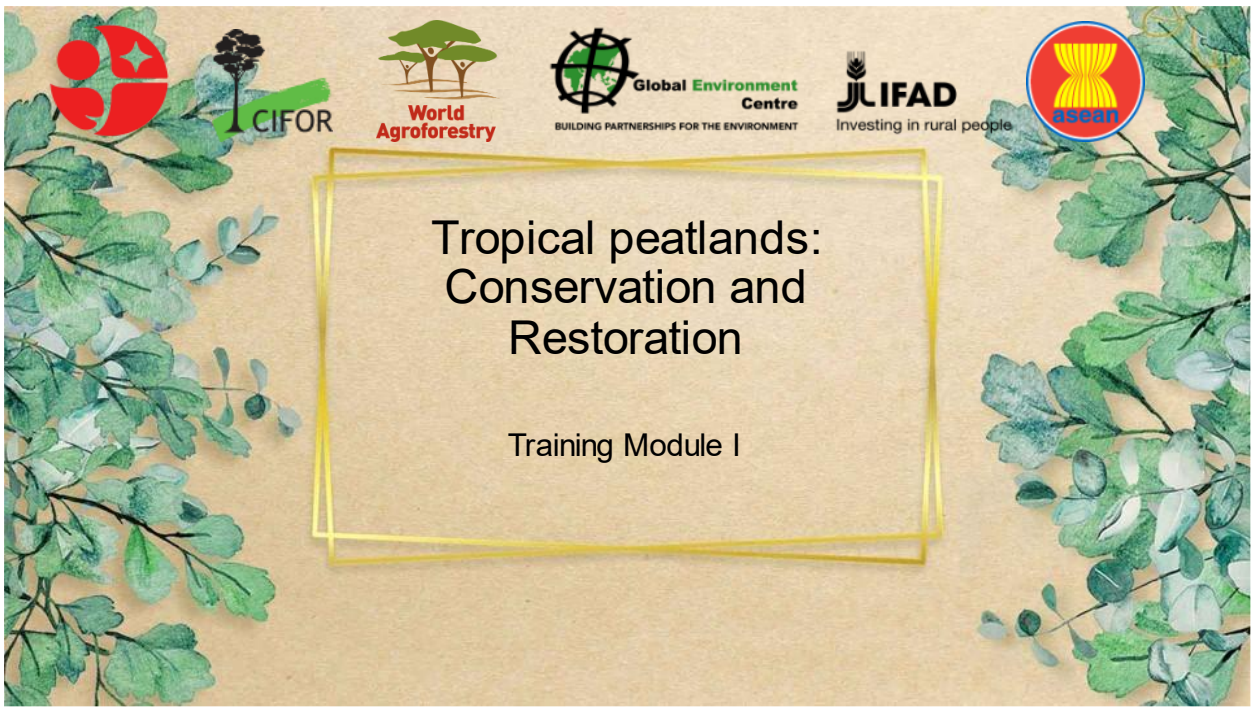
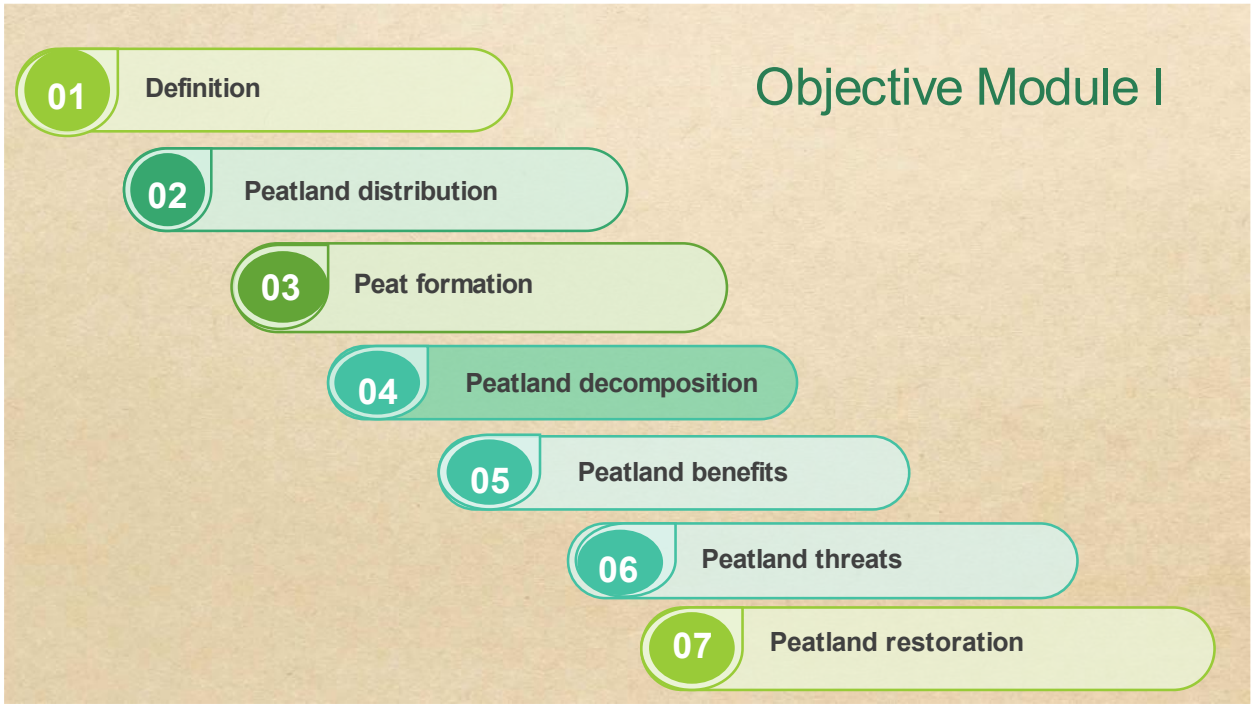
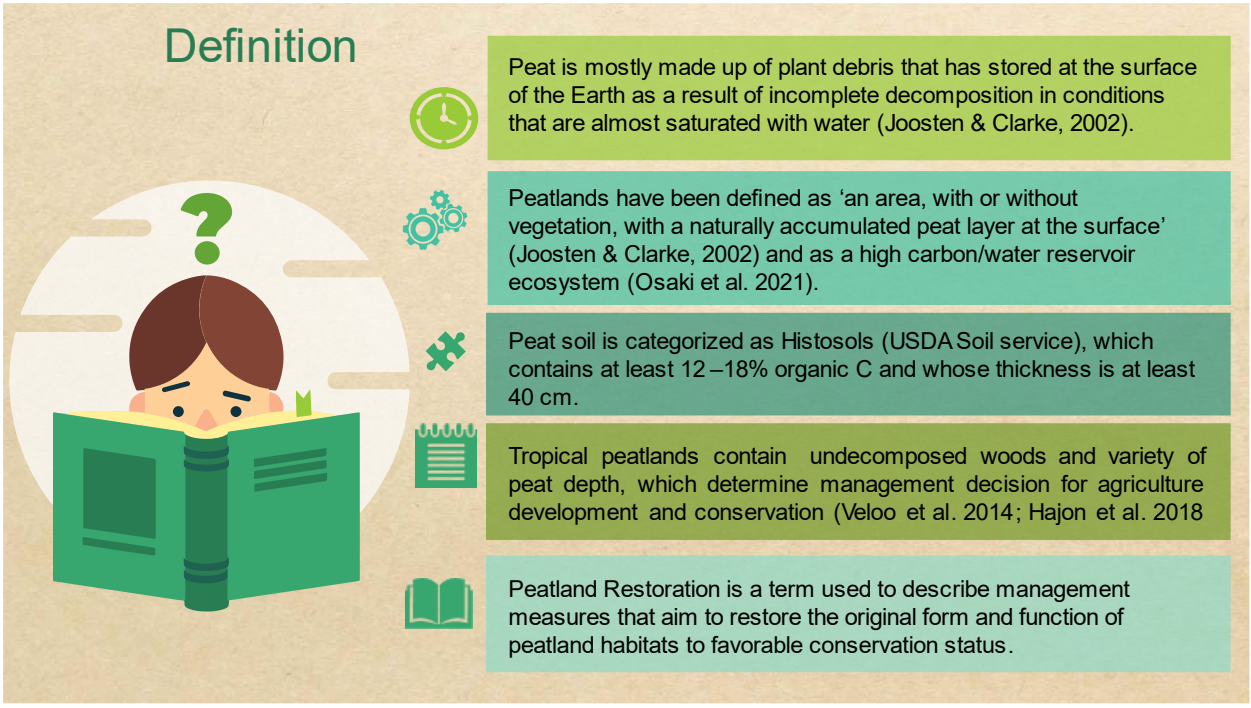
MODULE 1A

