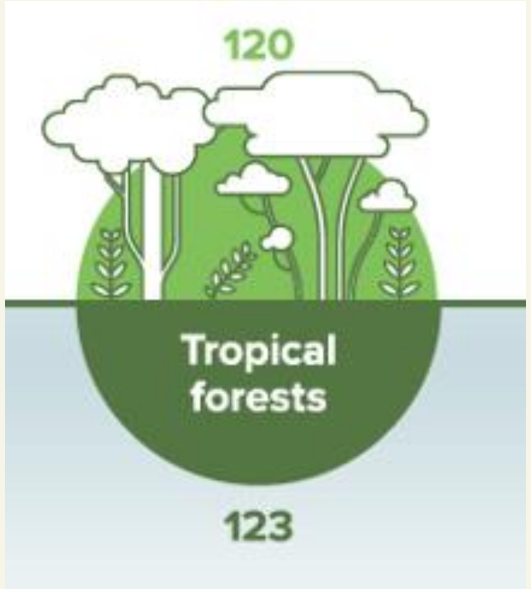
- Waterlogged (anaerobic)
- Oxygen deficient
- High acidity
- Nutrient stressed



Peatlands and carbon

Peatlands are among the largest terrestrial carbon reservoirs globally, storing an estimated **600 billion tonnes of carbon.**





https://unfccc.int/sites/default/files/draftpeatlandco2report.pdf

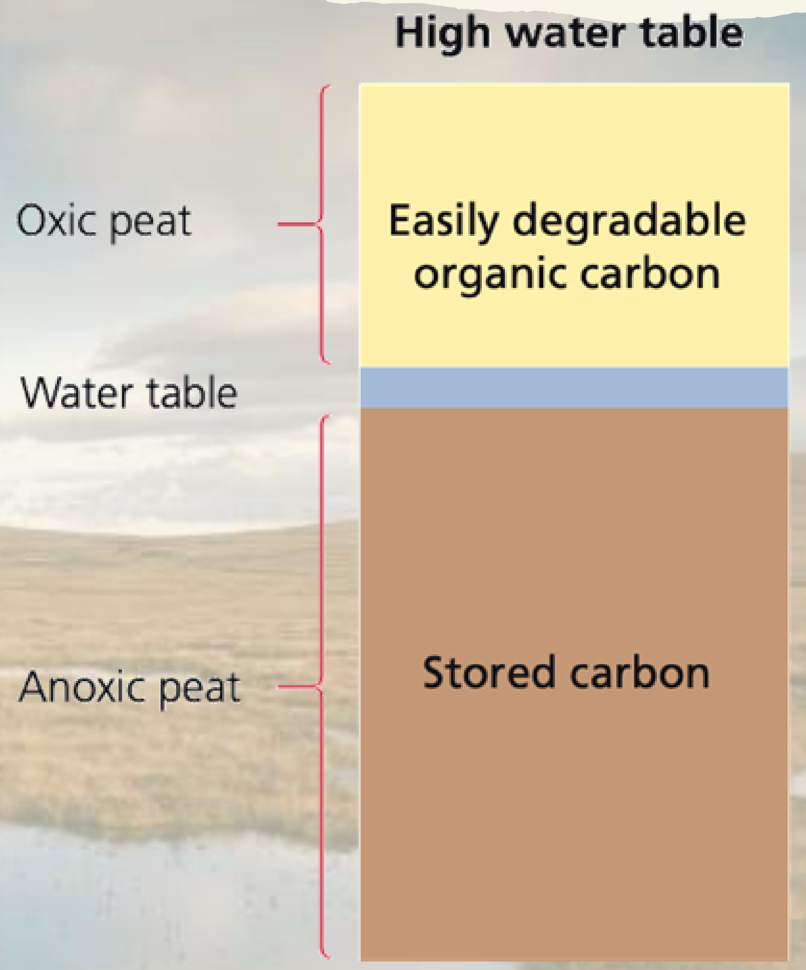
Peatlands and carbon

The carbon stored in peatlands is mainly in the form of organic matter within the peat layers.

Peatlands sequester carbon by capturing atmospheric carbon dioxide through the process of photosynthesis and storing it in the peat.

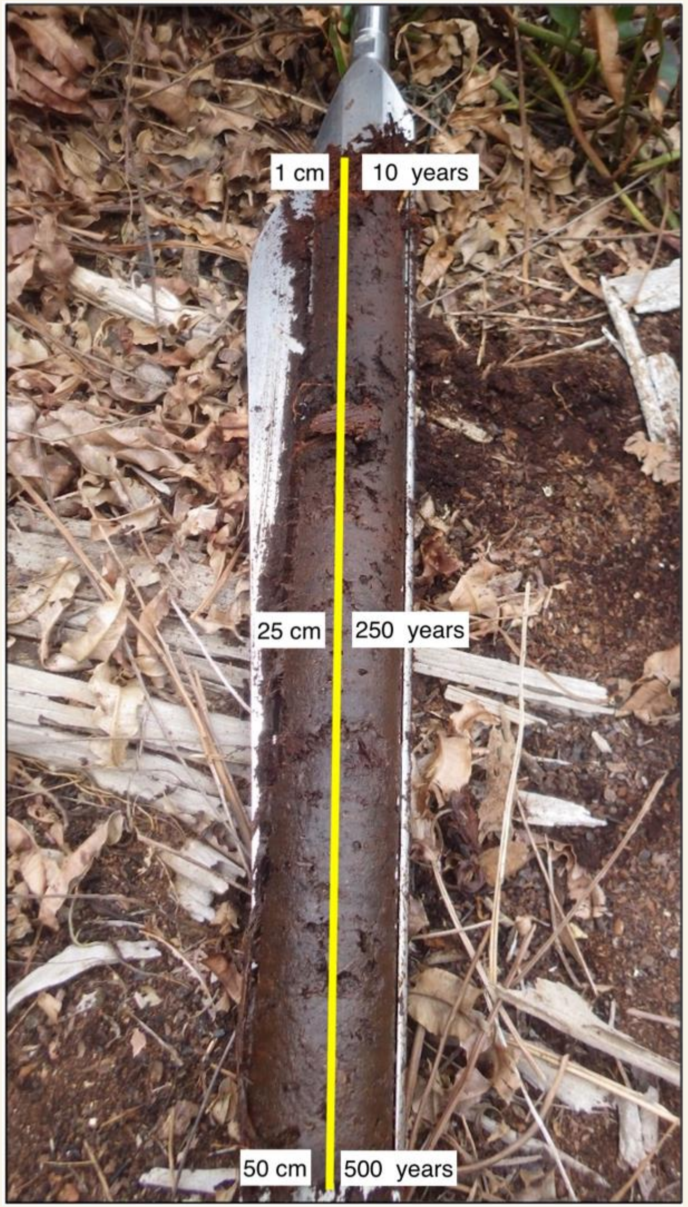
The slow decomposition rate of plant material in waterlogged conditions contributes to the long-term carbon storage in peatlands.

Peatlands act as a carbon sink, meaning they absorb more carbon dioxide from the atmosphere than they release.



- Anoxic conditions prevail
- Less microbial activity
- Organic matter is not degraded
- Carbon is stored

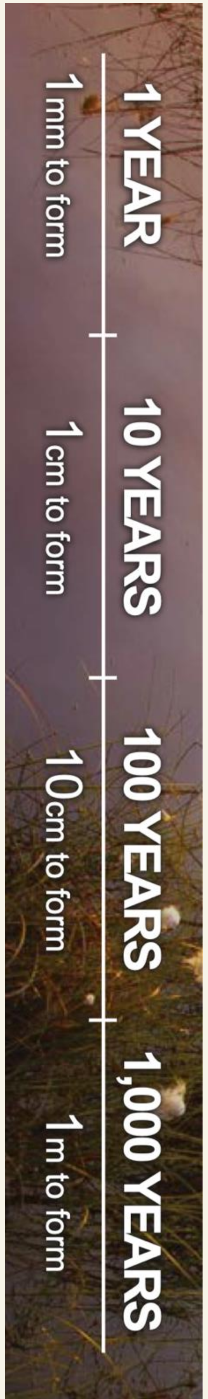
https://unfccc.int/sites/default/files/draftpeatlandco2report.pdf

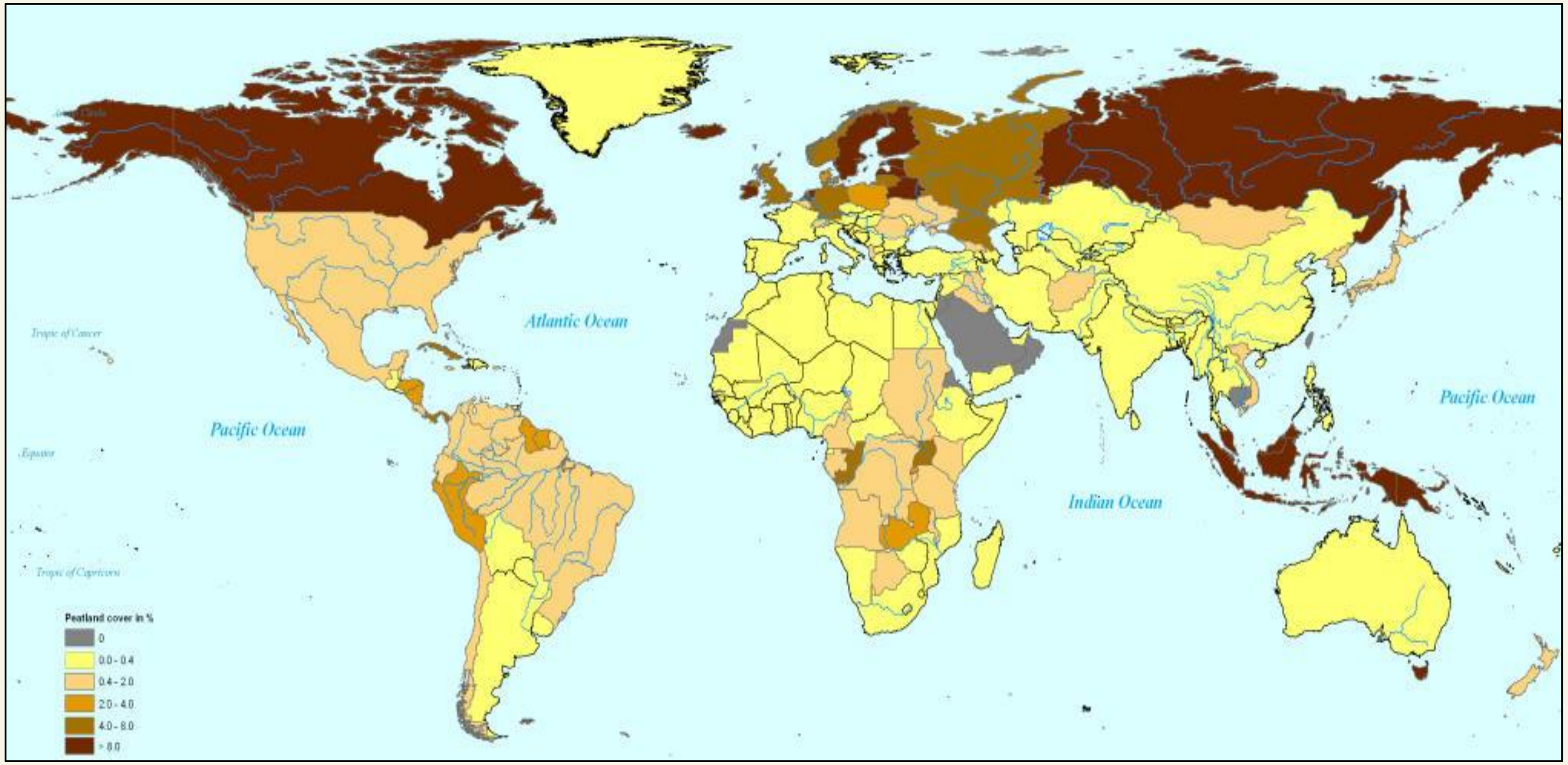


Core from a tropical peat palm-oil plantation in Sarawak, Borneo.

The yellow line illustrates the approximate rate of accumulation.

Peat forms at a very slow rate taking approximately 1 year to form 1 mm of peat, taking approximately 1000 years to form just 1 m of peat.





