Tropical wetlands: solutions for or drivers of climate change?

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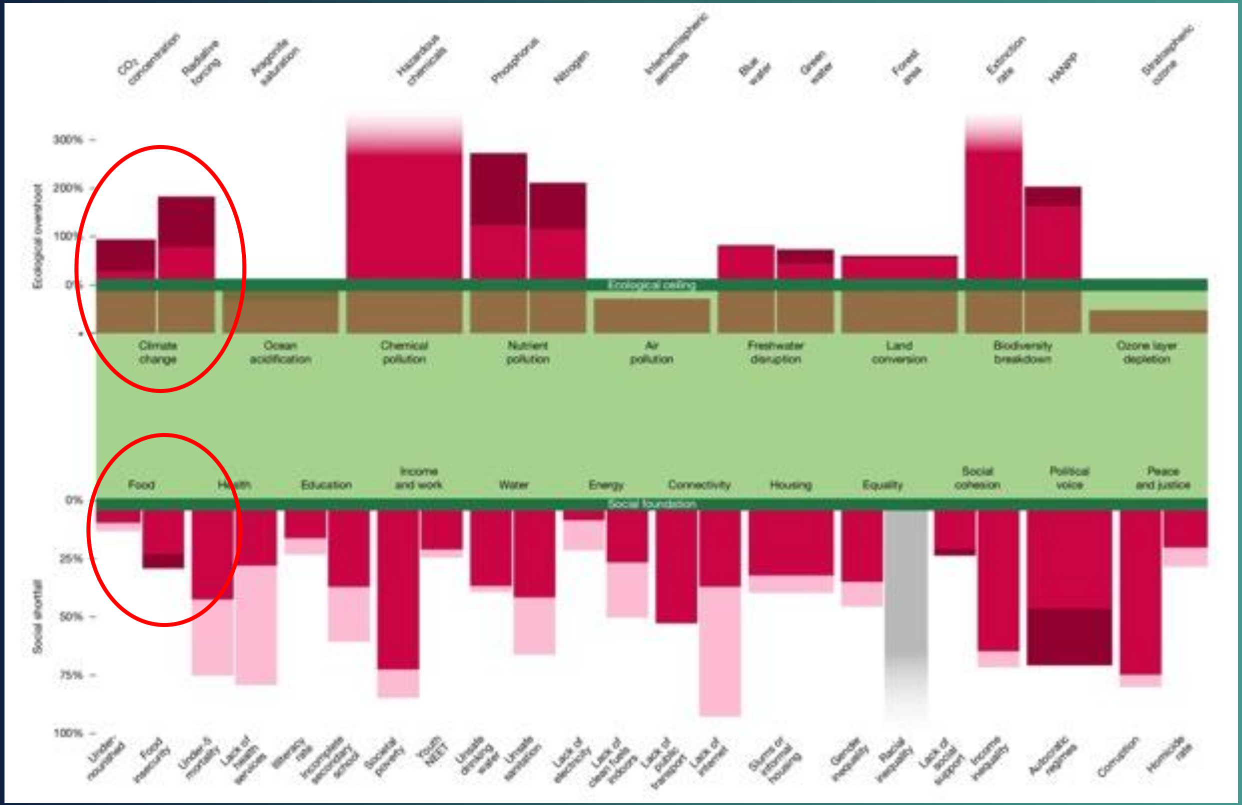
Global change in social shortfall and ecological overshoot: 2000–2001 to 2021–2022



Global GDP doubled between 2000 and 2022: only modest improvements in reducing social shortfalls worldwide, whereas ecological overshoot increased rapidly

Data hide environmental injustices of attempts to address "ecological overshoot" ….

Fanning, A.L. & Raworth, K. (2025) Doughnut of social and planetary boundaries monitors a world out of balance. *Nature* **646**, 47–56

Three premises:

1) Increased atmospheric concentrations of GHG driving global climate change

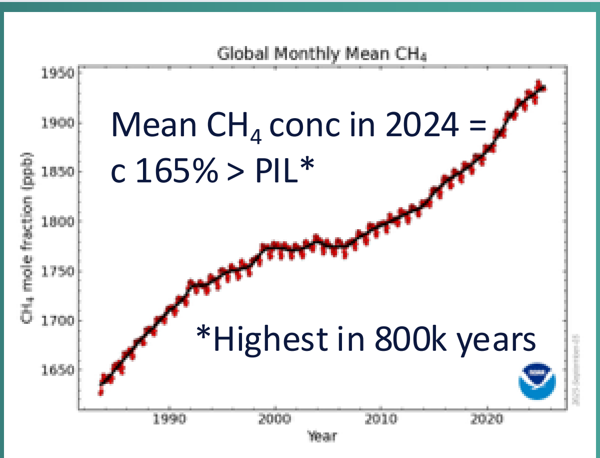
Methane (CH_4) important contributor; major source is modification of tropical wetlands