TROPICAL PEATLANDS: CONSERVATION AND RESTORATION



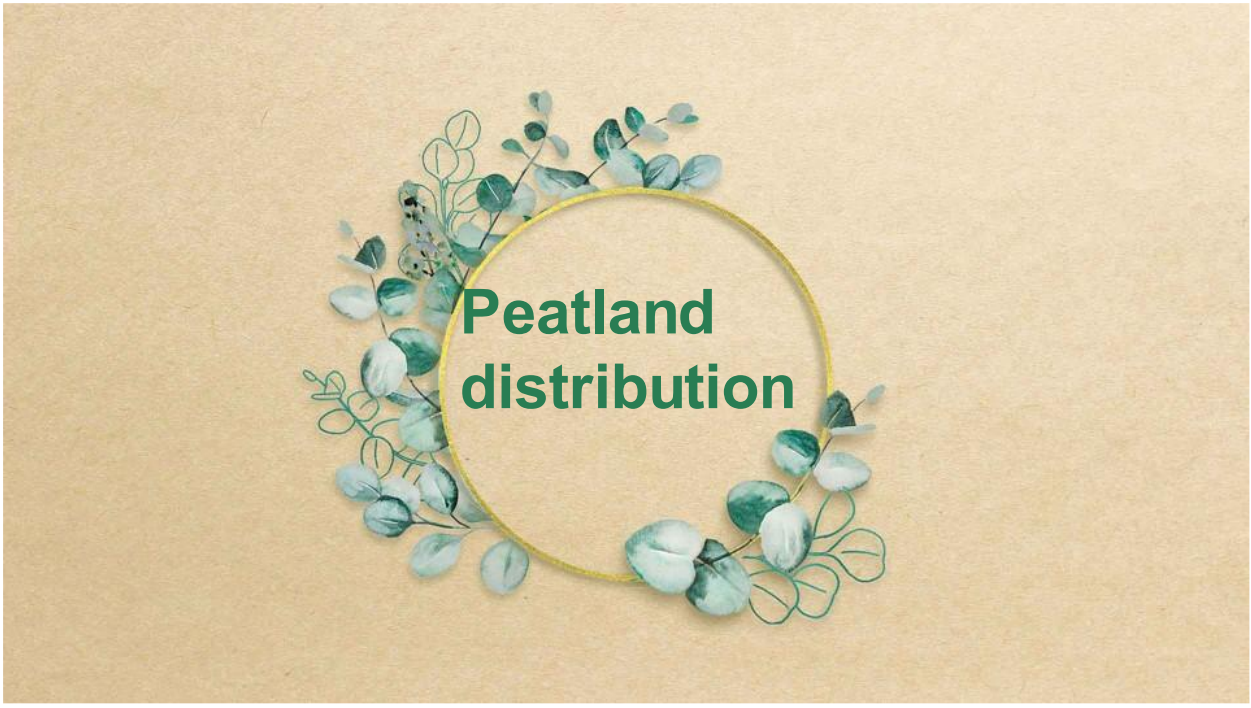


Objective of Module 1A is to learn about definition of peatlands, peatland distribution in the world and in Southeast Asia, peat formation, peatland decomposition, peatland benefits, peatland threats, and lastly, the concept of peatland restoration. The last topic has link with training module 1B.



Some terms that are commonly used in the training, are described as follow:

- Peat is mostly made up of plant debris that has stored at the surface of the Earth as a result of incomplete decomposition in conditions that are almost saturated with water.
- Peatlands have been defined as ‘an area, with or without vegetation, with a naturally accumulated peat layer at the surface’ (Joosten & Clarke, 2002) and as a high carbon/water reservoir ecosystem (Osaki et al. 2021).
- Peat soil is categorized as Histosols (USDA Soil service), which contains at least 12–18% organic C and whose thickness is at least 40 cm.
- Tropical peatlands contain undecomposed woods and variety of peat depth, which determine management decision for agriculture development and conservation Veloo et al. 2014, Haion et al. 2018).
- Peatland Restoration is a term used to describe management measures that aim to restore the original form and function of peatland habitats to favourable conservation status.



Peat distribution

Peatlands distributions in the World

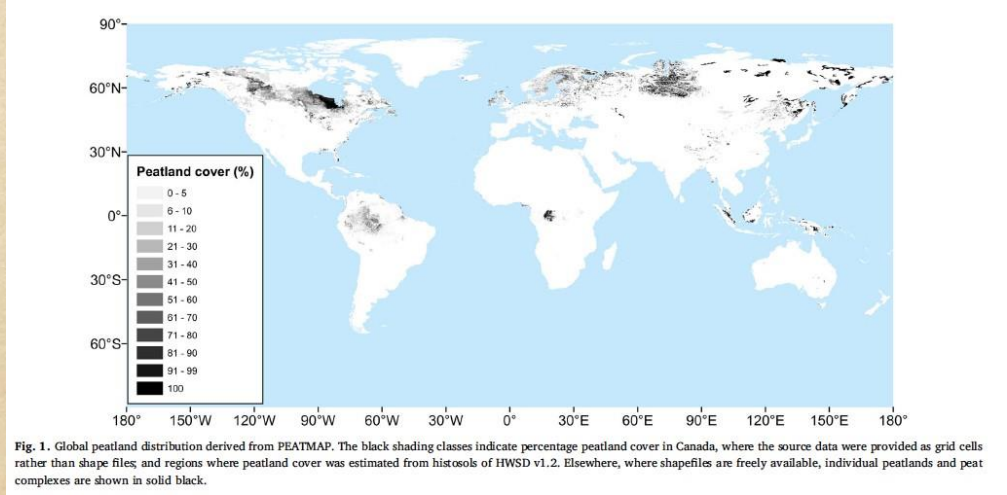
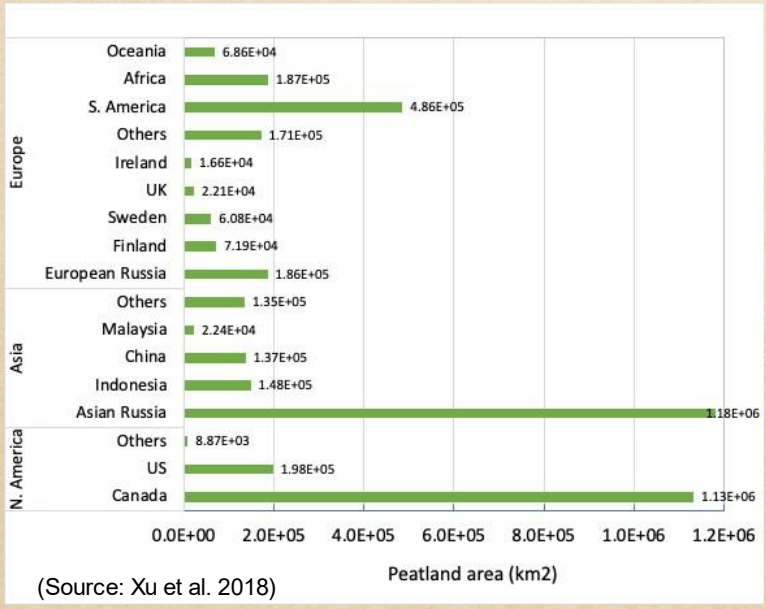


Fig. 1. Global peatland distribution derived from PEATMAP. The black shading classes indicate percentage peatland cover in Canada, where the source data were provided as grid cells rather than shape files; and regions where peatland cover was estimated from histosols of HWSD v1.2. Elsewhere, where shapefiles are freely available, individual peatlands and peat complexes are shown in solid black.

(Source: Xu et al. 2018. Peatmap: Rifining estimates of global peatland distribution based on meta analysis. Catena 160: 134 - 140).

Peatlands distribute all over the world, from the boreal, temperate to tropical countries in the Europe, America, Asia and Africa continents. In Southeast Asia, Indonesia and Malaysia are the two most countries where peat's dominant.