- Peatlands cover over 3% of the Earth's land surface but contain **twice as much carbon** as the world's forests
- Peatland extent is dominated by high-latitudes with 49% of peatlands concentrated in North America

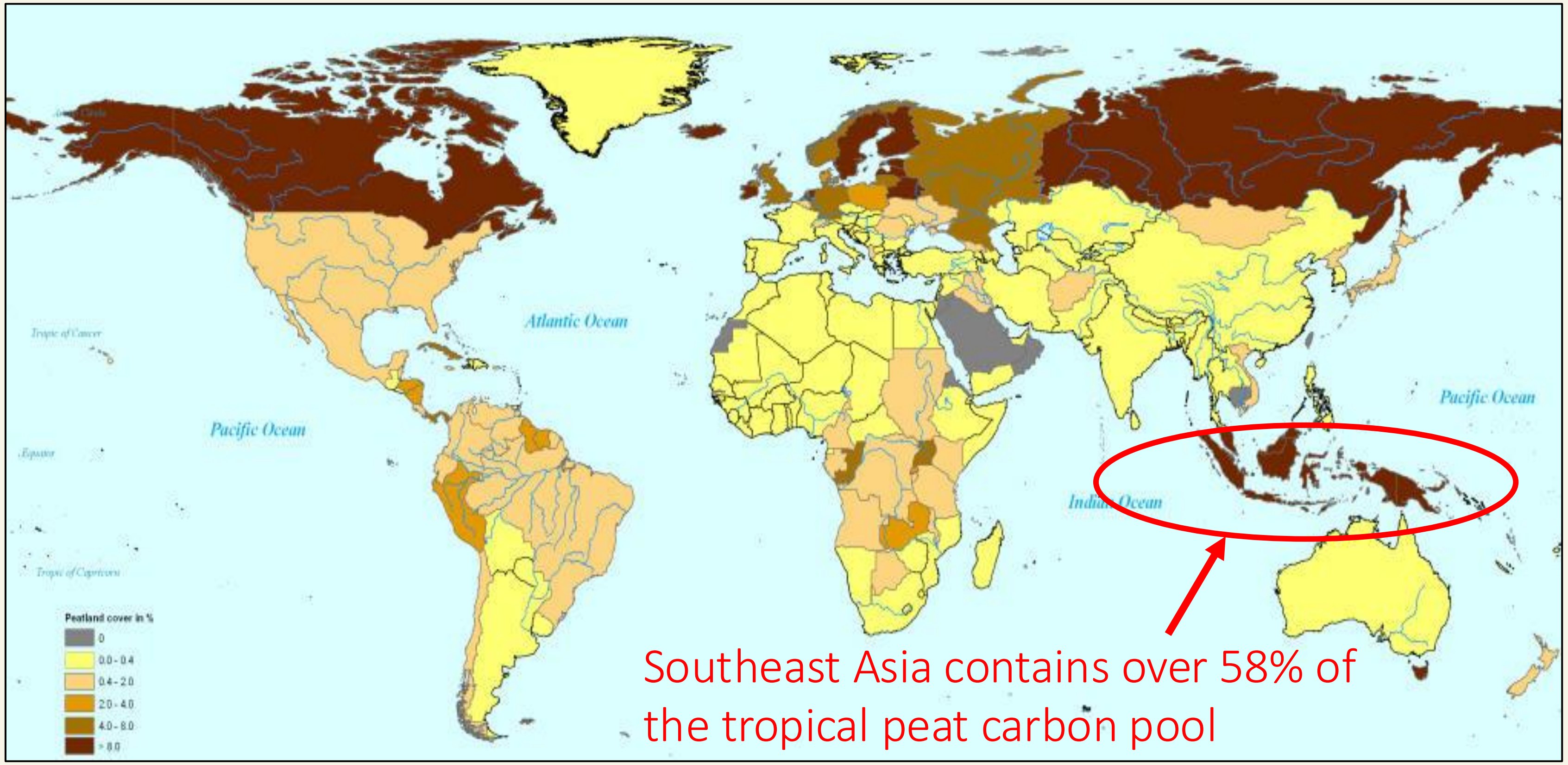
Peatlands in the UK

In the UK, three distinct types of peatland can be identified:

- Blanket bog: These expansive peat areas are predominantly located in upland regions and receive their primary water source from rainfall.

- Raised bog: Found in localized areas within lowland regions, these peat formations resemble domes and rely primarily on rainfall for their water supply.

- Fens: Fens are nourished by mineral-rich groundwater, river water, and rainfall, distinguishing them from the other types of peatland in terms of their water sources.



- While tropical peatland coverage is smaller, they store almost one fifth (105 GtC) of the entire peatland carbon pool- carbon dense ecosystem - of this 58% of this pool is in Southeast Asia.

Tropical peat swamp forest

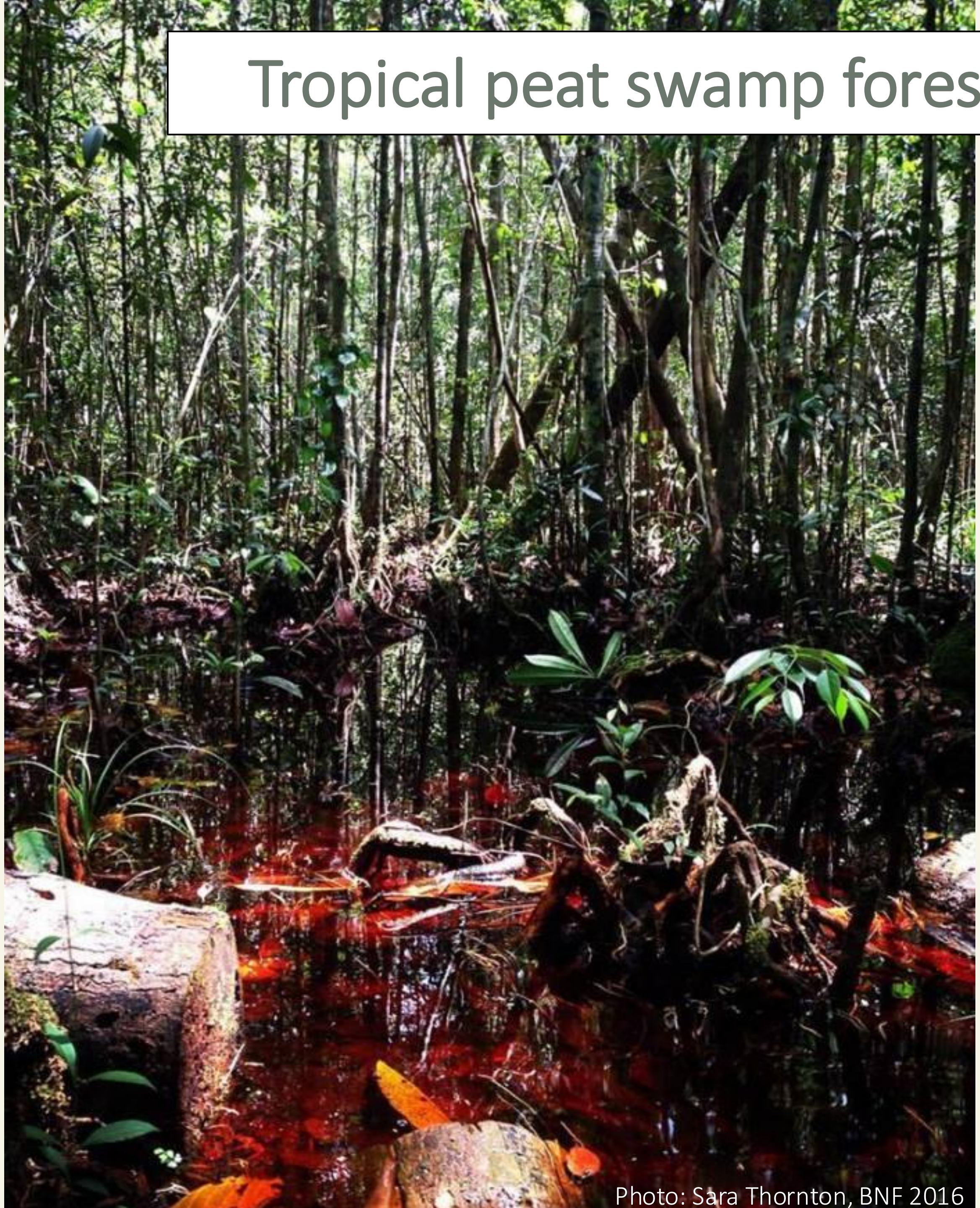
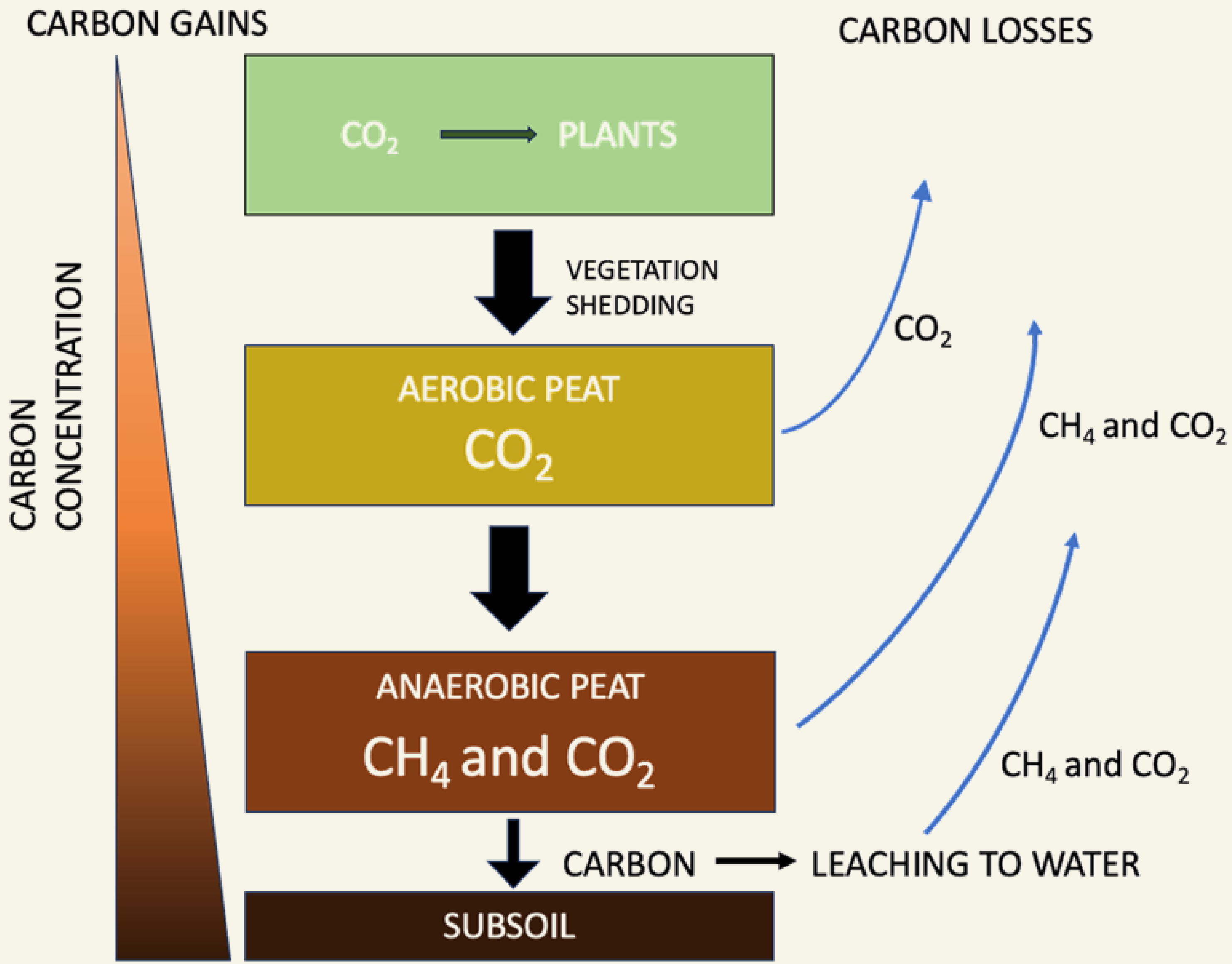


Photo: Sara Thornton, BNF 2016

provide unique wildlife habitats: orangutan (Pongo pygmaeus), gibbons (*Hylobates spp.*), proboscis monkey (*Nasalis larvatus*) alongside venomous pit vipers *(Tropidolaemus subannulatus)*