2) Wetlands are carbon "sinks"

C store = largely below the surface. High potential as "nature-based" means of climate change mitigation

3) Enhancement/protection of carbon-sink properties of wetlands can be funded through carbon credit schemes

Avoided destruction/additional sequestration

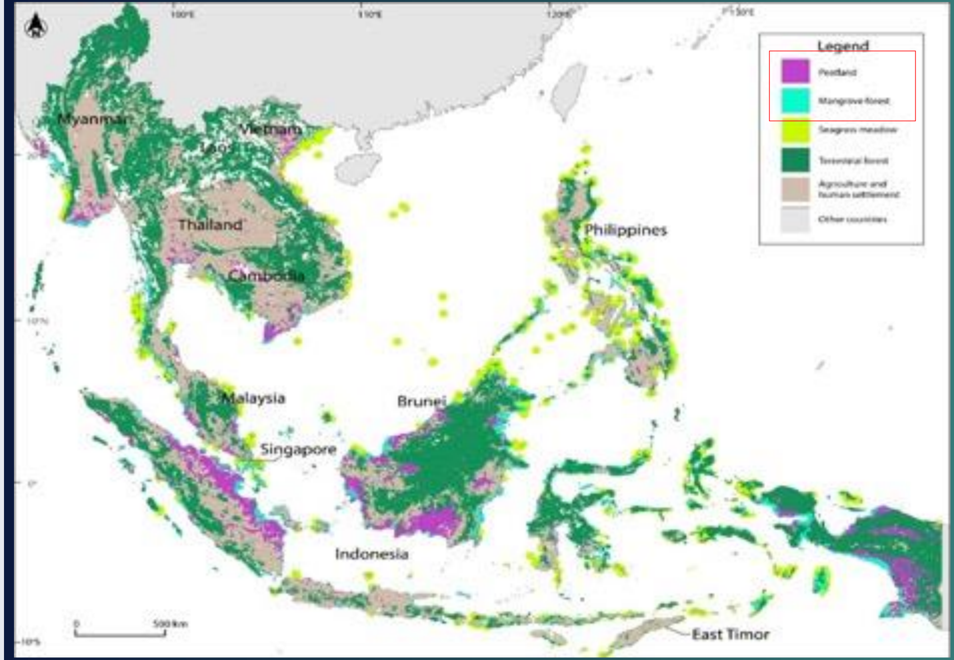


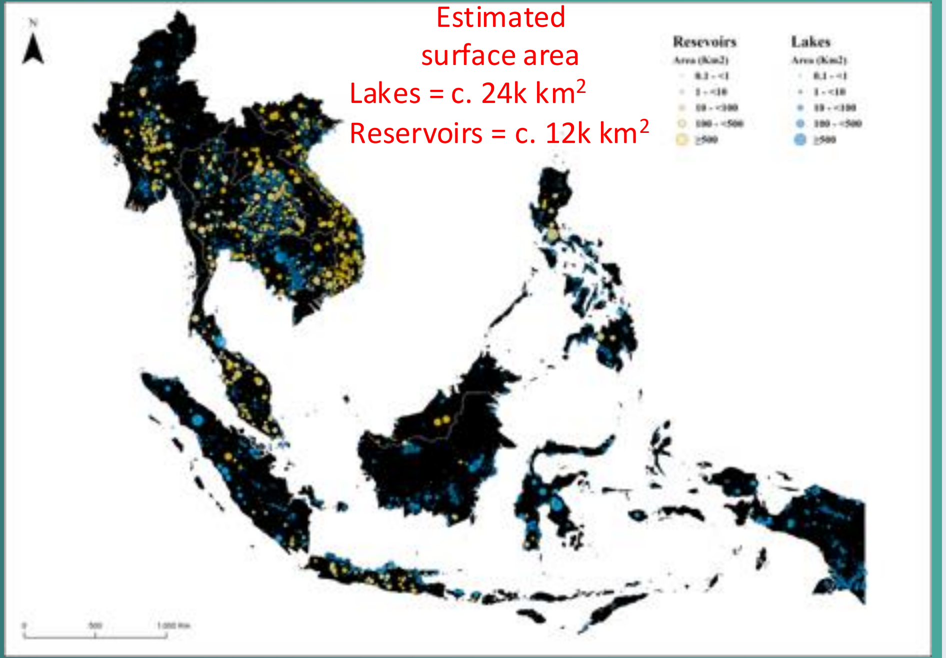
Saunois et al. (2025)