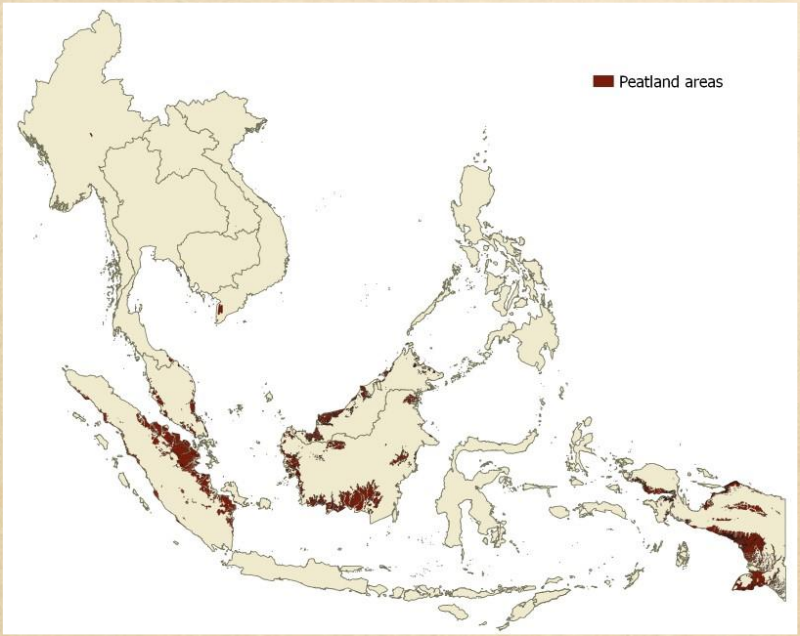
Peatlands area of the world



(Source: Xu et al. 2018)

Total peatland area of the world is about 4.23 Million km^2 of 147,647,000 km^2 of total land area. So peatland is only 2.85% of the globe. However, it has a significant role for the ecosystem and human being.

Peatlands distribution in Southeast Asia



Peatlands in Southeast Asia cover about 23 million hectares, or 60% or the world's tropical peatlands and 6% of the global peatlands.

With depths of peat between 0.5 and 10 m, peatlands are usually located in low elevation, sub-coastal areas.

(Source: https://www.mss-int.sg/vfsp-was/about/peatlands-in-southeast-asia)

Peatland distribution in Southeast Asia. Peatlands in Southeast Asia cover about 23 million hectares, or 60% or the world's tropical peatlands and 6% of the global

peatlands. With depths of peat between 0.5 and 10 m, peatlands are usually located in low elevation, sub-coastal areas.
Peatlands in ASEAN distribute in the countries of Indonesia, Malaysia, Brunei Darussalam, The Philippines, Thailand, Vietnam, Lao PDR, Myanmar, and Cambodia. Indonesia has the largest peatland area, and Cambodia has the smallest area of peatlands.

Peatlands in ASEAN countries

(Source: asean.org)

Country	Peatland Area (ha)	Management Use
1. Indonesia	13.43 Mha (Anda et al. 2021)	Peatlands are distributed in Sumatra, Kalimantan, Sulawesi and Papua. Recent report for peatland in Sulawesi (Anda et al. 2021). Peatlands have been used widely by local communities, and also as wood plantations of pulp and papers and oil palms
2. Malaysia	2.6 Mha of peatlands, of which about 70 % (~1.6 M ha) are in Sarawak (Melling, 2016)	Malaysia has approximately 2.6 Mha of peatlands, of which about 70 % (~1.6 Mha) are in Sarawak topo-morphology is strongly influenced by the hydrological conditions, which then determine the vegetation structure, species composition, and peat type.
3. Brunei Darussalam	90,884 ha (Kobayashi 2016)	Peatlands occur at low altitude, near the coast, from sea level to about 50 meters above mean sea level, although pockets of peatlands are found in highland areas which are referred to as 'kerangas' or tropical heatland . It consists of coastal peatland, river valley peat, highland peatland.
4. The Philippines	64,500 ha (Omar et al. 2022)	The IPAS surveys in 1991 briefly described peatland near Bunawan in the Agusan Marsh. peatland in the Agusan Marsh and the Leyte Sab -a Basin peatland. This included a possible peat dome at Caimpugan in the Agusan Marsh. Vegetation: *Terminalia copelandii/ Metroxylon sago.*

This table shows you the summarize of peatlands in ASEAN countries. Indonesia has the largest peatland area, which is reported about 13.43 Mha. Peatland distributes in Three main islands of Sumatra, Kalimantan, Papua, and small peatland area was found in Sulawesi. Peatlands have been used and cultivated by local people, and planted as wood plantation for pulp and paper and oil palms.

Malaysia has the second largest peatland area, which is about 2.6 Mha, and about 70% of the area are in Sarawak. In Brunei Darussalam, peatland areas cover 90,884 ha. While the peatland area in The Philippines is 64.500 ha.

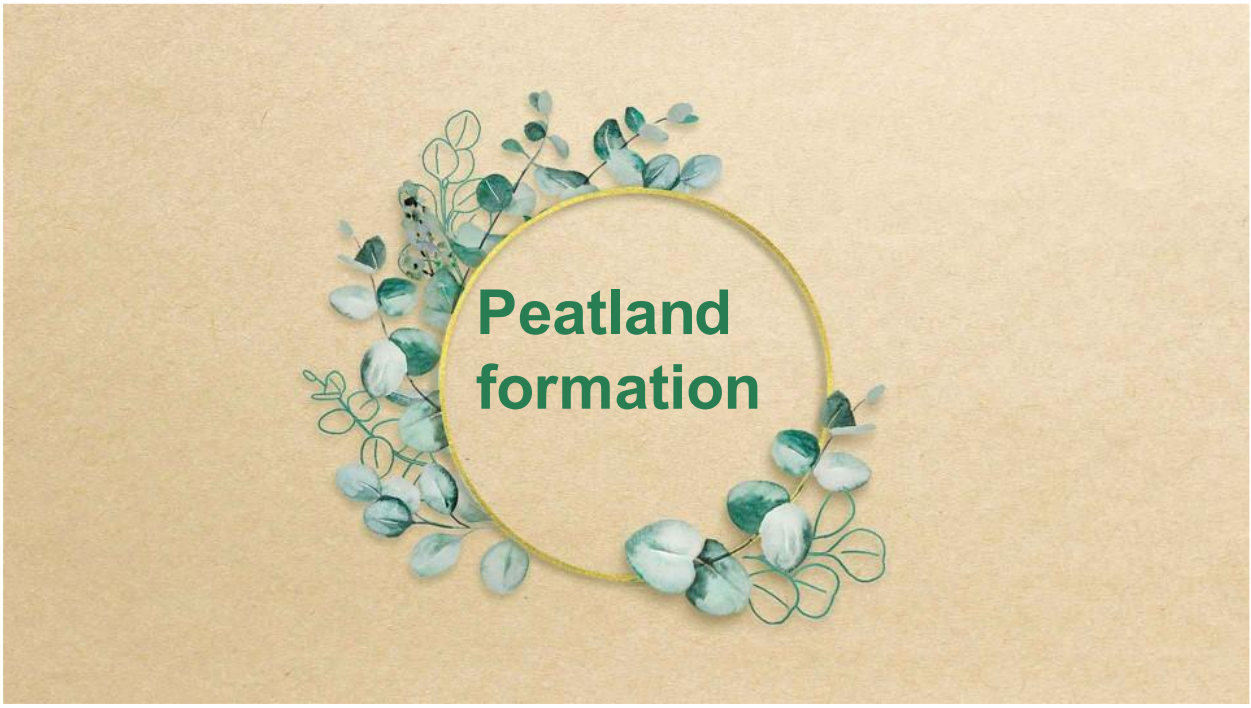
Peatlands in ASEAN countries

Country	Peatland Area (ha)	Management Use
5. Thailand	63,800 ha (Omar et al. 2022)	Peatlands distribute in the southern Thailand. Pru Toh Daeng (200 km2), a peat swamp in Narathiwat province, has been declared a wildlife sanctuary area.
6. Vietnam	53,300 ha (Omar et al. 2022)	Melaleuca forest (12,000 ha). In the Mekong delta is 24,000 ha. Peatland area has mostly designated as National park.
7. Lao PDR	19,100 ha (Omar et al. 2022)	3 locations have been identified as peatland. They are in Phapho, Nong Phou and Nongphangdeng
8. Myanmar	>10,000 ha in Shan state and 500 ha at Htu lake. (Mekong peatland project)	In Shan state and Hopong Valley, southern Shan State; Pyin Oo Lwin Township, Mandalay; Bokpin and Palaw Townships, Tanintharyi; Indawgyi Lake, Kachin State; and Kyaukme Township, northern Shan State.
9. Cambodia	4,580 ha (Omar et al. 2022)	Coastal mangrove of Peam Krasaop Wildlife Sanctuary and one in Botum Sakor National Park, both in Koh Kong Province. Habitat of wildlife, water quality, carbon sequestration, fishery.
10. Singapore	50 ha (Omar et al. 2022)	Singapore has limited forest land and peatlands. The most distinctive peatland in Singapore is the freshwater swamp forest at Nee Soon. Nee Soon freshwater swamp forest lies entirely within the Central Catchment Nature Reserve, protected under the Parks and Trees Act.