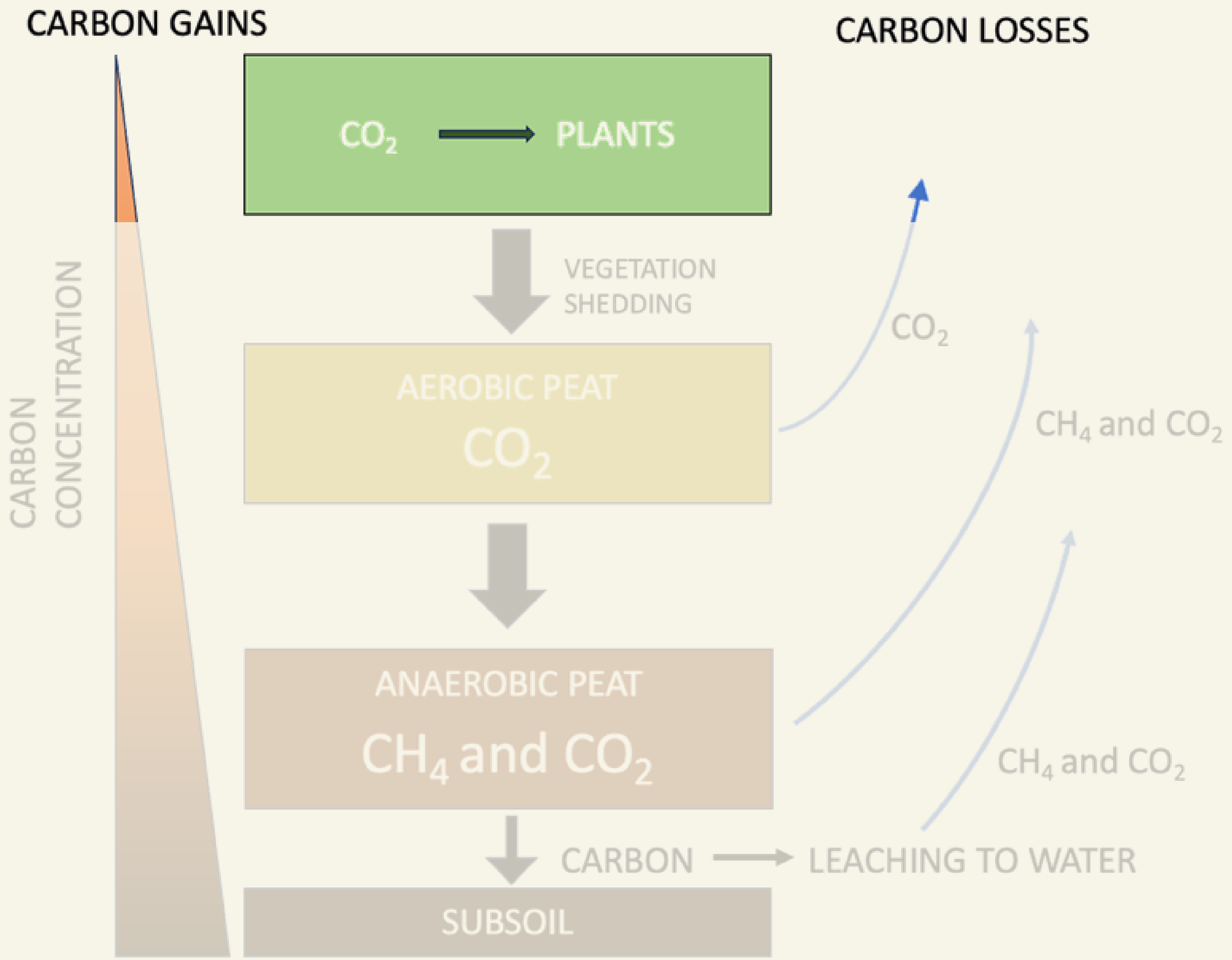
Carbon cycling in peatlands

The cycling of carbon within peatlands is a complex process that involves the exchange of carbon between atmosphere, biomass, and peat substratum itself. Microbial activity plays a central role in this cycle.



Carbon cycling in peatlands

The carbon cycle begins with the primary production of vegetation, which captures atmospheric CO_2 during the process of photosynthesis.



Carbon cycling in peatlands

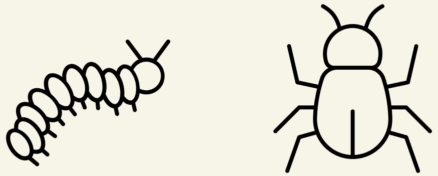
Temperate peat -> Sphagnum moss

In temperate regions, such as the UK, peatlands are often dominated by mosses, notably *Sphagnum* species. These mosses thrive in waterlogged, acidic conditions, and play a pivotal role in the unique hydrology of peatlands.

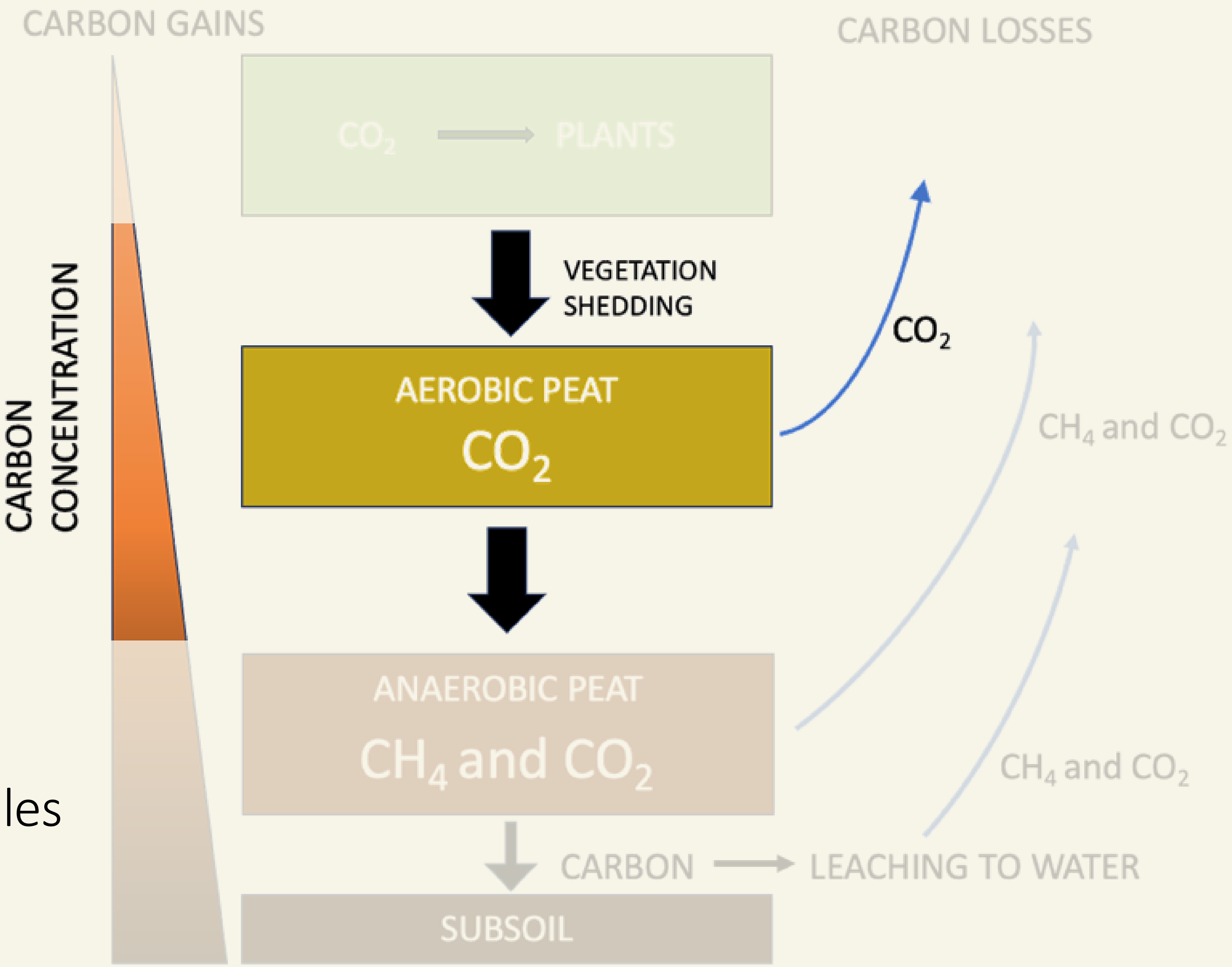
Tropical peat -> buttress roots / silted roots

Support tree species that have evolved remarkable adaptions to waterlogged environments, with buttress and stilted root systems to gain both stability and access to essential nutrients.

Organic matter accumulation: As vegetation grows it sheds organic litter including leaves and wood debris.



Microbial communities (including saprabiont bacteria and fungi) act as primary decomposers and breakdown accumulated organic matter -> CO_2 released

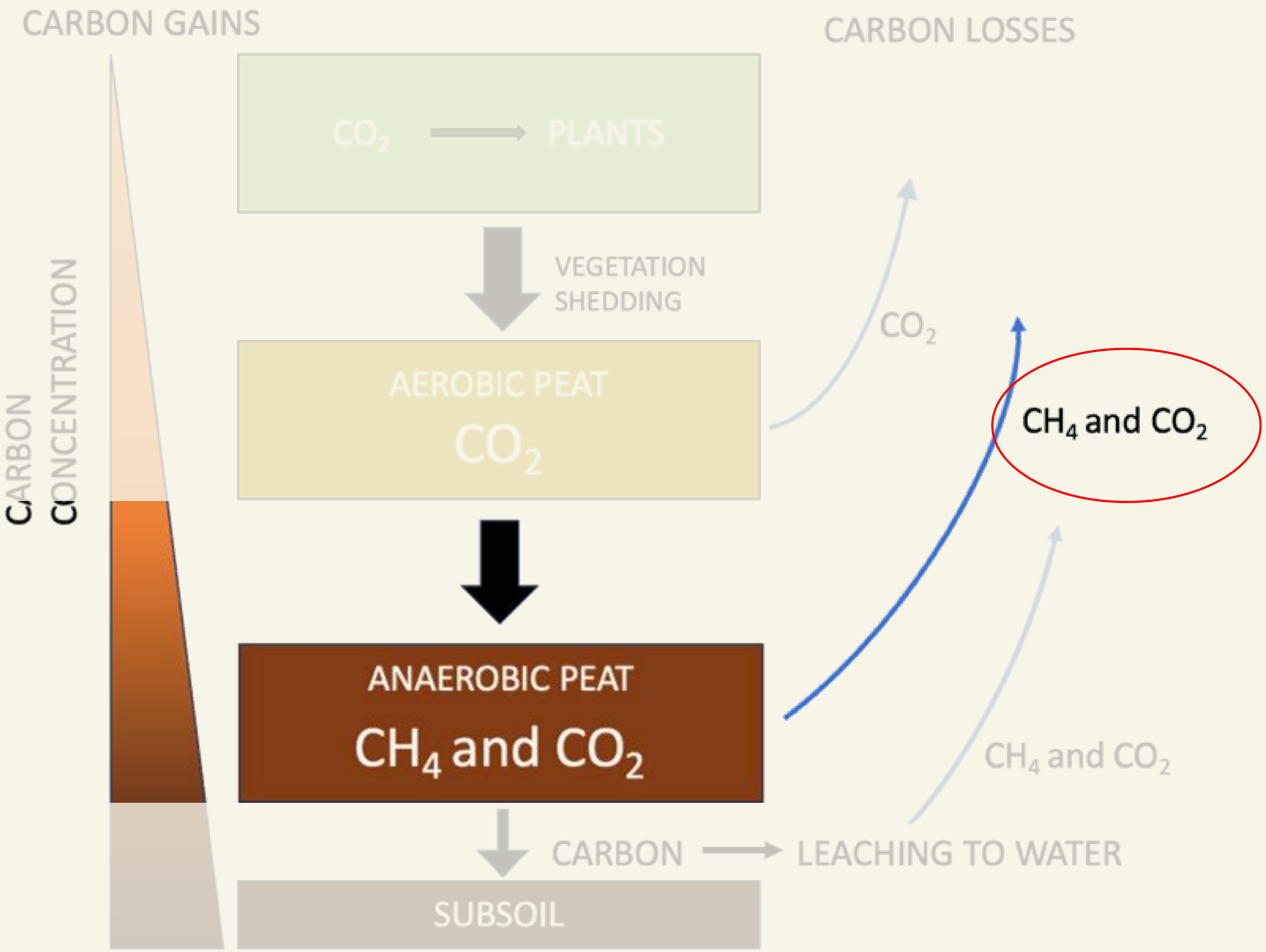


Bacteria -> complex organic molecules

Fungi -> lignin-rich substances

The anaerobic conditions prevailing in peatlands slow down the decomposition process, allowing organic matter to accumulate over extended periods.