Intact peatland & lake, Kampar Peninsula, Sumatra

Drained and burnt peatland, Jambi, Sumatra

Southeast Asia has high potential for **enhanced** carbon sequestration in **nature-based carbon sinks**, including **wetlands** (peatlands, lakes, reservoirs etc)

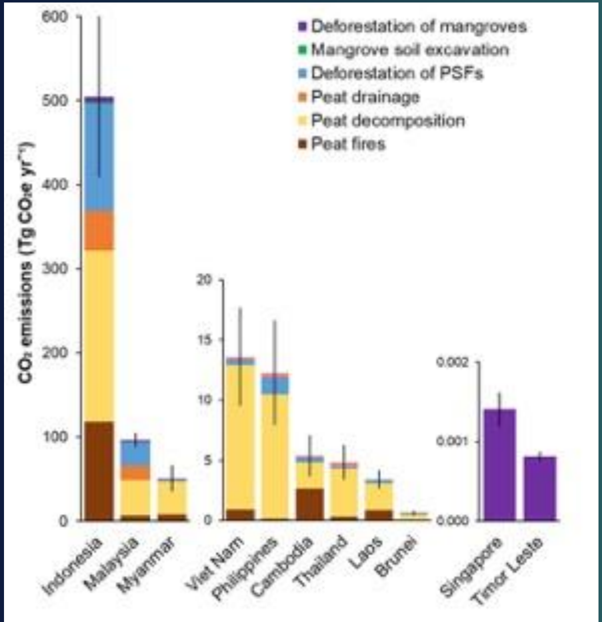




Locations of main types of nature-based carbon sinks found in Southeast Asia (from Miller & Taylor 2024)

Sinks also provide **ecosystem services** in addition to carbon sequestration (“**co-benefits**”)

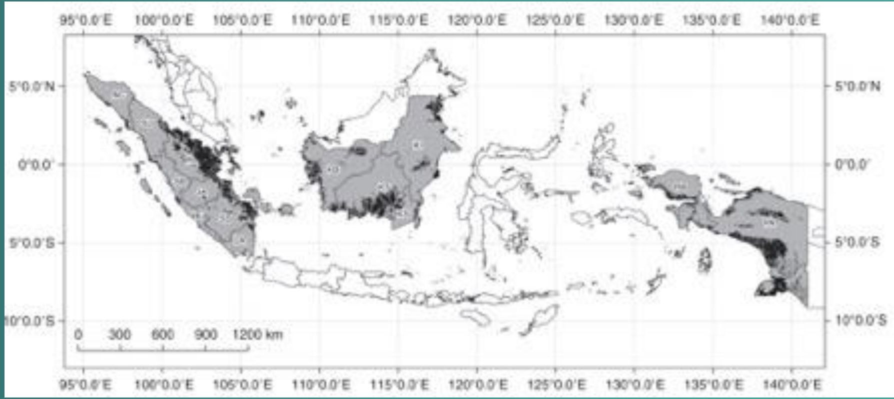
Degraded peatlands in Southeast Asia ~ currently a **source** of GHG emissions…



Ave annual CO_2 emissions from degraded peatland and mangroves in SE Asia 2001-2022 (Sasimato et al. (2025) *Nature Comm*)

Drained and burnt peatland, Sumatra, Indonesia

Peatland (black shading) in Indonesia (Tan et al., (2021) *Int. J. Wildland Fire*)



SE Asia (5% global land area) accounts for **30% of global landuse emissions**

Scope for enhanced carbon sequestration through **restoration and protection?**

Indonesia – particularly rich in peat-based carbon stores
Much of carbon = "irrecoverable"