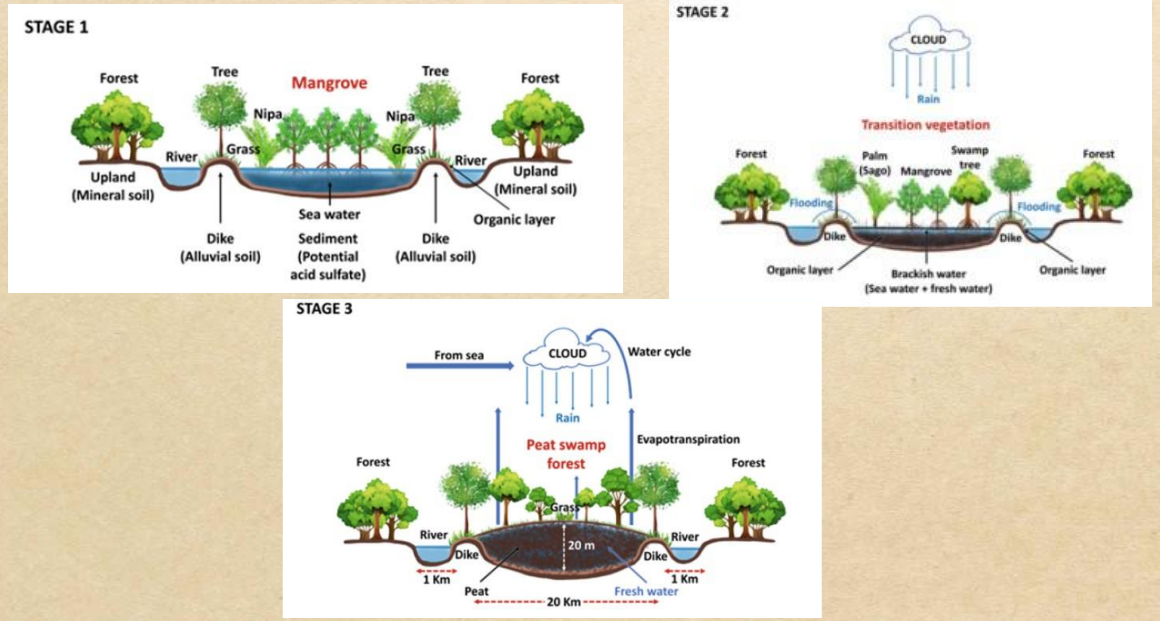
(Source: en.aseanpeat.id)

(Omar et al. 2022: Peatland in Southeast Asia: a comprehensive geological review. Earth Science Review 232.)

Thailand has peatland area of 63,800 ha, where mostly conserved as wildlife sanctuary area. Vietnam covers peatland area of 53.300 ha. In this country, peatlands are mostly designated as conservation area, as national park. Other four countries, such as Lao PDR, Myanmar, Cambodia and Singapore, has small peatland area, and recently reported in 2022, after intensive survey and investigation.



Peatland formation in S.E. Asia (hypothesized by Osaki et al 2021)



As we seen in the peatland map of Southeast Asia, peatlands usually distribute along the coastal areas. Peatlands can be found in the same landscape with mangrove, another wetland ecosystem.

In this slide we see the hypothesis how peatland formation in the adjacent of coastal areas of S.E. Asia, or particularly in Indonesia.

Mangrove present firstly in the see water, Nypa and mangrove trees live. In the second stage, there is brackish ecosystem (with lower salinity) where sago tree and swamp tree can live. Here, the organic layers accumulated. Years by years, peat dome is established. This hypothesis has written by Osaki et al. (2021).

Peat formation

- Peat formation has been classified based on water source (Joosten & Clarke, 2002; Lindsay 2016):
  - (a) Geogenous (or Topogenous) peatland; is nutrient rich peat (so called, Minerotrophic) and connected to ground water, rich with base cations Ca and Mg.
  - (b) Ombrogenous peatland; receive water only from precipitations. It has thicker peat layer, acidic, high organic content, and nutrient-poor, so called Mesotrophic).

Topogen

Ombrogen

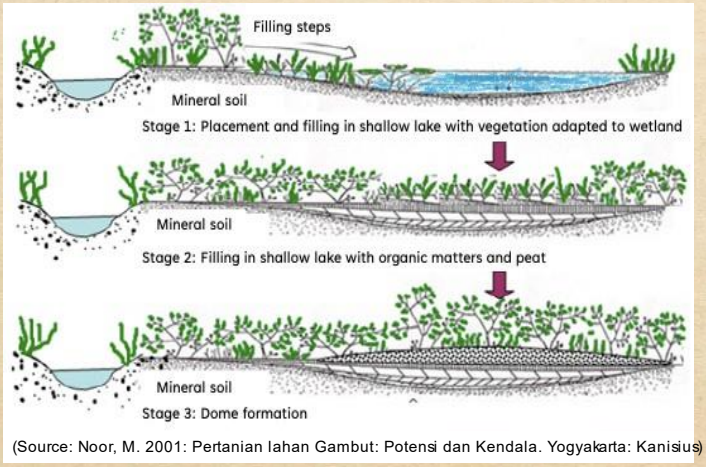
Peat formation has been classified based on water source.

(a) Geogenous (or Topogenous) peatland; is nutrient rich peat (so called, Minerotrophic) and connected to ground water, rich with base cations Ca and Mg.

(b) Ombrogenous peatland; receive water only from precipitations. It has thicker peat layer, acidic, high organic content, and nutrient-poor, so called Mesotrophic).

In case for Indonesia, mostly peatlands is categorized as ombrogenous.

Peat (ombrogenous) formation



(Source: Noor, M. 2001: Pertanian lahan Gambut: Potensi dan Kendala. Yogyakarta: Kanisius)

The link of tropical peat formation: https://www.youtube.com/watch?v=1C7ecAoXav0

Usually, peatland is positioned between two rivers, or in the adjacent of coastal area and a river, and a peat-island (for example: Rupat and Merbau islands of Riau province) .

Here the figures of Ombrogenous peat formation. Peat-swamp ecosystem is established from a lake or water basin. Initially, the shallow lake is filled with vegetation. Since then, years by years, the water basin filled by organic matters and undecomposed material organics). Lastly, dome is formed.

Peat starts to accumulate wherever the rate of organic deposition exceeds the rate of decomposition, which is due to a combination of environmental conditions, such as temperature, oxygen supply and pH, and intrinsic properties of the organic matter, such as low nutrient content. In the tropics, decomposition rates are not limited by temperature or its seasonal variation. The primary trigger for organic matter accumulation in the form of peat is excess rainfall over drainage, as tends to occur in flat terrain on less permeable soils or in contact with a permanent groundwater table.