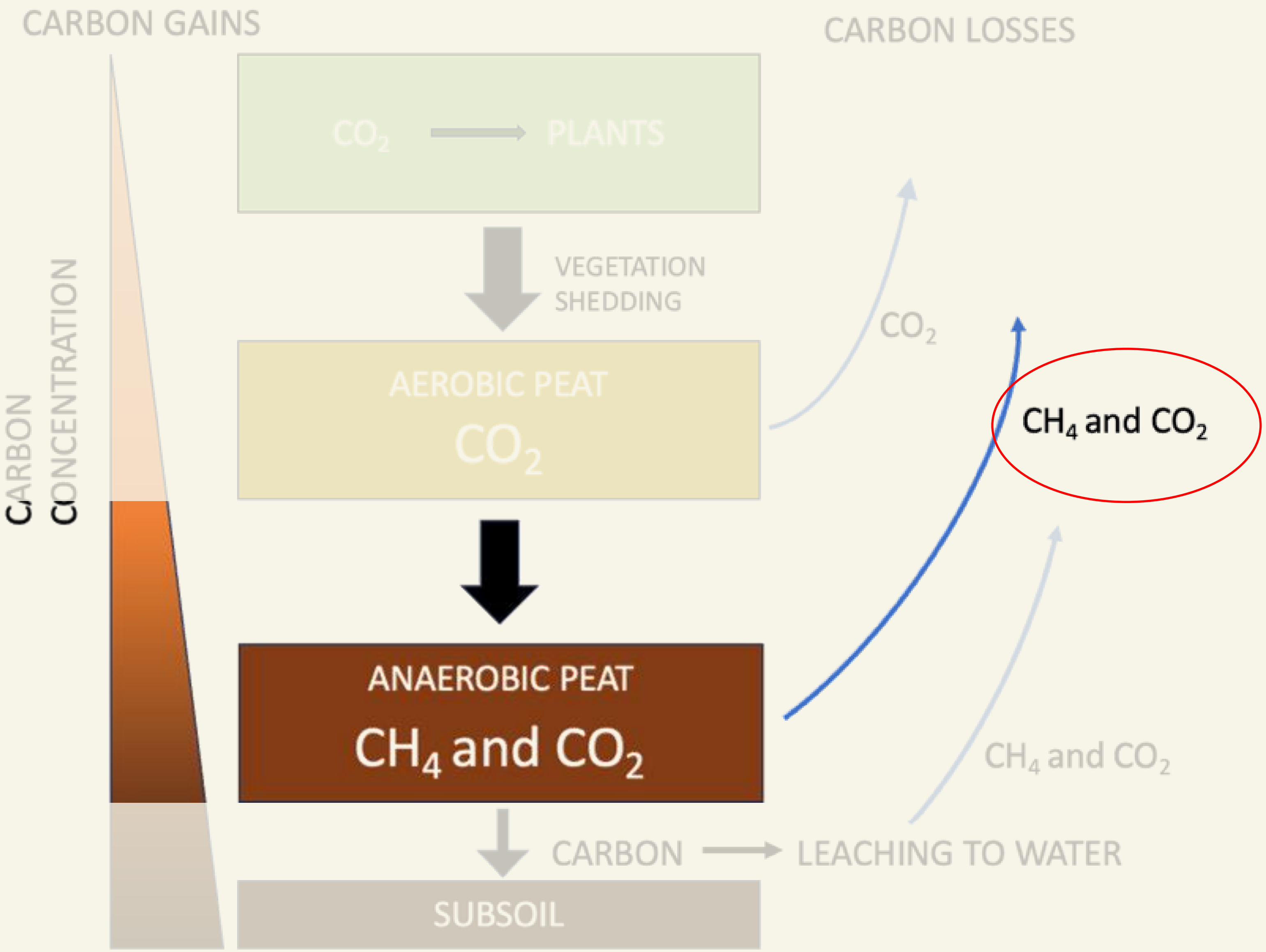
This stored organic matter eventually contributes to the formation of the peat itself.



Methane production: In the oxygen-deprived depths of the peat a specialized group of microorganisms called methanogenic bacteria reside -> thrive in anaerobic conditions

Produce of CH_4 as a metabolic by-product during the decomposition of organic matter -> methanogenesis.

And can be characterised by the release of methane in the form of bubbles, termed ‘ebullition’.



Carbon lost in the water: Carbon is naturally leached from the peat into the water (dissolved/ particulate form).

Once in the water it can be broken down by microbes -> CH_4 and CO_2

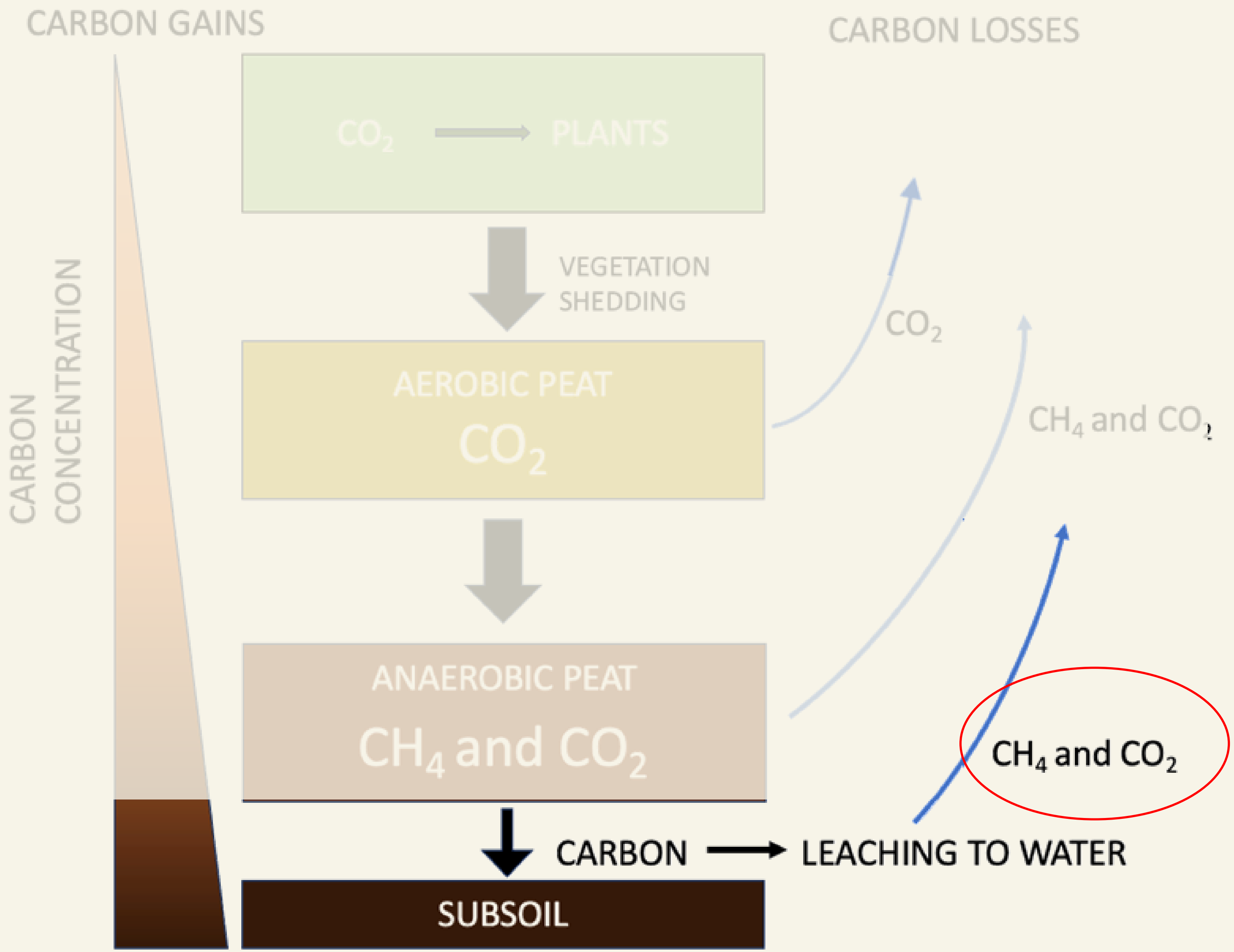
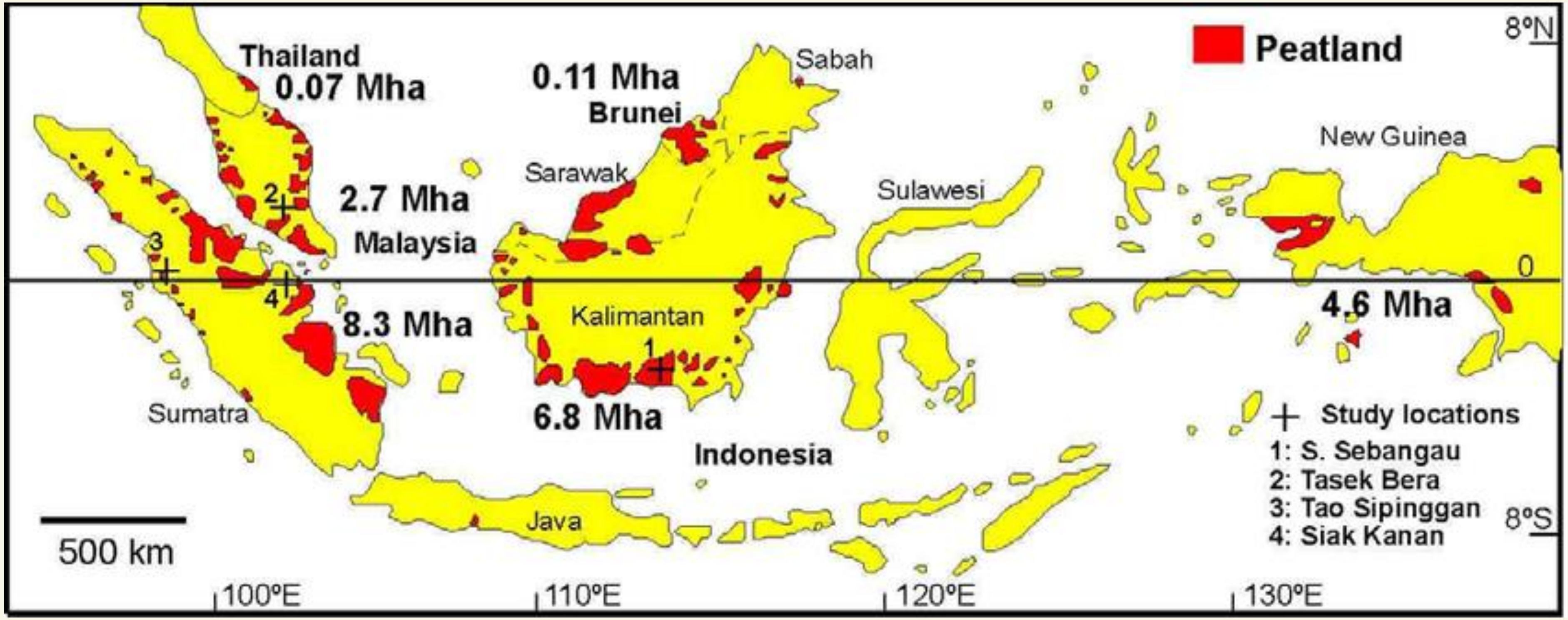



Photo: Sara Thornton, BNF 2016

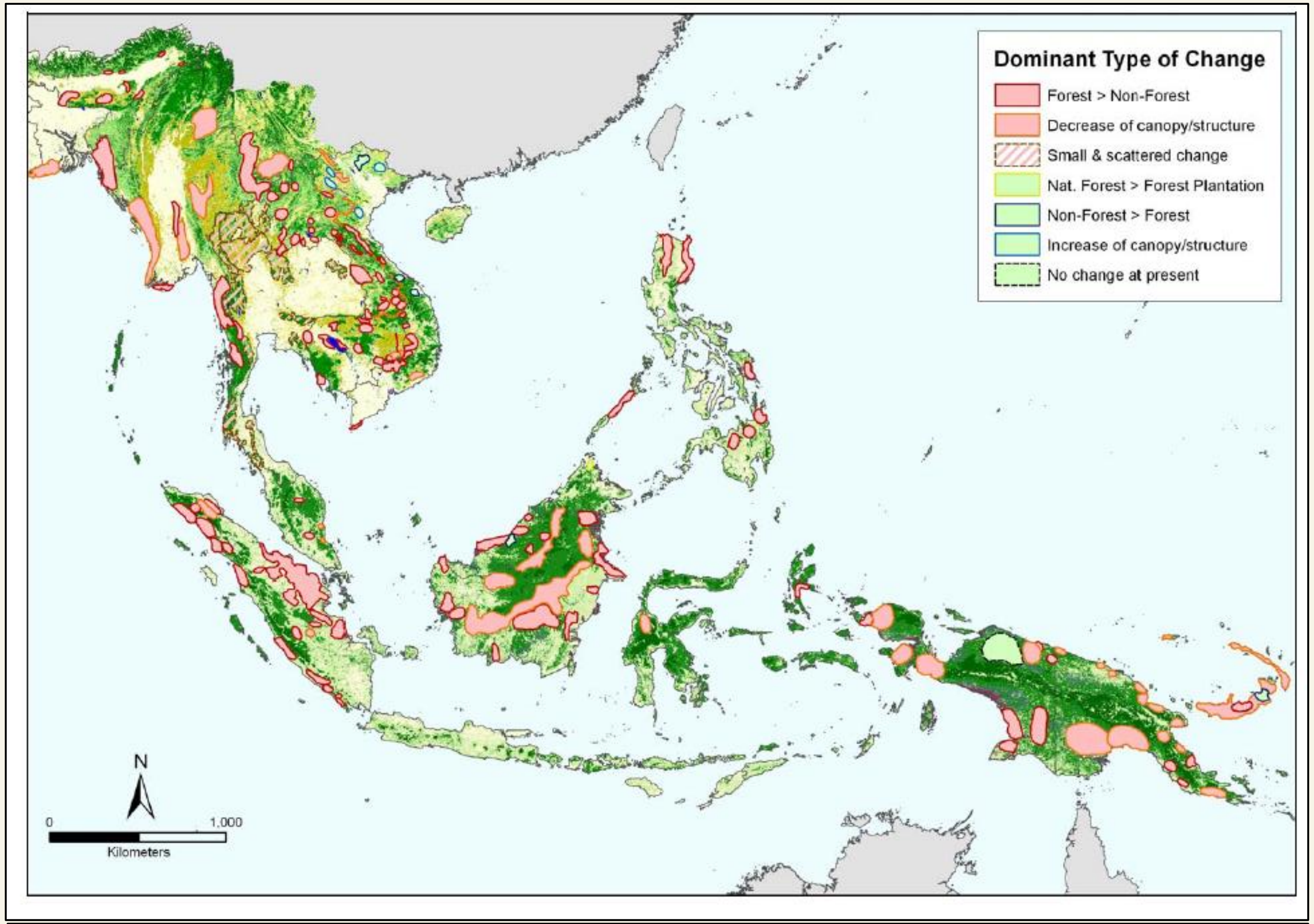
What happens when peatlands are damaged?