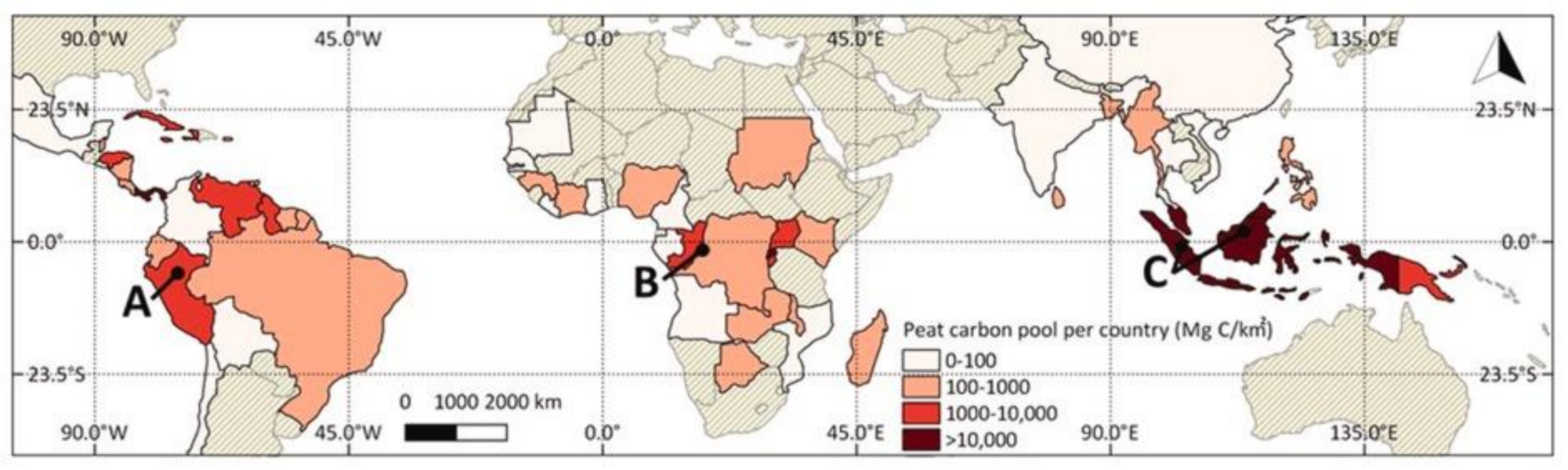
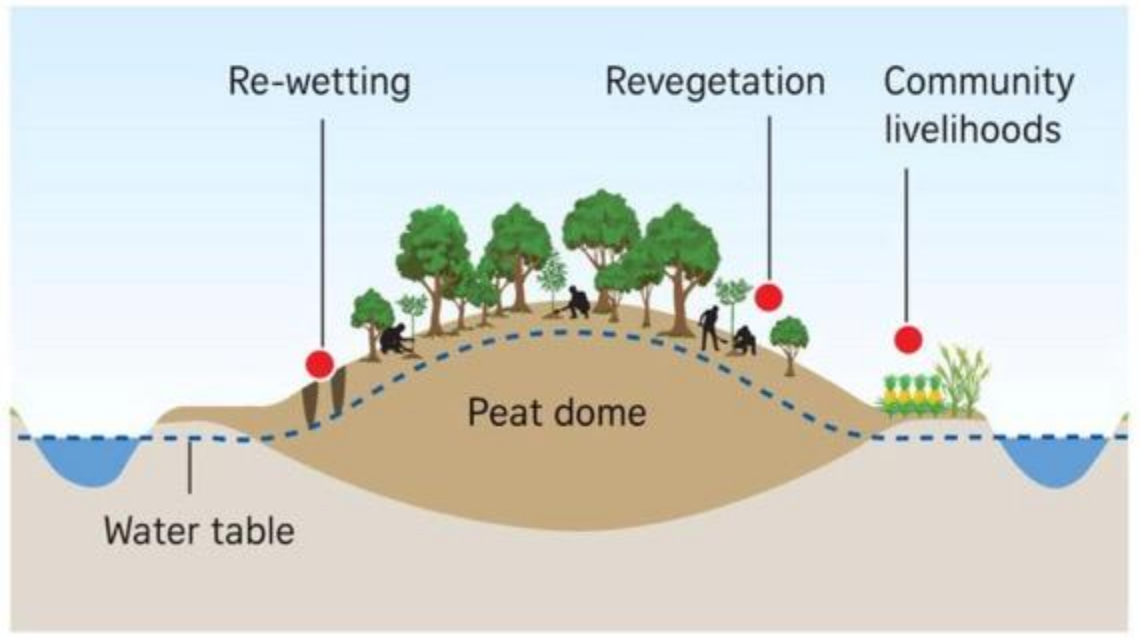