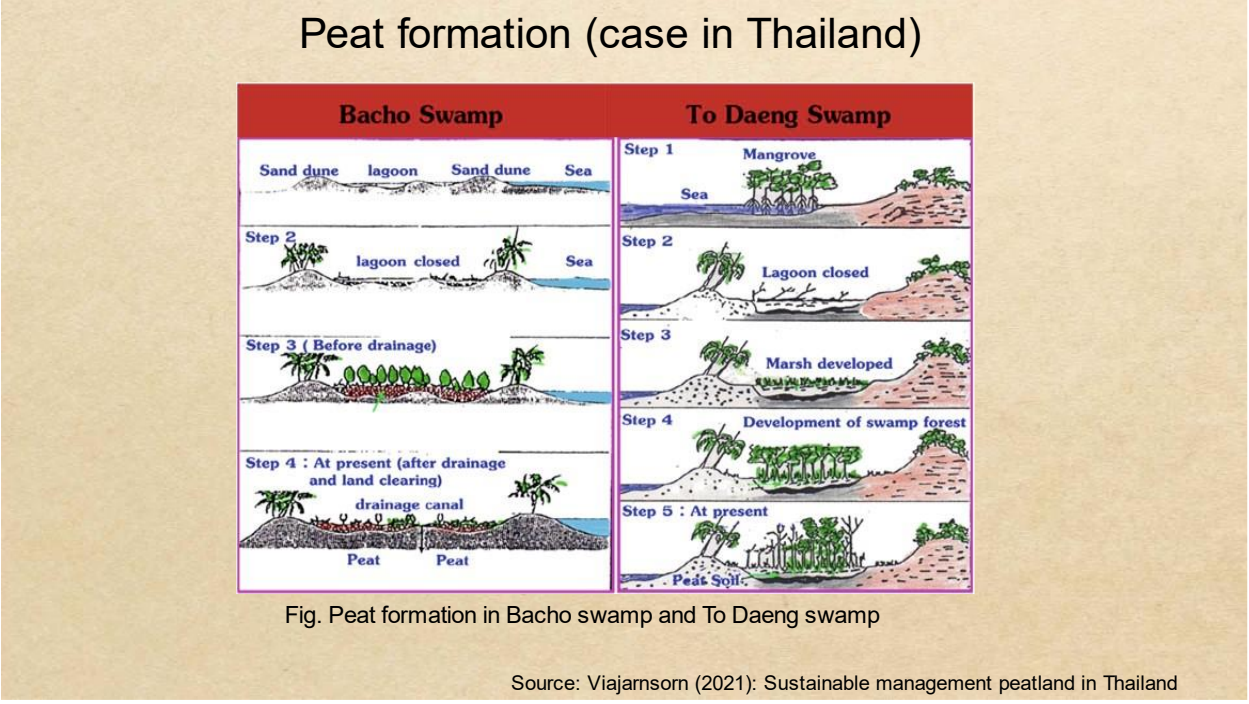
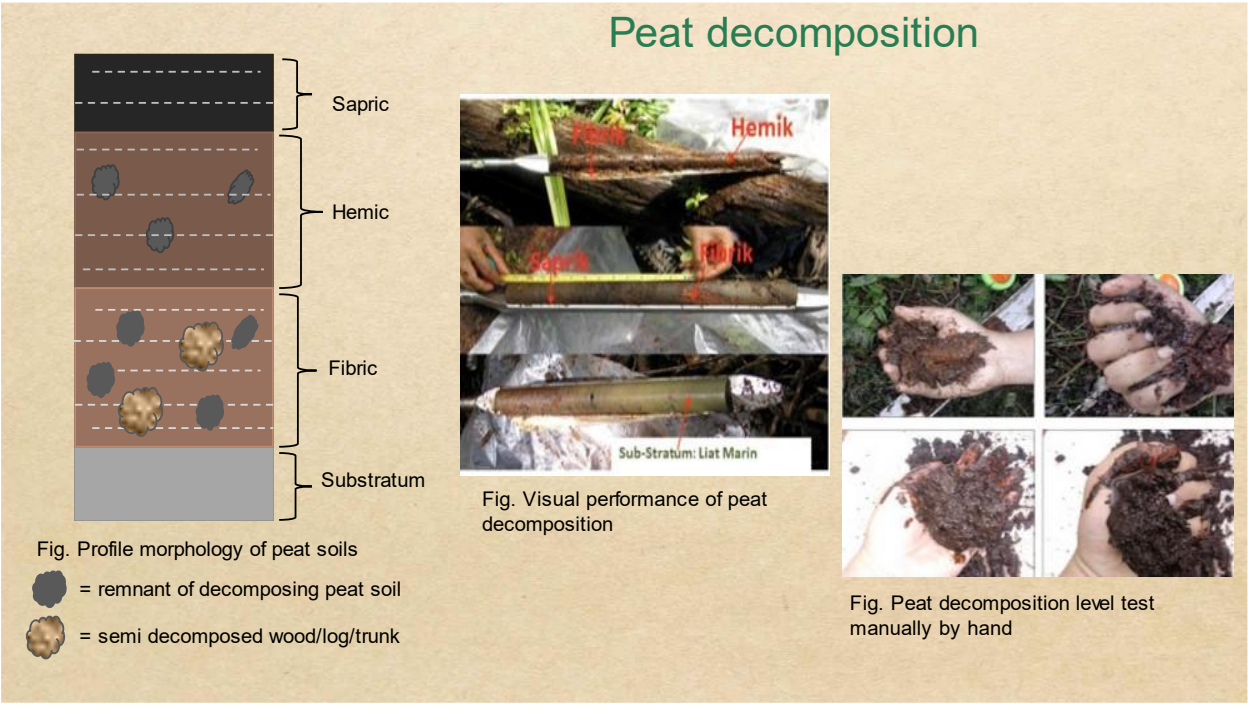


Fig. Peat formation in Bacho swamp and To Daeng swamp

Source: Viajarnsorn (2021): Sustainable management peatland in Thailand

Different area has different peat formation mechanism. In Bacho swamp, peatland was derived from lagoon, and it filled out with organic materials. In To Daeng swamp, the peatland was formed initially from mangrove. After the lagoon closed and filled out with organic materials, swamp slowly developed.

We are now discussing about Peat decomposition.



Peat is consisted of different decomposition level. Under natural conditions, peat is in a water-saturated state and anaerobic, so that organic materials are not easily decomposed. The upper layer of peat soil, the peat is usually highly decomposed, particularly when the vegetations are already cut down, the peat layer has exposed by

sun light and water table decreased, so that decomposition has increased. It is called sapric, in the field we can easily see the dark color of peat, less water content and no free-water emitted upon squeezing.

The second peat layer, usually consisted of hemic peat, which has lighter color than the above layer. We may still find remnant of decamping peat soil. It has higher water content.

The lower peat layer is fibric peat, which has light reddish brown color. It has high water content, so that when we squeeze the soil by hand, the water comes out. There are semi decomposed wood/log/trunk.

In the bottom, we will find the substratum, which can be clay, quartz sand, granit, and others.

Indices the class of decompostion using the Von Post's estimate of decomposition

Code	Classes	Description
01	Living moss layer	Living moss layer. Usually the surface 2 -4 cm. Cannot be considered "peat" as such as it is not yet dead.
02	Plant material is dead	The structure and form of the plant material is complete. The only difference between01 and 02 is that a 02 peat is not living. When squeezing, clear to slightly yellowish water is emitted. The peat sample in the hand is normally bright yellowish orange in colour, especially after squeezing. The sample is spongy, or elastic; upon squeezing, the compressed sample springs back, and will take little or no shape.
03	Plant material very easily distinguis hable	The plant material is still very easily distinguishable, but the individual sphagnum "stalks" are breaking up into pieces, as opposed to continuous lengths of stems, etc. When squeezing, yellow water with some plant debris (mostly individual leaves is emitted. The colour of the sample is somewhat darker that a 02 peat. The sample is still spongy, but less than 02; after squeezing, the peat will spring back to a point where a vague to fairly definite form of the handprint is distinguishable.

Fibric/fibrous: Mostly undecomposed, typically tan to light reddish brown in color

(Source: sis.agr.gc.ca)

Decomposition level of peat has been classified by Von Post, like we see in the following table. There are 10 indices of decomposition class. Code 01 to 03 is categorized as fibric or fibrous peat. The peat is semi decomposed, where dead plant materials can be found, high water content.

Indices the class of decompostion using the Von Post's estimate of decomposition (cont.)

Code	Class	Description
04	Plant material disintegrating	Slightly decomposed peat. The plant material is not as easily distinguishable. When squeezing, light brown to brown water with a lot of debris is emitted. The sample is not spongy, and upon rubbing, a slightly soapy or humic texture is detected. Upon squeezing, the sample makes a perfect replica of the handprint. It should be noted that after squeezing a peat sample, the difference in shape between a03 and a 04, is that a 03 is "rounded off" whereas a 04 peat has definite "sharp" ridges left by the fingers. No peat escapes the fingers.
05	Some unstructured material is present	Moderately decomposed peat. The plant material is reaching a stage of decomposition where the individual components (branches, leaves, stem) are starting to breakup, such that some amorphous or unstructured material is present. When squeezing, definitely brown water is emitted. The sample has a more definite soapy or humic texture, yet roughness is still present. Upon squeezing a very small amount of the sample escapes between the fingers.
06	Half of the material is unstructured	Moderately highly decomposed. The plant material has decomposed to the extent where almost half of the sample is in an amorphous or unstructured state. Plant constituents are still distinguishable upon close examination in the hand. upon squeezing, brown to dark brown water is emitted. The sample is pasty and very malleable. Upon squeezing, approximately one -third of the peat escapes between the fingers as a paste.