Case study: Fluvial carbon losses from peatland oil palm plantations

Approximately half on the world's tropical peatlands are found in Southeast Asia, where they serve as a major carbon sink. However, nearly 80% of natural peatlands in this region have been drained or deforested.



Distribution of peatlands (in million ha, after (Rieley et al., 1996) in SE Asia where ~70% of global tropical peat deposits occur.



Land cover change in Southeast Asia

EUR 22896 EN – Joint Research Centre; Title: Forest Cover Change in Southeast Asia - The Regional Pattern; Author(s): H-J Stibig, F. Stolle, R. Dennis and C. Feldkötter; Luxembourg: Office for Official Publications of the European Communities; 2007 – 41 pp. – 21 x 29.7 cm; EUR – Scientific and Technical Research series – ISSN 1018-5593

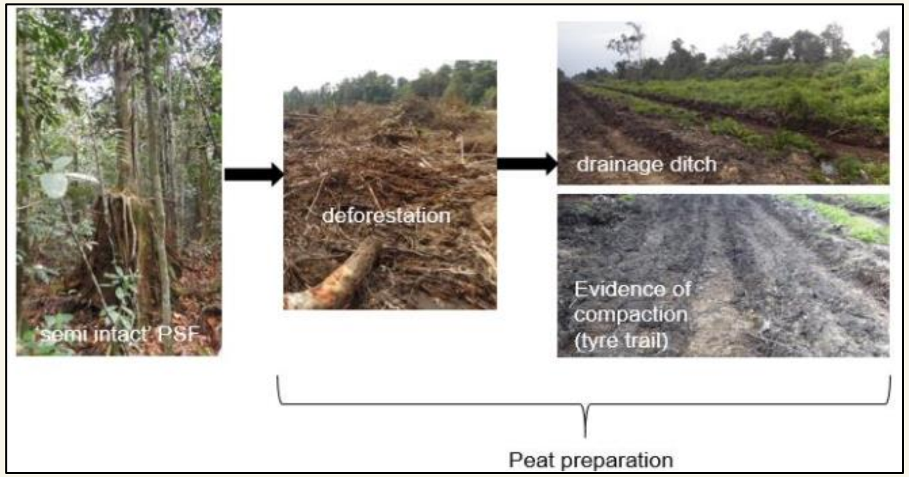
Between 1990 and 2010, Southeast Asia registered an average net loss of 1.6 million ha yr^{-1}.

At least 50 % of tropical peat in this region are covered by managed land.

Fire employed as a means to clear land for cultivation, but these fires often spread uncontrollably into neighbouring forests.

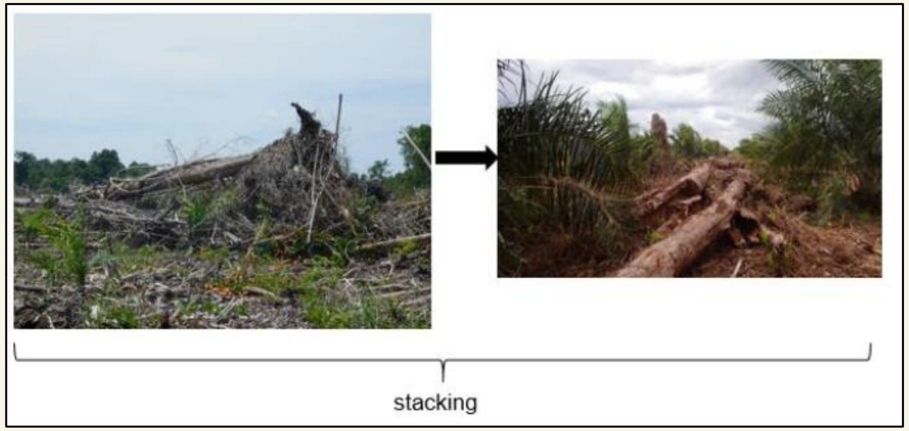
According to the Intergovernmental Panel on Climate Change (IPCC), the cultivation of tropical peatlands is estimated to generate approximately 440 million tonnes of CO_2 equivalent per year.

Conversion stages



Stage 1

- Deforestation
- Drainage
- Compaction



Stage 2

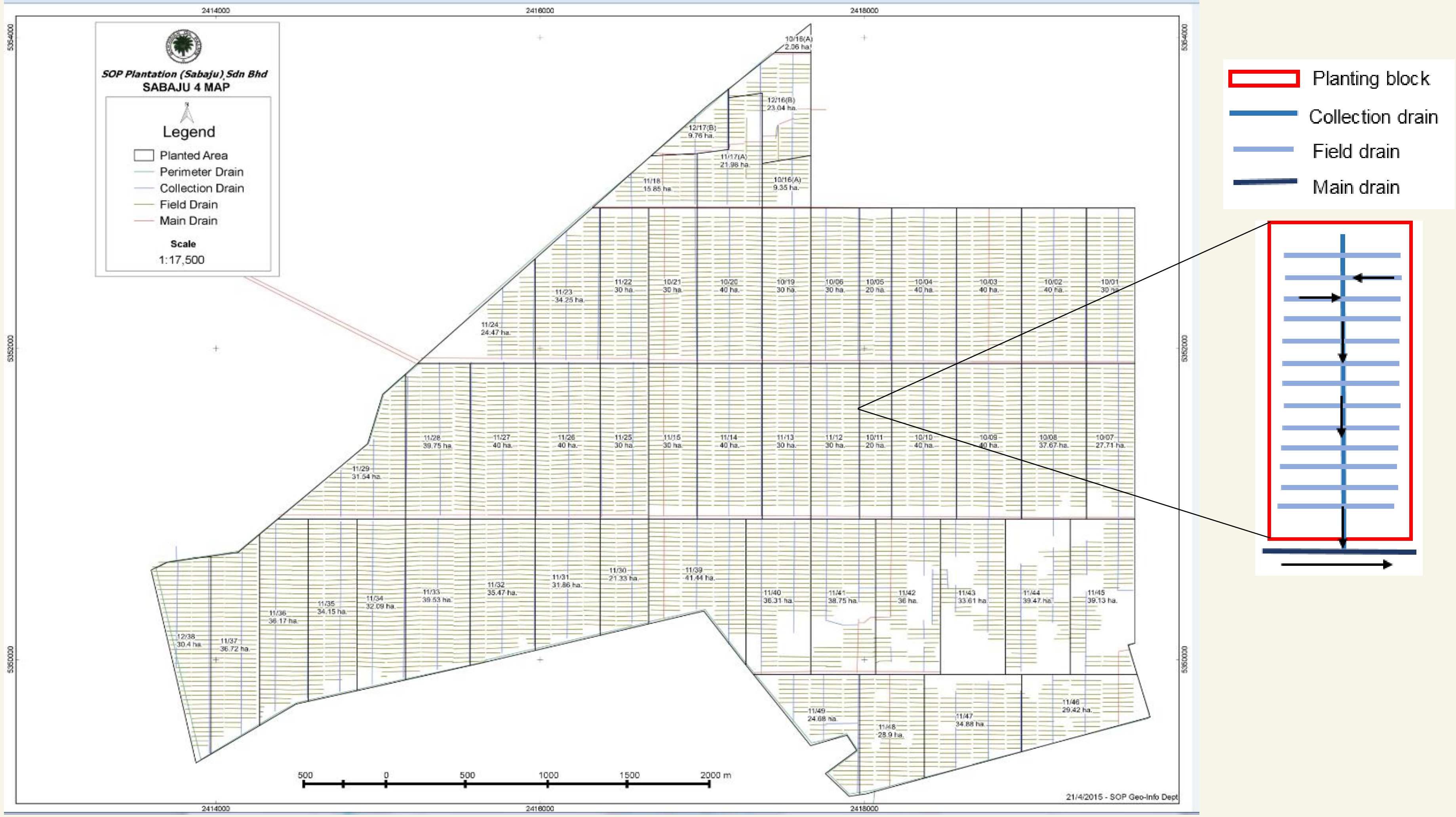
- Stacking of debris to form divisions between plantation inter-rows
- Decomposes overtime but still visible

Stage 3

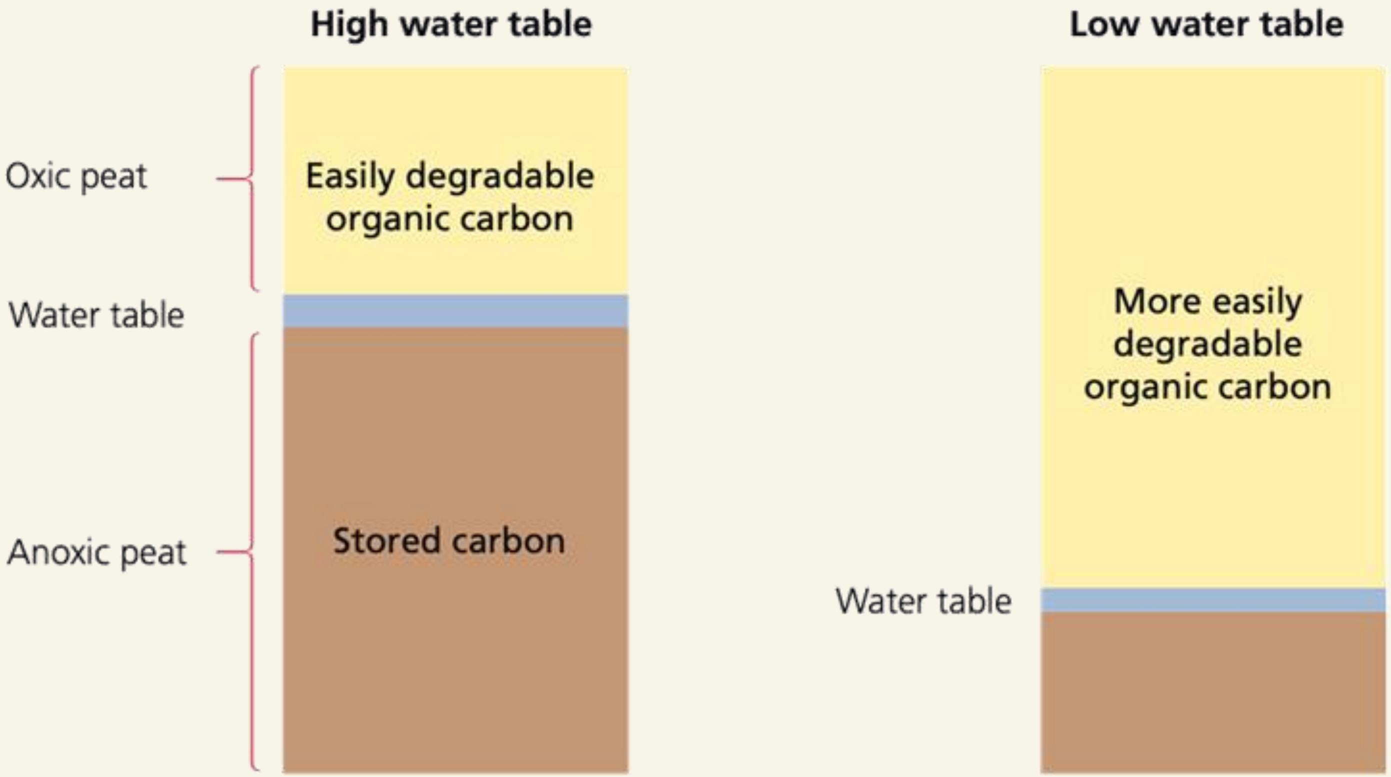
- Drainage channel infrastructure is developed forming a dense network or channels – first oil seedlings are planted

Stage 4

- Harvesting after 5 years but life cycle only 25 years on peat


SOP Plantation (Sabaju) Sdn Bhd
SABAJU 4 MAP
Legend
Planted Area
Perimeter Drain
Collection Drain
Field Drain
Main Drain
Scale
1:17,500
21/4/2015 - SOP Geo-Info Dept
Planting block
Collection drain
Field drain
Main drain