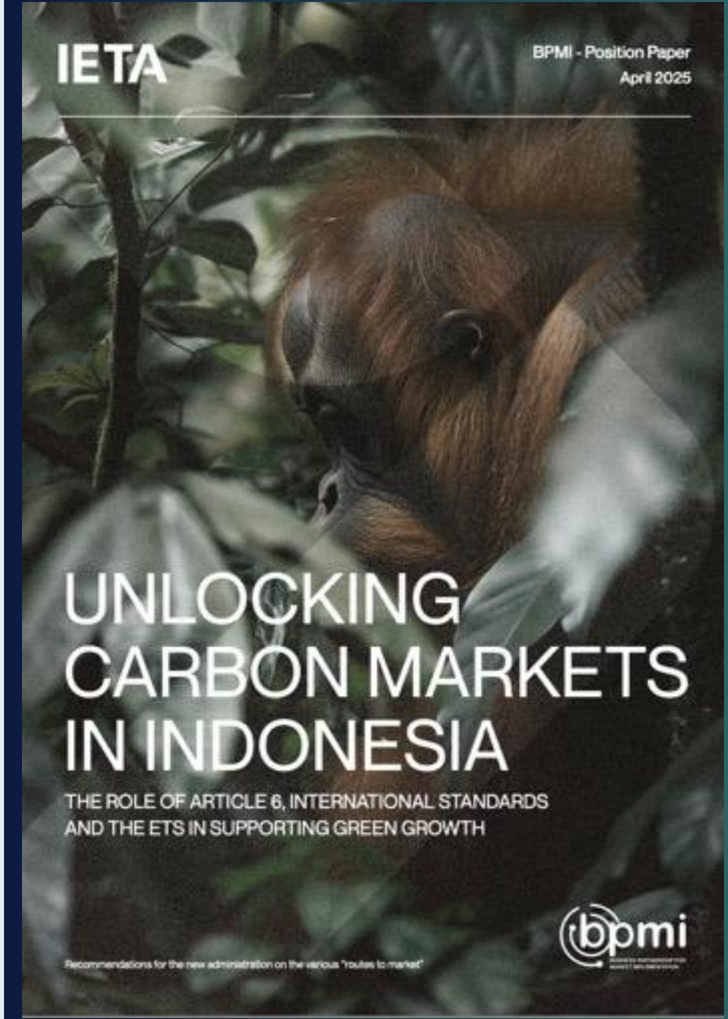
Figure shows Estimated peat carbon density (Mg C/km2) for countries in the tropics for which data exist (grey dashing represents a lack of data). A – Amazonia (Peru); B – Central Congo Basin (Democratic Republic of Congo, Republic of Congo); C – Southeast Asia (Sumatra, Indonesia, and Sarawak, Malaysian Borneo). From Cole et al (2022)

Peatlands in Southeast Asia = ca 70% total of tropical peatlands; Indonesia estimated to host around 10% of global total of peat-based carbon

Indonesia's Peatland Restoration Agency (formed in 2016 and extended to include mangroves) had a mandate to restore @ 2 million hectares (20,000 km^2) of degraded peatland and mangroves ….



Peatland restoration based on "Hydrological unit" and largely involved raising the groundwater table level & revegetation. WTD = -30 to -40cm seen as *optimum*



Peatlands in Indonesia frequently cited as a basis of future carbon-credit supplies – and thus of international finance

Peatland-based carbon credits – not just environmental assets, but also seen as strategic economic instruments for “green growth” and fiscal revenue.

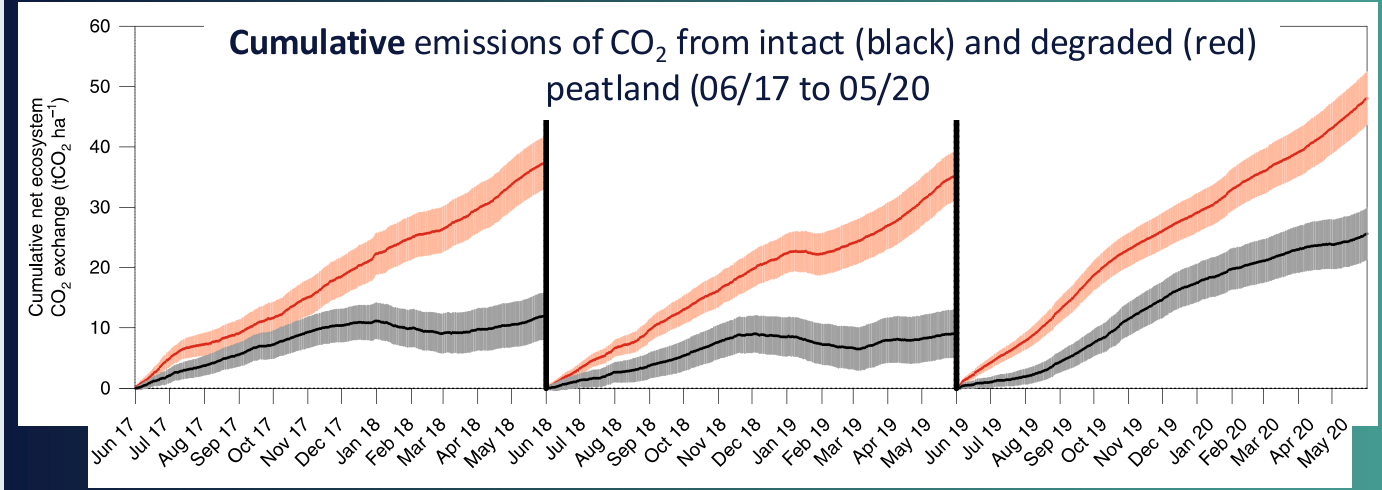
Pay for restoration and future protection …

e.g. International Emissions Trading Association (IETA) **2025** report …..