HEMIC/Moderately decomposed: Intermediate in degree of decomposition, organic content and bulky density, dark, reddish brown in color

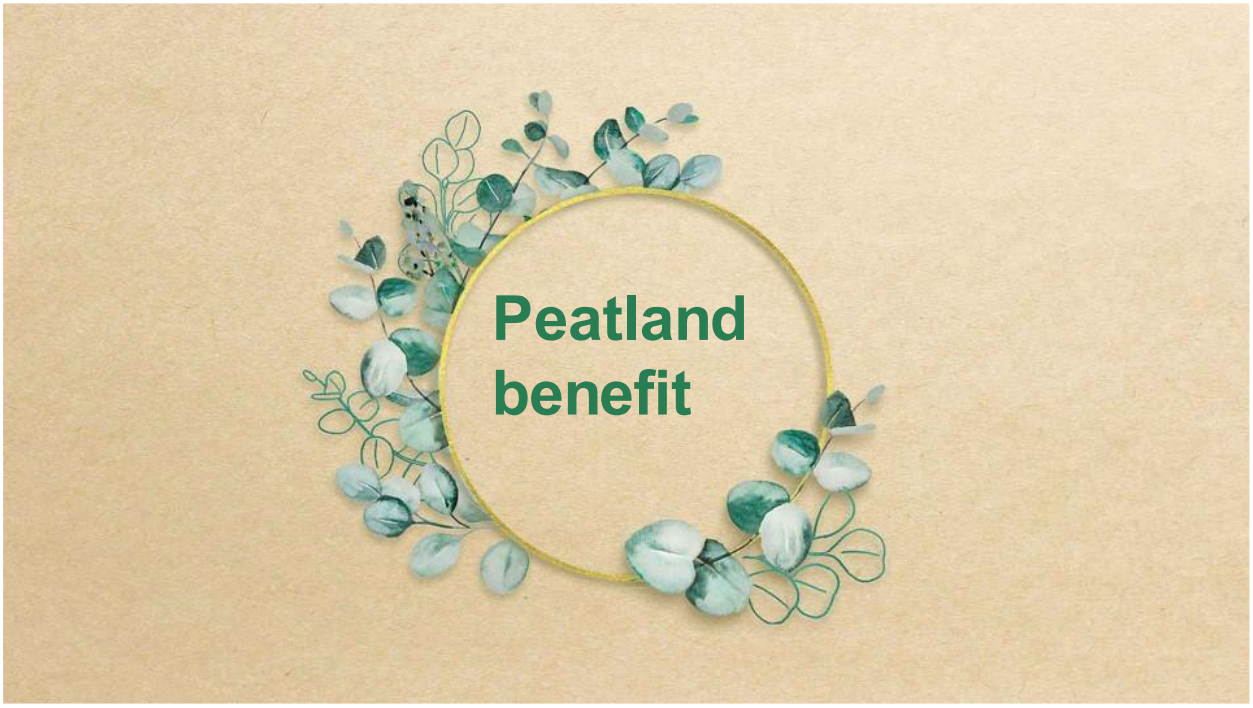
Code 04-06 is categorized as hemic or moderately decomposed, which is intermediate in degree of decomposition, organic content and bulky density, dark, reddish brown in color.

Indices the class of decompostion using the Von Post's estimate of decomposition (cont.)

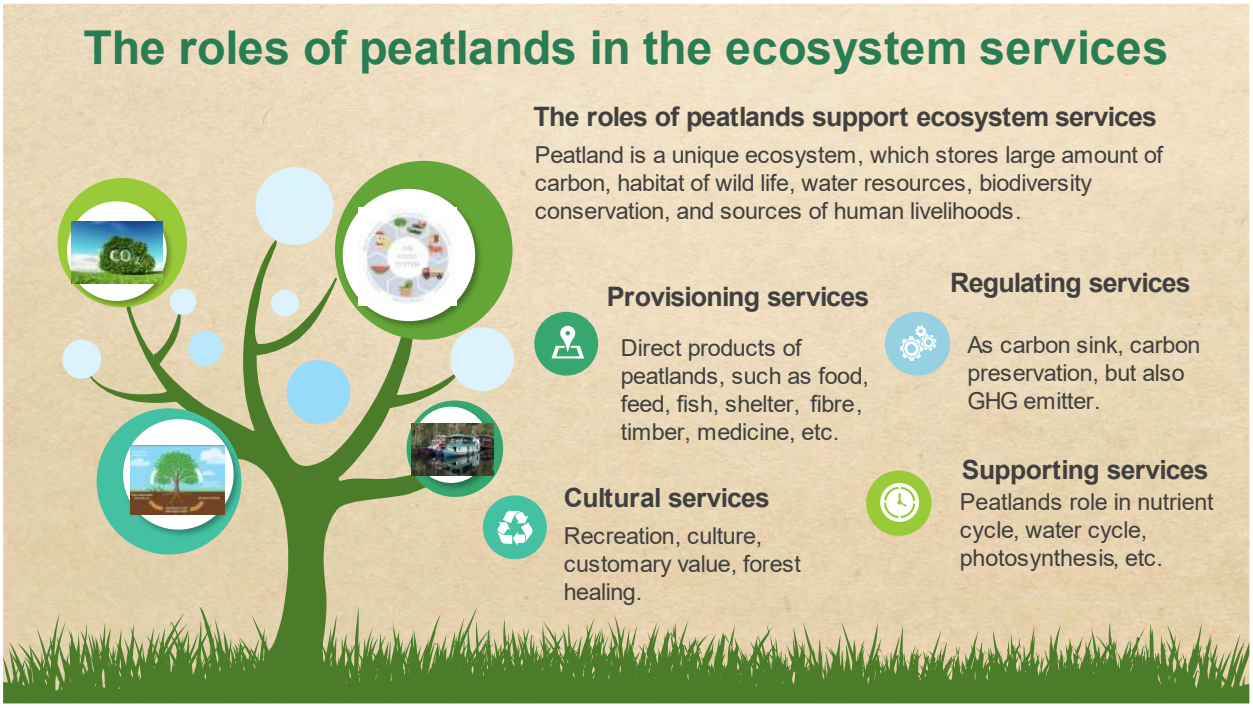
Code	Class	Description
07	Plant material practically indistinguishable	The original plant material is practically undistinguishable and a very close examination in the hand is needed to see that there are still vague structures present. If the sample is "worked" in the hand, this structure will disappear. It should be noted that such things as weed, sedge roots, and Eriophorum fibres are often very resistant to decomposition, and can be present in their "original" state in humified peats up to 07. Upon gentle squeezing, a small amount of very dark water is emitted. When the final squeeze is performed, over half of the material escapes the hand.
08	No appreciable roots or fibres	The only distinguishable plant remains are roots or Eriophorum fibres, when present. If appreciable amounts of roots or fibres are present, the peat cannot be considered to be a 08, even though the remaining material is such. The "appreciable amount" of these materials occur when they interfere with the squeezing out of the remaining amorphous material. If pieces or chips of weed are present in the sample, regardless of the amount, this alone classifies the peat as a 07. Little or no water is emitted upon gentle squeezing. The final squeeze results in over two thirds of the peat escaping the hand.
09	Homogeneous amorphous	A very homogenous, amorphous sample containing no roots or fibres. There is no free water emitted upon squeezing, and almost all of the sample escapes the hand
10	Pudding-like homogeneous	Very rare to non-existent in non-sedimentary peats. In sedimentary peats, the particle size can be extremely small resulting in "pudding -like" homogenous material. Upon squeezing, all of the sample escapes the hand.

SAPRIC/amorphous: highly decomposed with the highest organic content and bulk density. Darker in color.

Code 07-09 is categorized as sapric or amorphous, which is decomposed with the highest organic content and bulk density. Darker in color, no plant materials, roots or fibres. It has homogenous amorphous.