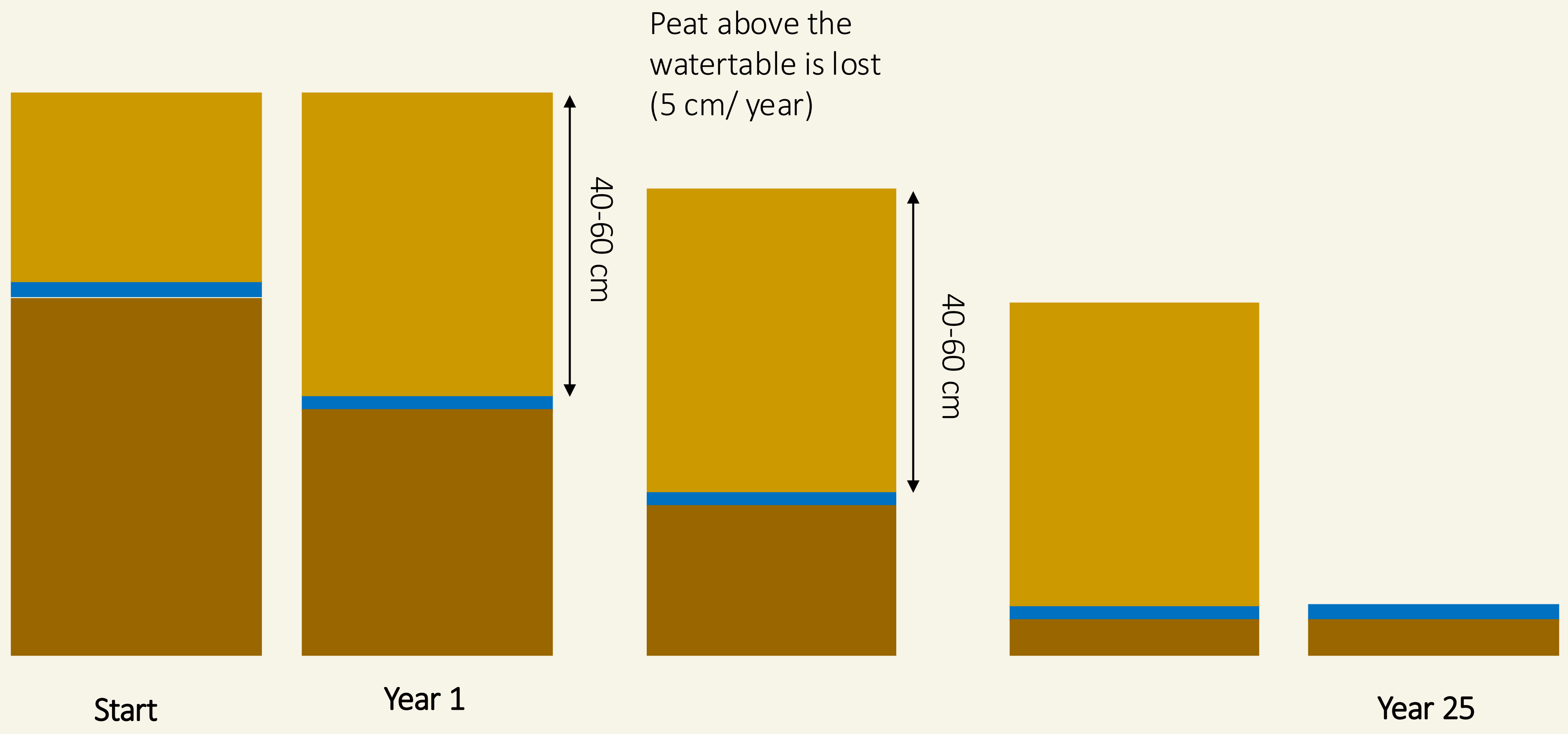
Microbial decomposition: Seasonal changes in hydrology, such as fluctuations in water levels, can influence peatland decomposition rates.



- Anoxic conditions prevail
- Less microbial activity
- Organic matter is not degraded
- Carbon is stored

- Oxic conditions
- Activates microbes
- Organic matter is degraded
- Carbon is released in the water and into the atmosphere

Figure 2 Differences between natural (left) and drained (right) peatland systems

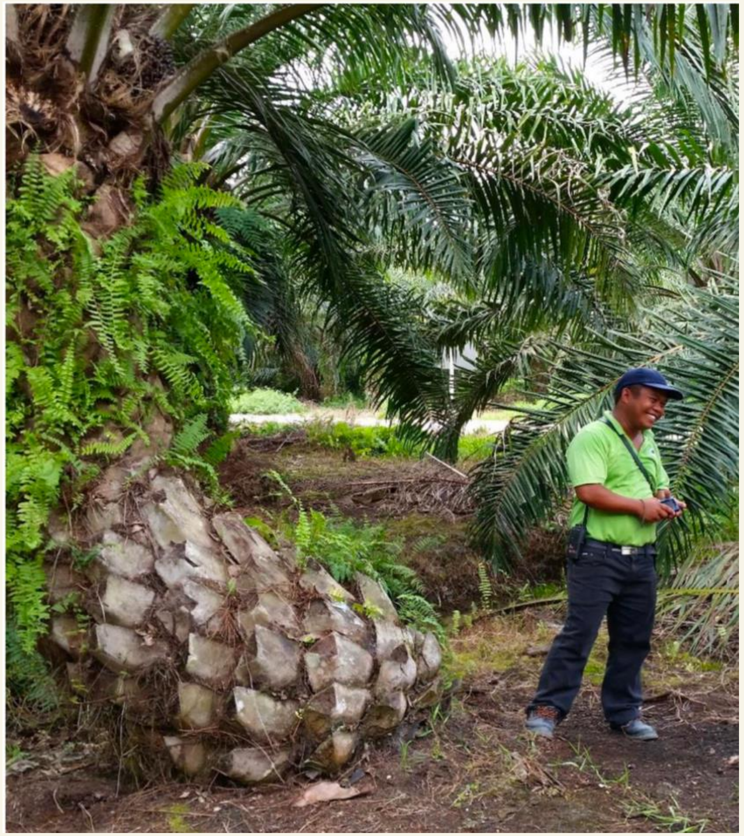

Peat above the watertable is lost (5 cm/ year)
40-60 cm
40-60 cm
Start
Year 1
Year 25

Issues of using peatlands for agriculture

•High acidity – soils require addition of wood ash or lime to raise pH

•Low fertility – soils require fertiliser inputs (N,P,K)

•High lateral conductivity (hydraulic conductivity) which enhances leaching of nutrients



•Very low availability of micro-nutrients (e.g. copper, zinc)

•Tendency for hydrophobicity if peat is over-dried

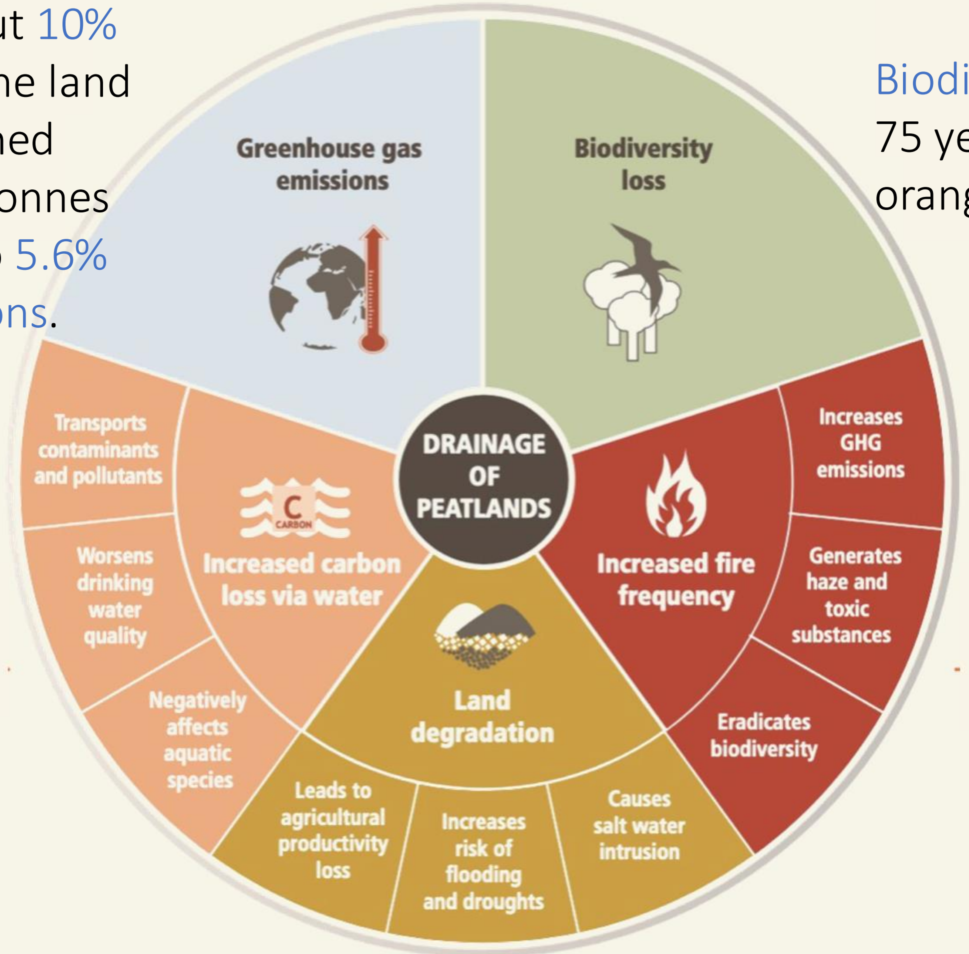
•Tendency for waterlogging – water management is critical

•Weak load bearing capacity (e.g. tree instability)

•Subsidence and increased risk of flooding

There are numerous environmental consequences of drained peatlands.

Damaged peatlands contribute about 10% of greenhouse gas emissions from the land use sector. CO_2 emissions from drained peatlands are estimated at 1.3 gigatonnes of CO_2 annually. This is equivalent to 5.6% of global anthropogenic CO_2 emissions.



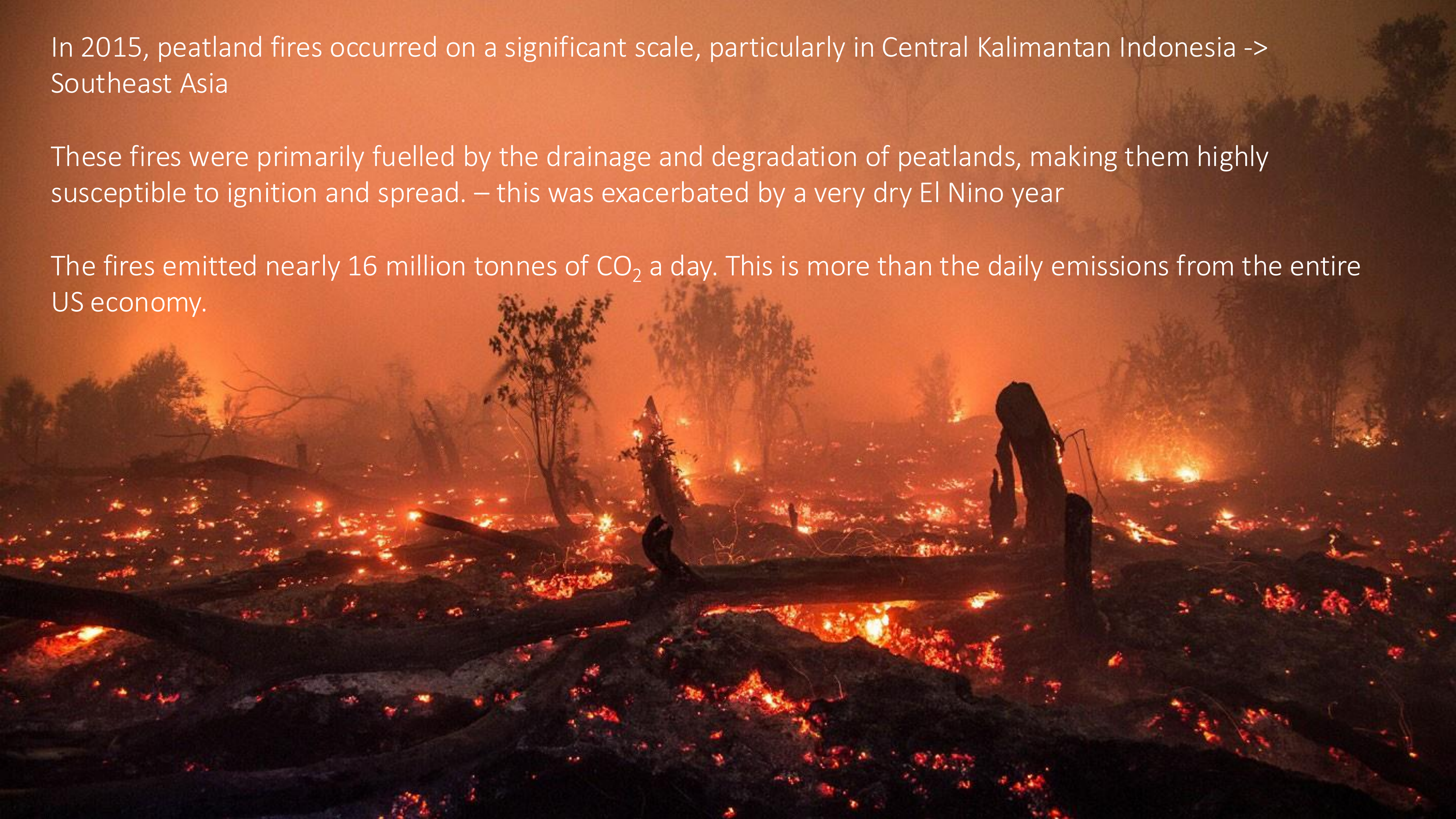
Biodiversity loss -> over the last 75 years the number of Sumatran orangutans has declined by 80%

Increased carbon in the water -> When intact peatlands are drained carbon losses via water can increase by 50%.