Singapore, Indonesia, Malaysia, Thailand launched carbon exchanges … Philippines & Vietnam to follow …

But…

Evidence points to **both degraded and restored peatlands** in Sumatra, Indonesia, are **net emitters of CO_2 and CH_4 to the atmosphere**



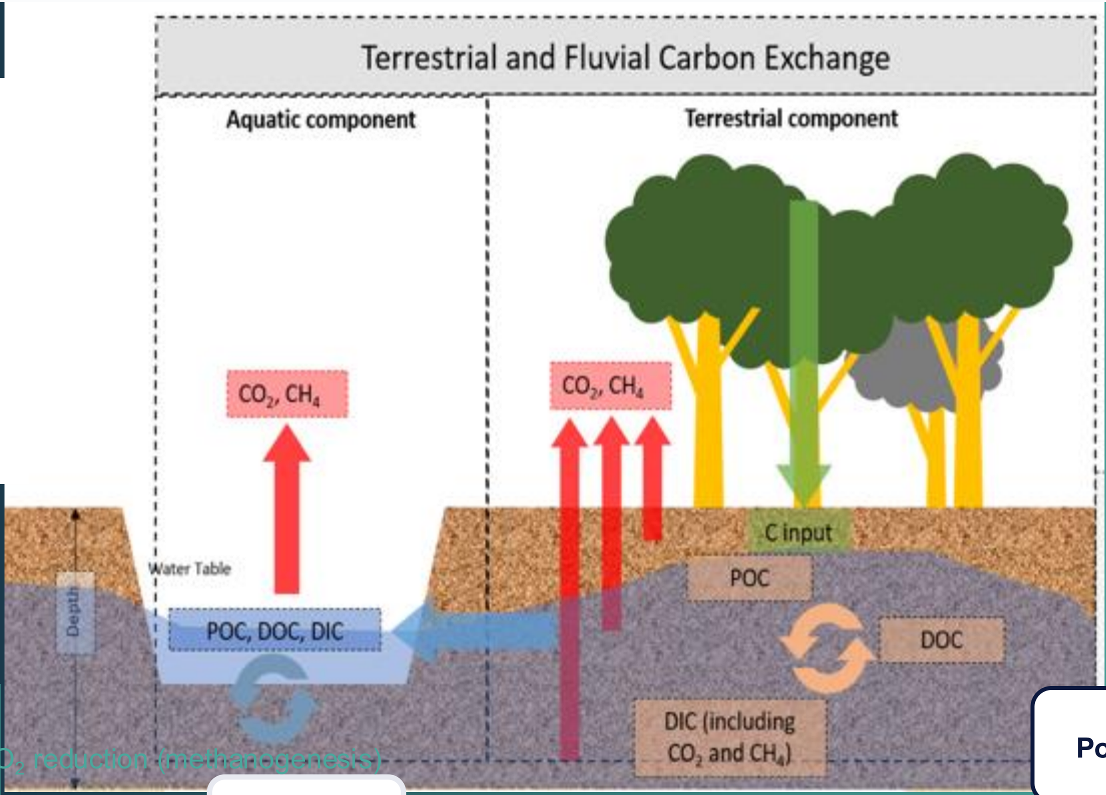
From Deshmukh et al. (2021) *Nature Geoscience*

But these data do not identify the precise sources

Tower for carbon flux measurements, APRIL planation, Kerinci, Riau Province, Sumatra

INTPREP research aimed to identify & quantify sources of carbon & to determine influence of water table depth on carbon emissions from tropical peat

Impact of raising the water table/blocking canals level on carbon export (DOC) & emissions (CO_2 & CH_4)?