We are moving toward Peatland benefits.



Peatlands play pivotal roles in the four pillars of ecosystem services: in the provisioning services, regulating, cultural and supporting services. Let us discuss them consecutively.

Provisioning services

Direct products of peatlands, such as food, feed, fish, shelter, fibre, timber, medicine, etc.

Community based rehabilitation strategies: agrosilvofishery
Apiculture: honeybee and stingless bee

Fishery (*Anabas* sp.) on peat in Riau

Stingless bee (*Trigona* sp.)

In the provisioning service, peatland provide direct benefits, such as food (from fruits, starch of sago, medicine, feed, fish, shelter, latex, fiber and timber. Like for example: agrosivofishery and apiculture on peatlands.

Regulating services

As carbon s ink, carbon preservation, but also GHG emitter.

Tropical peatlands are estimated to store over 75 Gt Carbon, preserved as peat where decomposition of woody organic matter is slowed by inundation (Warren et al. 2017).

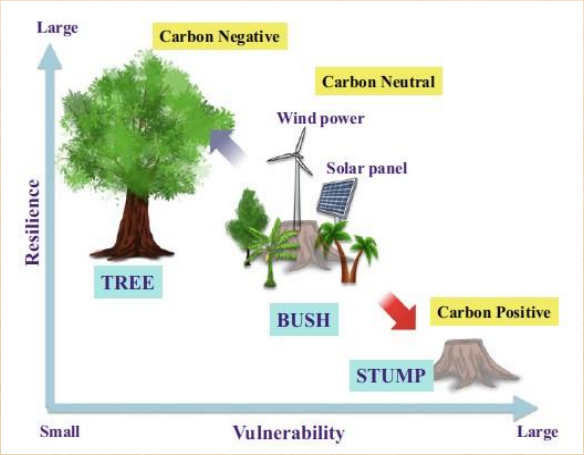
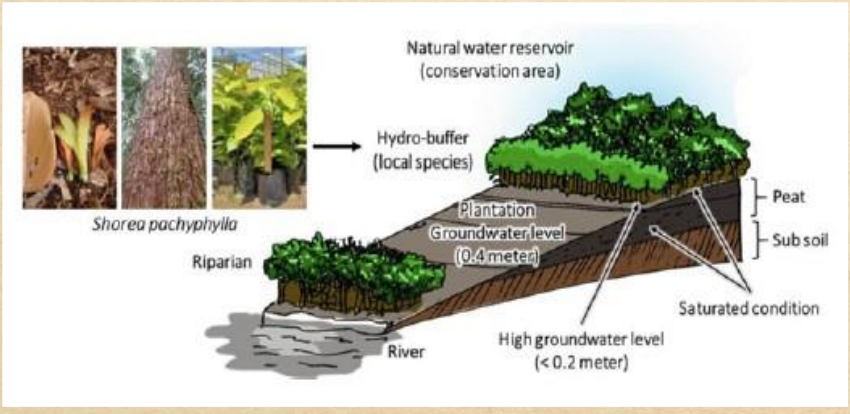


Fig. Three carbon societies in tropical peatlands (Source: Kato et al. 2021)

Peatland also contributes in regulating services: such as carbon sink.
Tropical peatlands are estimated to store over 75Gt carbon, preserved as peat, where decomposition of woody organic is slowed by inundation.

Supporting services

Peatlands role in nutrient cycle, water cycle, photosynthesis, etc.

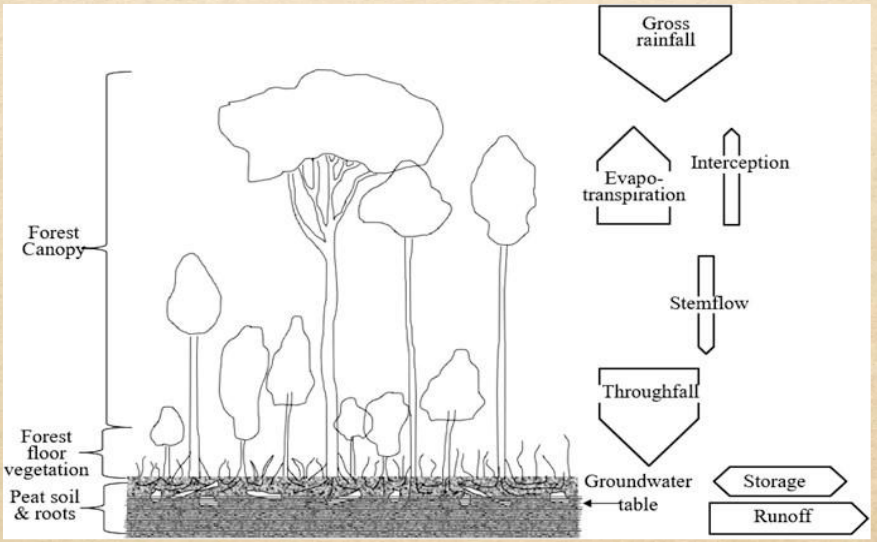


Peat swamp forest (in the higher elevation) as water reservoir for a concession forest of pulp and paper in the downsream in West Kalimantan (Kato et al. 2021).

In the supporting service: peatlands play role in nutrient cycle and photosynthesis, and other cycles. Here we see that the peat swamp forest plays role as water reservoir for

the pulp and paper plantation in the downstream in West Kalimantan, as reported by Kato et al.

Supporting service role



Water flow and balance in the biosphere in peatland (Source: Takahashi et al. 2021)

According to Takahashi et al., the water flow and balance in the biosphere of peatlands. Vegetations maintains the balance of water flow. Rainfalls in the forests go throughfall and stemflow. The water is stored as well as runoff. The water storage will maintain the groundwater table. Water is also evaporate and interception to the atmosphere. Forest canopy maintains the throughfall. While roots in the below ground bind and joint the peat soils, so that they preserved groundwater table.

Cultural services

Recreation, culture, customary value, forest healing.

Reeds for handicraftin Thailand and Indonesia

Ecotourism, recreation, research & education

Purun (*Lepironia* sp.) as biodegradable pot) at Katingan Mentaya Project

Peatland is also important for cultural services, recreation, customary values and forest healing.
Like for example some picture are shown here: Leipronia sp, in Indonesia is known as purun, is used as handicraft and biodegradable pot.

Ecotourism in the peatlands has been emerging in some areas in Indonesia, such as in Central Kalimantan and South Sumatra. Where can be promoted as forest healing.

Peatland's threats

Beside of benefits, peatlands also have many threats.

- Canals establishment increase C -emission and subsidence (Dadap et al. 2021).
- Once peat dried, it becomes susceptible to fire. During the catastrophic fire in October-November 2015 in Indonesia, it is estimated that mean of emission rate per day reach was 11.3 Tg CO_2 per day (Huijnen et al. 2016).
- Peat fires and smokes produce pollutants including particulate matters (PM). The concentration of PM2.5 during the fire in 2015 was reported above 2000 µg/m^3 (Hein et al. 2022). These pollutant contains carcinogenic and non carcinogenic matters, which impacted negatively to human health (Hein et al. 2022; Siregar et al. 2022).
- Peatland drainage alters the hydro -physical properties of peat, which play an important role in regulating water storage and nutrient transport (Liu et al. 2020).
- The conversion of pristine peatlands into agricultural land through artificial drainage resulted in a water storage loss of approximately 20.3 km^3 (Liu et al. 2021).

We have noticed in the real condition some threats because of mis-management of peatlands.

- Canal establishment on peatland increase C-emission and subsidence.
- Once peat dried, it becomes susceptible to fire. Peat fire emits huge amount of GHG emission.

- Peat fire and smokes produce pollutants and particulate matters. These pollutant contains carcinogenic and non-carcinogenic matters, which affect negatively human health.
- Not only increase the GHG emission, canal establishment on peatlands resulted water storage loss approximately 20.3 km^3.