Increased frequency of fire -> the dried out peat is rich in organic matter which is highly flammable. Smouldering peat first can persist of months. An example of this took place in 2015

Land degradation -> The drainage of peatland lowers the water table and exposes previously saturated peat layers to oxygen -> microbes. They start to break down the peat – as a consequences the surface of the land can decrease in height by up to 2.5 meters after 25 years of drainage.

Miles, L., Ravilious, C., Garcia-Rangel, S., de Lamo, X., Dargie, G., Lewis, S., 2017. Carbon, biodiversity and land-use in the Central Congo Basin Peatlands.



In 2015, peatland fires occurred on a significant scale, particularly in Central Kalimantan Indonesia -> Southeast Asia

These fires were primarily fuelled by the drainage and degradation of peatlands, making them highly susceptible to ignition and spread. – this was exacerbated by a very dry El Nino year

The fires emitted nearly 16 million tonnes of CO_2 a day. This is more than the daily emissions from the entire US economy.

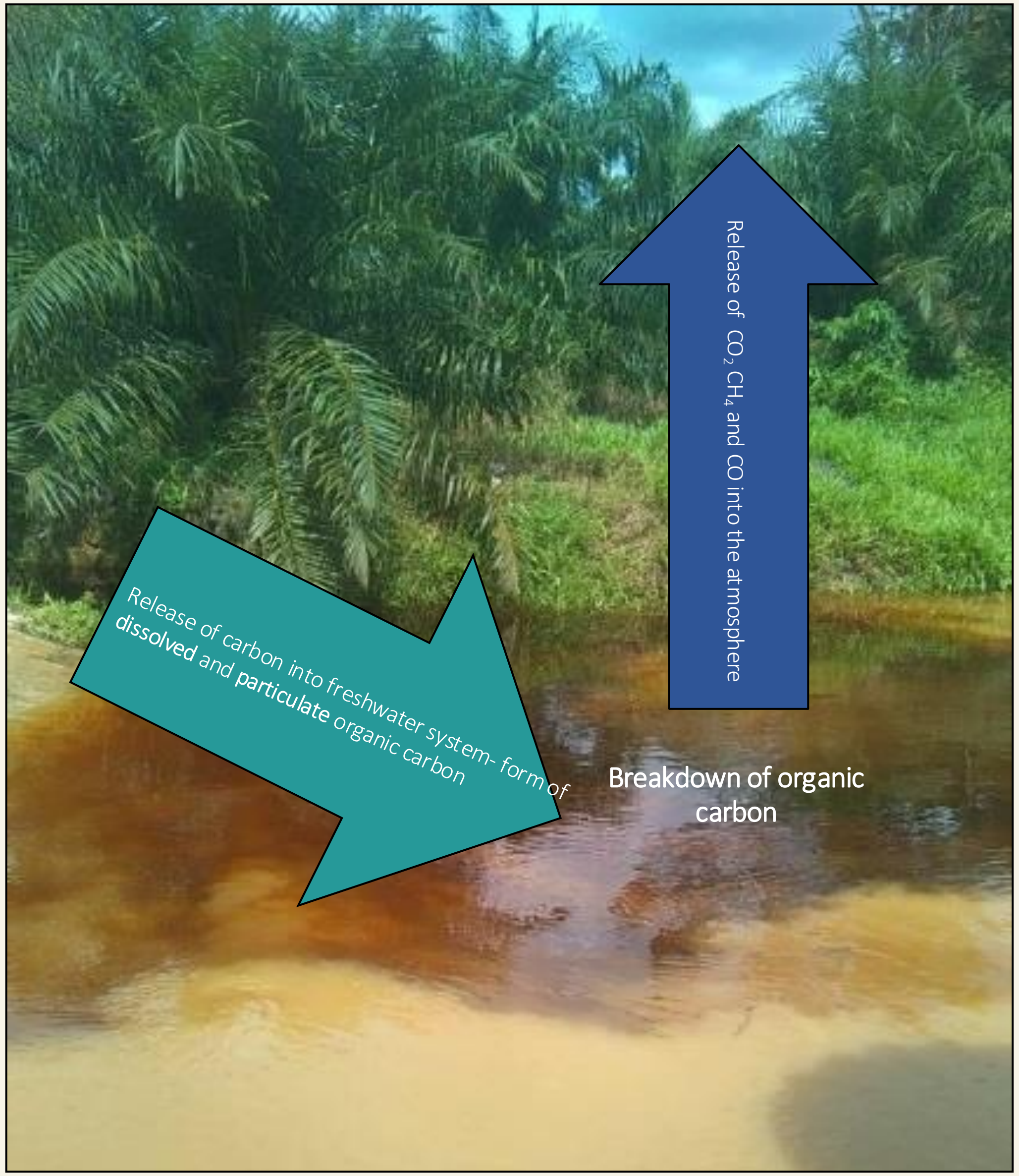
Why is it important to look at carbon in the water ?

1. Links terrestrial, aquatic and atmospheric carbon cycles

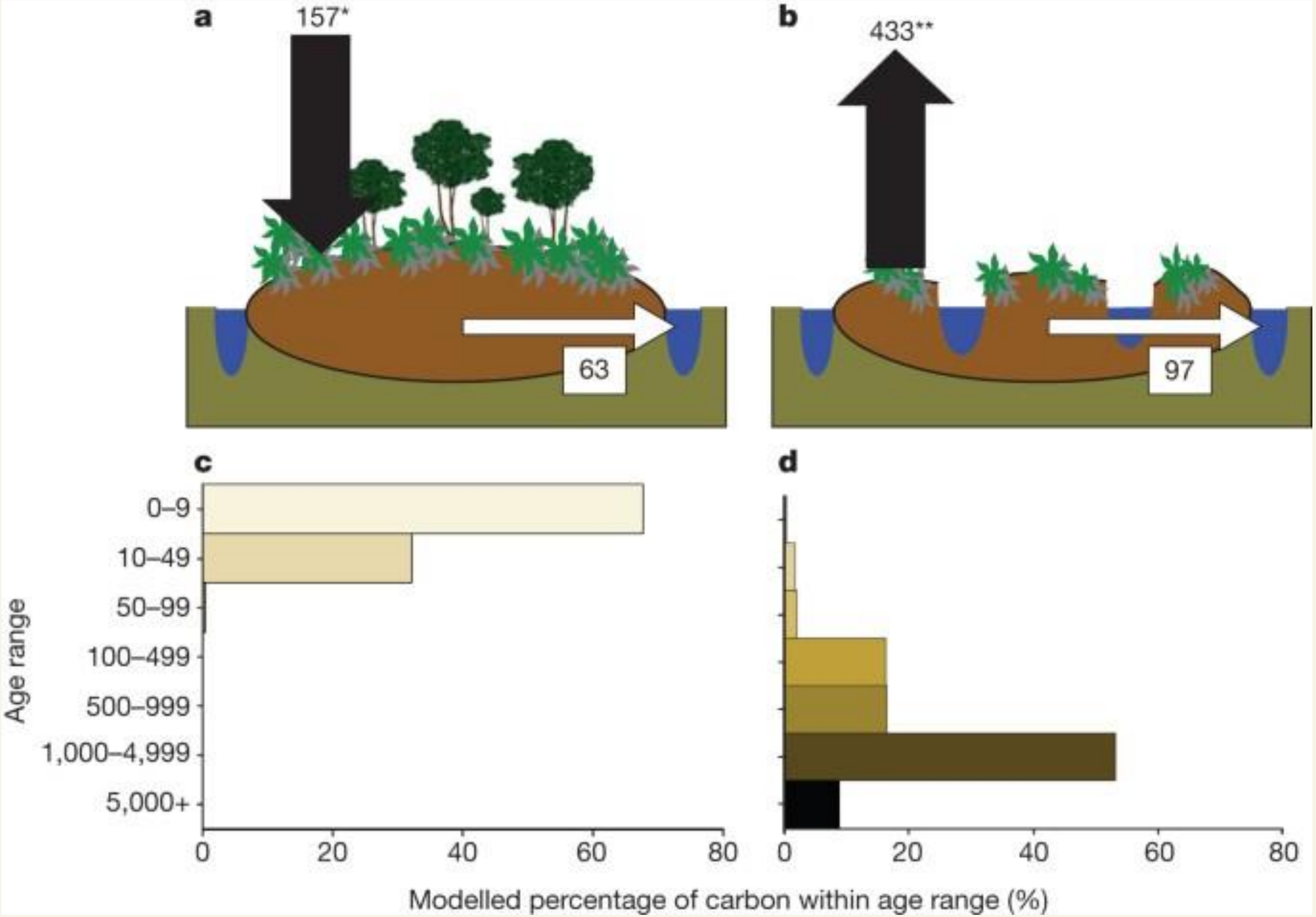
2. Breakdown of fluvial organic carbon releases greenhouse gas emissions

3. Environmental health risks:
   - Reacts with chlorine to form a carcinogenic toxin
   - Contamination of drinking supplies

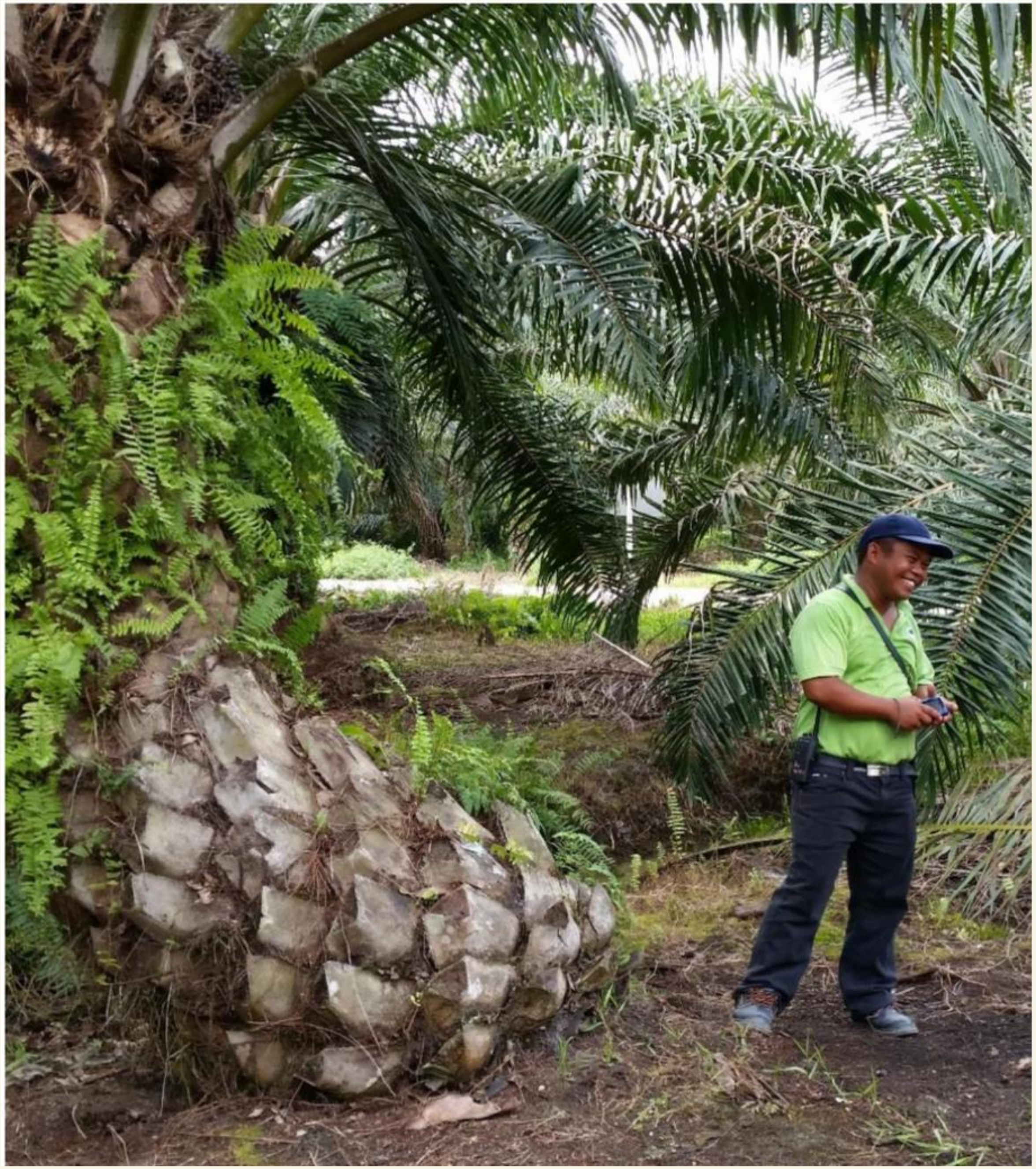
4. Impacts ecosystem functioning:
   - Darkening/ browning of water systems
   - Light absorbance and penetration
   - Aquatic energy supplies/ nutrient levels