Vegetation

Peat

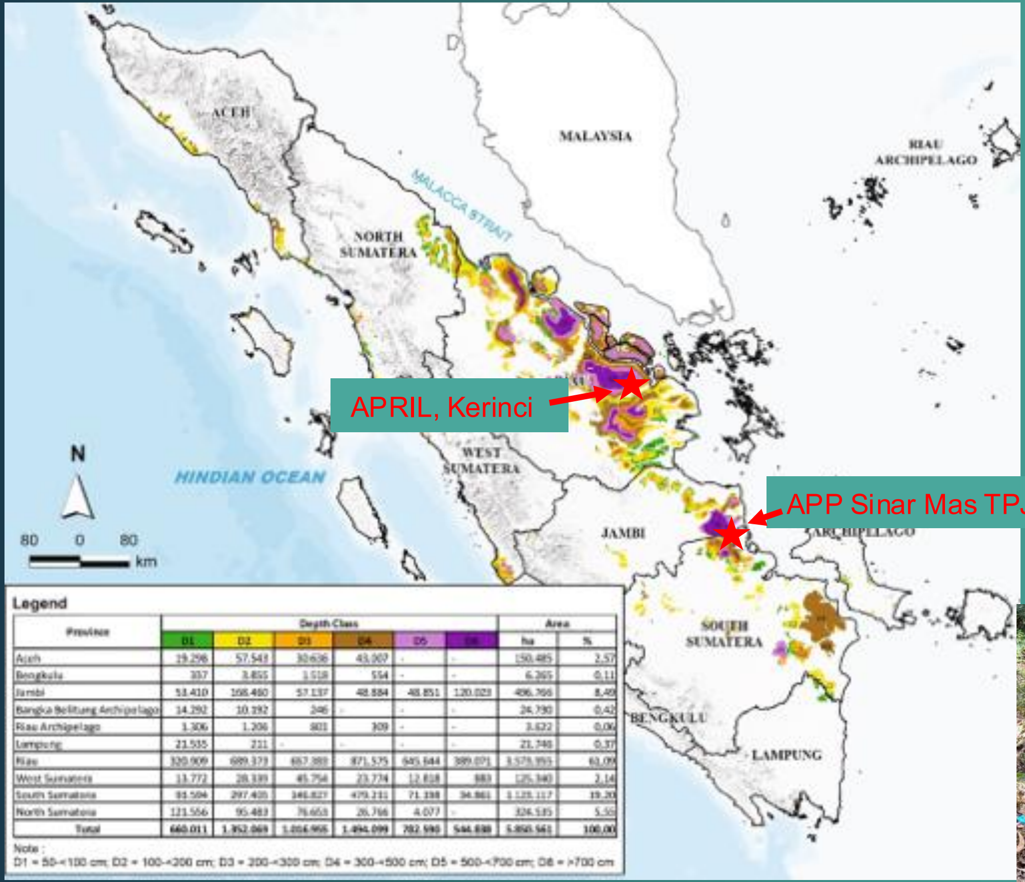
Porewater

Canals

INTPREP

APRIL

APP sinarmas



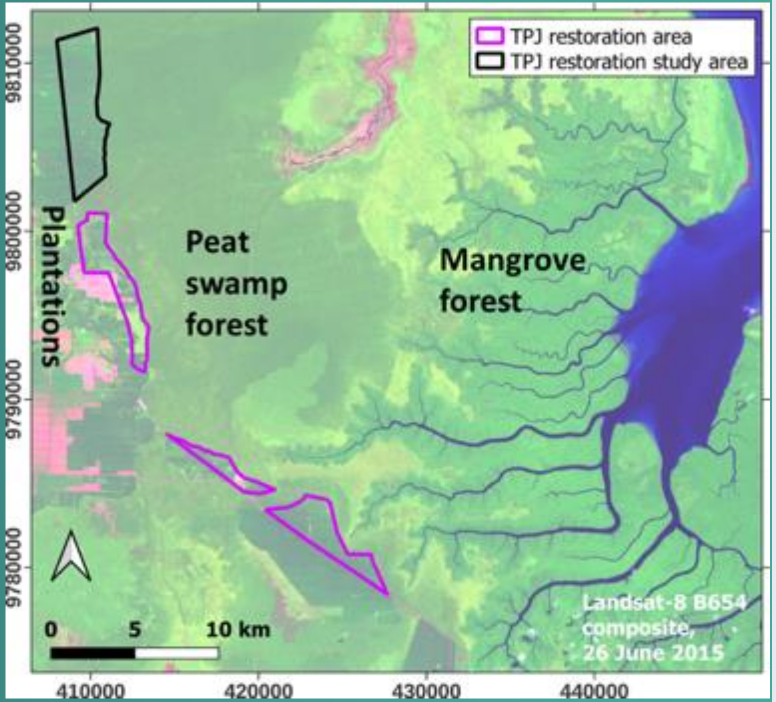
Legend

Province	Depth Class						Area	
	D1	D2	D3	D4	D5	D6	ha	%
Aceh	19.298	57.543	30.636	43.007	-	-	150.485	2,57
Bengkulu	337	3.855	1.518	554	-	-	6.265	0,11
Jambi	53.410	168.460	57.137	48.884	48.851	120.023	496.766	8,49
Bangka Belitung Archipelago	14.292	10.192	246	-	-	-	24.730	0,42
Riau Archipelago	1.306	1.206	801	309	-	-	3.622	0,06
Lampung	21.535	211	-	-	-	-	21.746	0,37
Riau	320.909	689.373	657.383	871.575	645.644	389.071	3.573.955	61,09
West Sumatera	13.772	28.339	45.754	23.774	12.818	883	125.340	2,14
South Sumatera	93.504	297.405	146.827	479.211	71.398	34.861	1.123.117	19,20
North Sumatera	121.556	95.483	76.653	26.766	4.077	-	324.535	5,55
Total	660.011	1.352.069	1.016.955	1.494.099	782.590	544.838	5.850.561	100,00