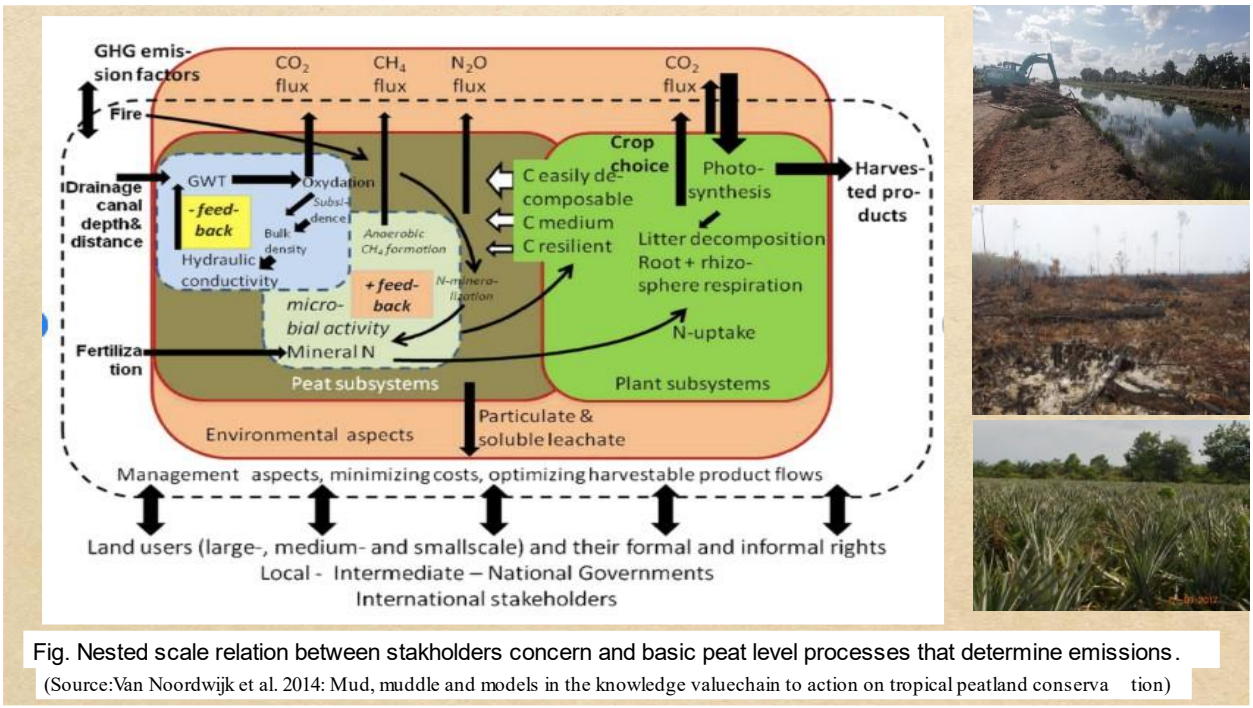


Fig. Nested scale relation between stakholders concern and basic peat level processes that determine emissions.
(Source:Van Noordwijk et al. 2014: Mud, muddle and models in the knowledge valuechain to action on tropical peatland conserva tion)

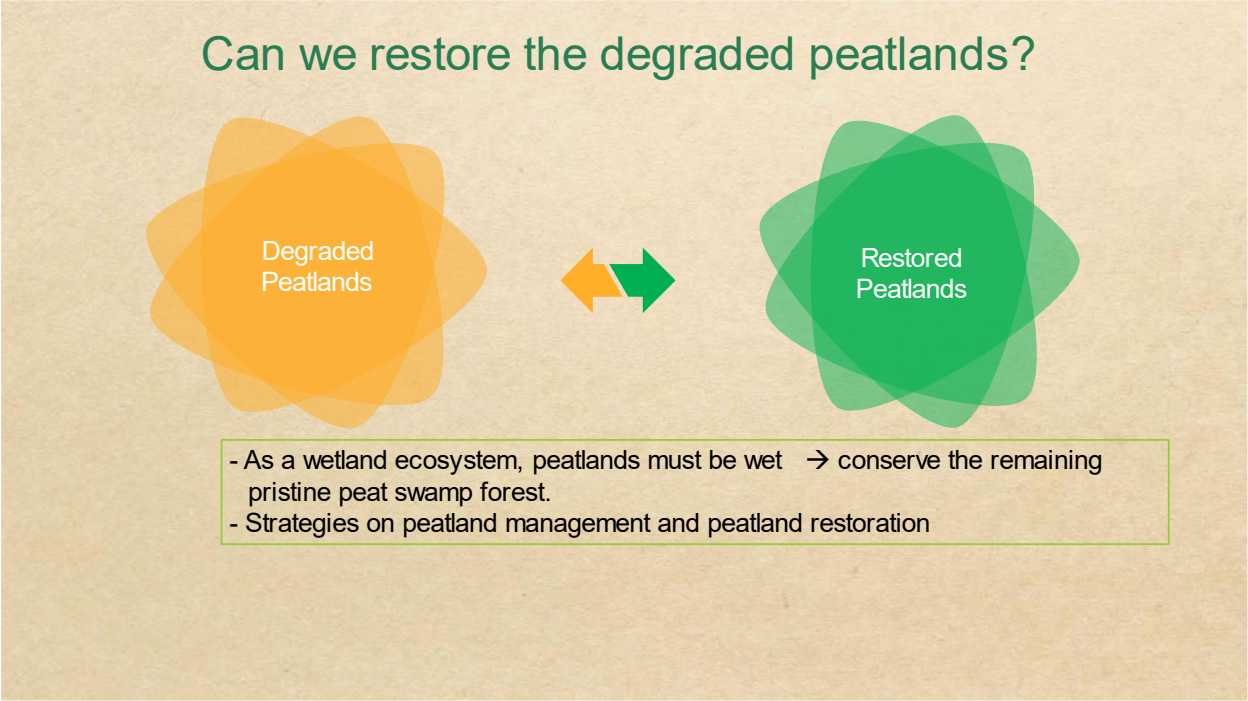
This figure seems bit complicated, isn't it? However, this figure is a summarize of basic peat level process that determine emissions.

We start from the brown-color side in the left. This shows the process that occurs in the peat subsystem. GWT is affected by canals depth and distance. It affects the oxidation and subsidence level, the bulk density and hydraulic conductivity of the peat soil. When the oxidation increase, emission of CO_2 flux increases. When the microbial activities, in increases the CH4 flux emission. N mineralization due to fertilizer application onto peat soil will increase N_2O flux emission.

In the plant subsystem in the right side, it shows the mechanism occurs in the plant. It depends on crop choice, whether we chose the plant species that are adaptive and native to peatland, or the plant species which do not tolerate saturated? When fertilizer is applied onto the plant, it increases litter decomposition, roots and rhizosphere respiration. The photosynthesis affects the yield or harvested products. While respiration also contribute to CO2 flux.

Management aspects, minimizing costs, optimizing harvestable product flows may influenced by land users (either large-, medium-, and smallscale), and their formal and informal rights. Local, National and even international stakeholders have direct influence

on the GHG emission, like for example in the global scale, we know there are some standards for palm oil on peatland (for instance: RSPO, MSPO, and ISPO), Paris agreement on climate and others.



Owing to large area of degraded peatlands, the question is: can we restore degraded peatlands?
As a wetland ecosystem, peatlands must be wet. But in the same time, human being also need to better manage the peatlands, so that we get benefit from it. Therefore, a strategy on peatland management and peatland restoration should be applied.
We also have to conserve the pristine peat swamp forest and minimize the risk of degradation.

There are some strategies on peatland, as follow:

1) Rewetting: aims to increase water content of peat soil, and groundwater level.
2) Revegetation: aims to increase canopy covers, and the ability of roots in anchoring the peat soils. Planting the right plant species, in term of ecology and social economic benefits, which is called **paludiculture**.
3) Revitalization of community, which includes improve awareness about the importance of peatlands, capacity building, extension, access to market, and publica-private partnership.
4) Fire prevention and control, fire is the biggest threat on degraded peatlands. Therefore, patrolling, monitoring should be conducted regularly. Fire danger rating system also has to be established. Not to mention the importance of Fire Care Community to enable fire patrolling and monitoring regularly on the grassroot level.
5) Policy support: We need rules and regulations related with peatland management and peatland restoration, in the local, national, regional dan global levels.
6) The strengthen of law enforcement in peatland use, peatland management in fire, in order for better manage and peatland governance.

In the second module, we will discuss more about paludiculture.

This is a very short summary for a very large topic. Tropical peatland ecosystem has a significant role in the sustainable development and ecosystem services. Direct anthropocentric, such as logging, canal development, intensification of agriculture, and others, resulted a greater impact to the Ecosystem. Therefore, the pristine peat swamp forest shall be conserved, while degraded peatland shall be restored.

This is end of Module 1A.