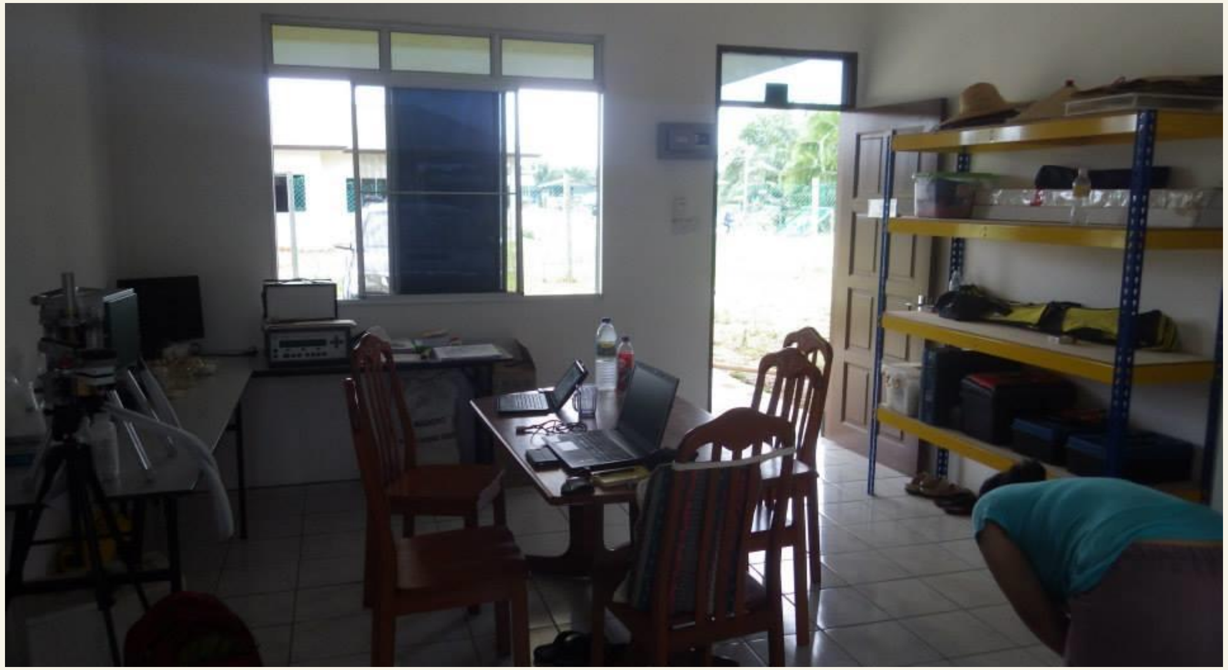
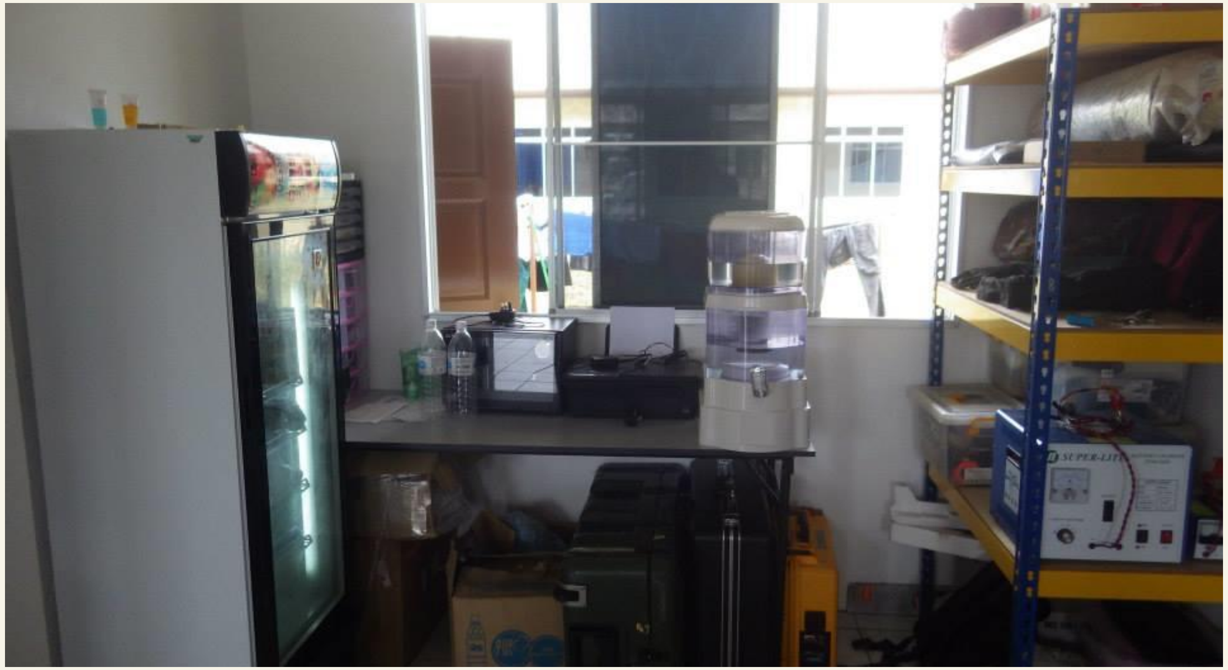


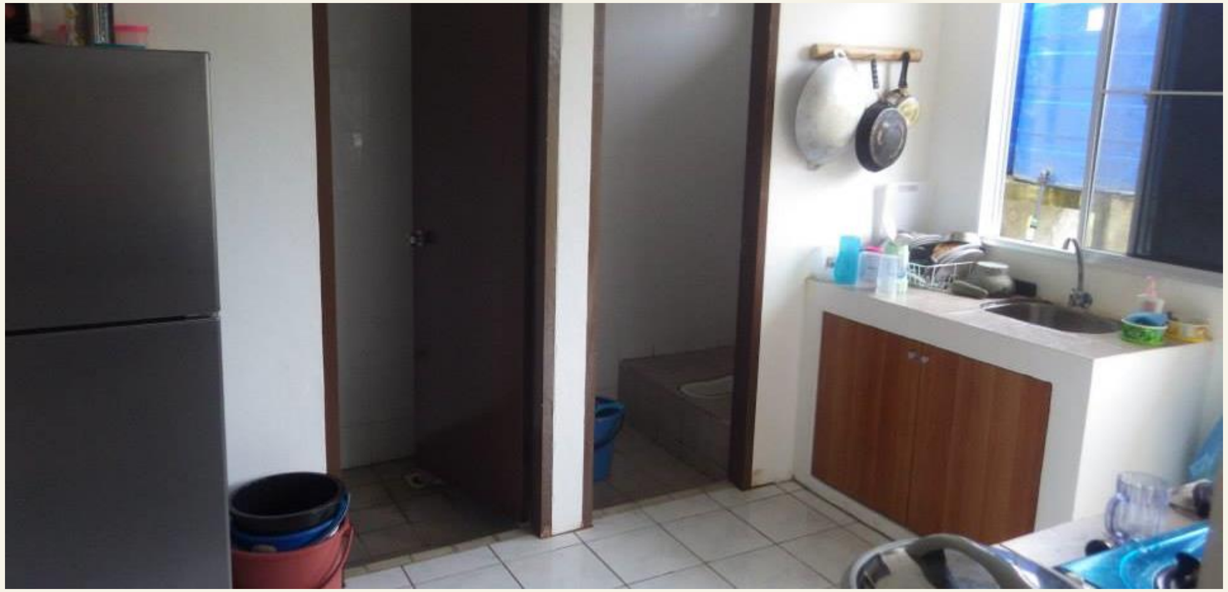
https://hess.copernicus.org/articles/22/5281/2018/

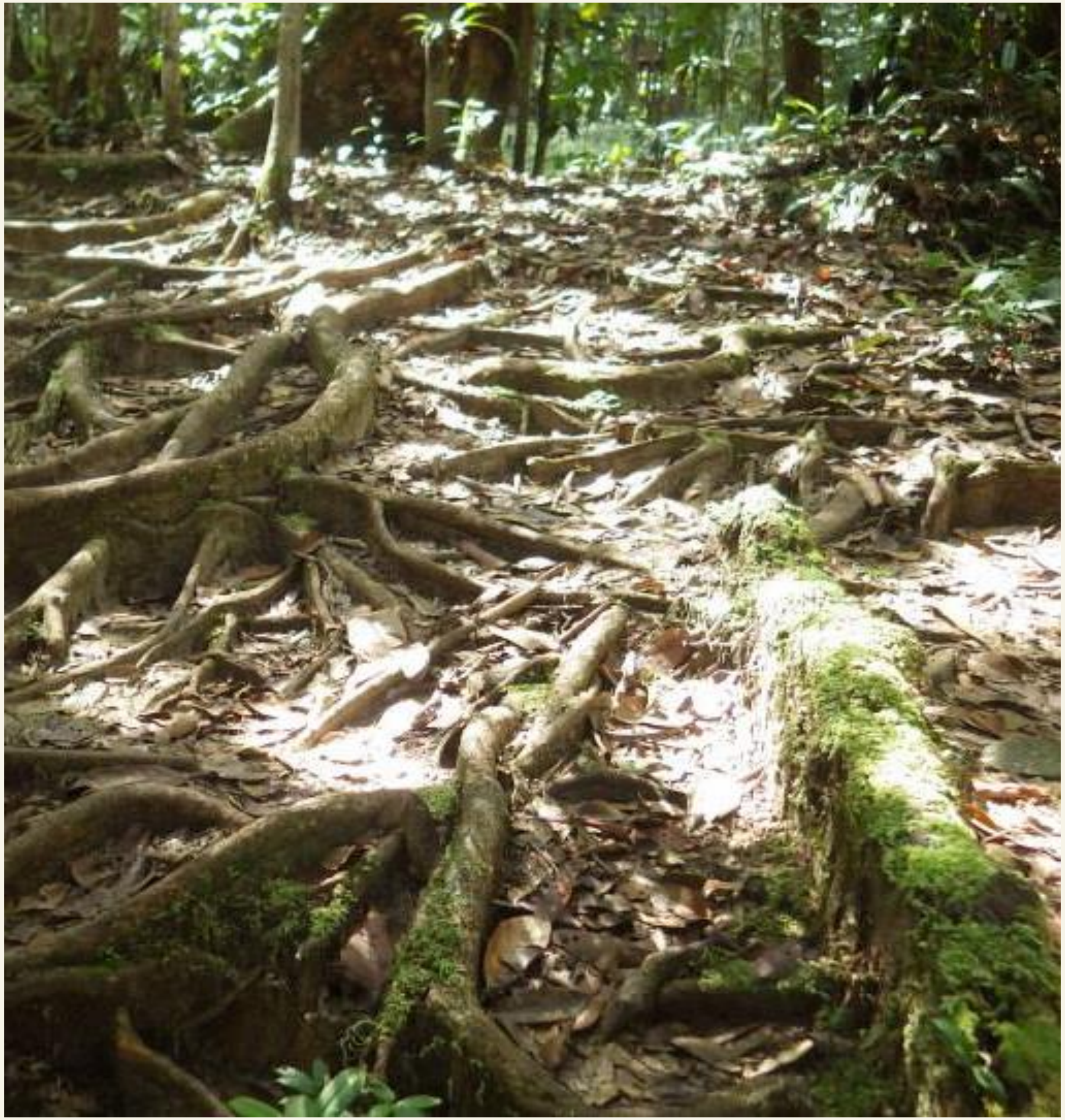


Moore S et al. 2011 doi: 10.1038/nature11818. PMID: 23364745





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Urgency in peatland restoration

Unlike other degraded ecosystems from agriculture the carbon emissions from peatlands are continuous and accumulate each year.

They are no a one-off emission.

5% of human induced greenhouse gas emissions come from degraded peatlands.

Time for responsible peatland management

Conserve

Protect from conversion, fire and logging.

How realistic is this?

Mitigate ?

Keep water-table levels regulated (40 cm)

Balance livelihoods with emissions.

Restore ?

Restore peatland hydrology/ vegetation to capture carbon.

How long does it take to swap them back to a sink?

Long-term monitoring

Thank you for listening

Any Questions?