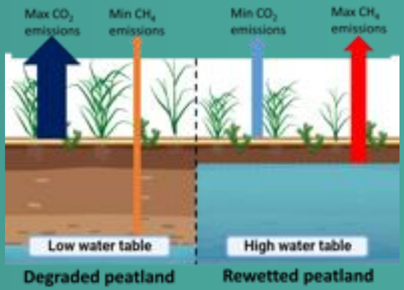
Note :
D1 = 50-<100 cm; D2 = 100-<200 cm; D3 = 200-<300 cm; D4 = 300-<500 cm; D5 = 500-<700 cm; D6 = >700 cm

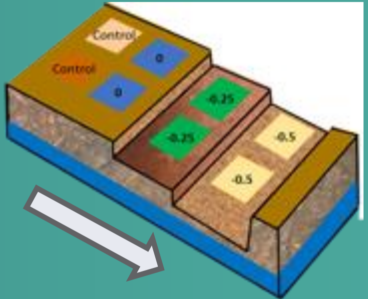
Two study sites on the island of Sumatra, Indonesia

Research site in South Sumatra (TPJ) - Asia Pulp and Paper (APP) blocked drainage canals on area of recovering *Acacia* plantation, 2015 - INTPREP monitored surface subsidence, WTD and revegetation, and set up a mesocosm experiment

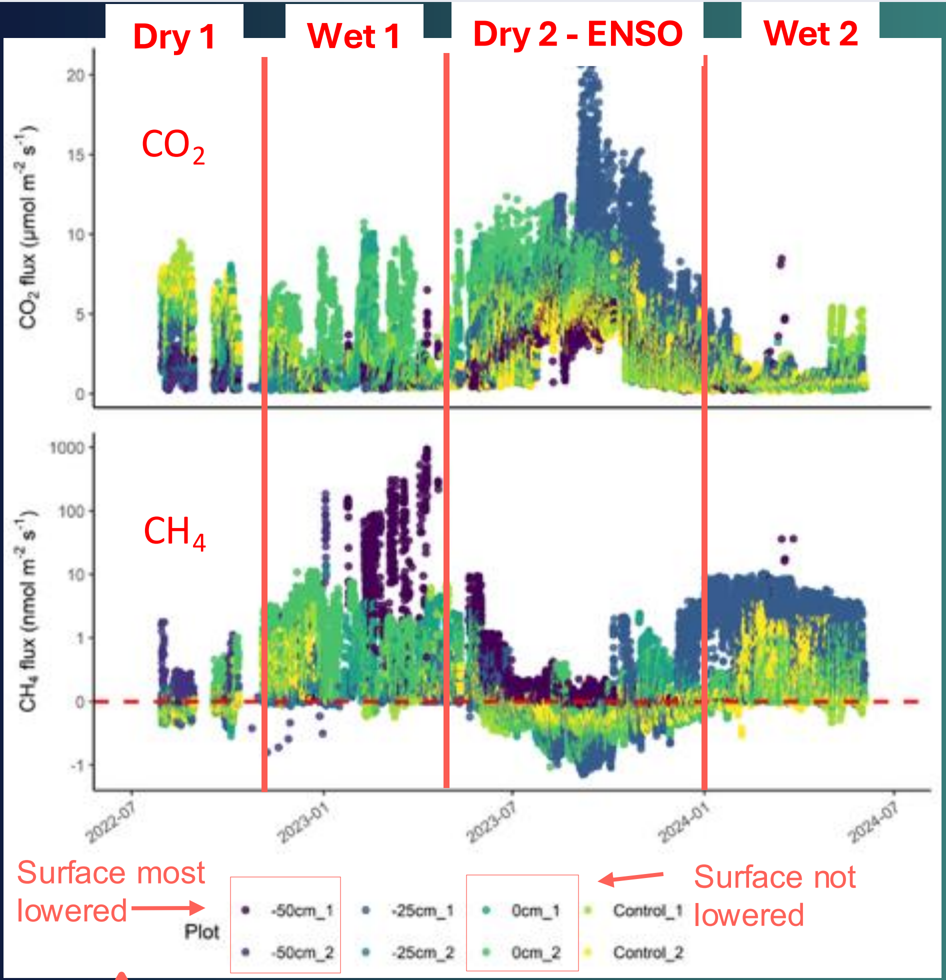


Peatland Mesocosm Experiment in a Retired Plantation in Sumatra



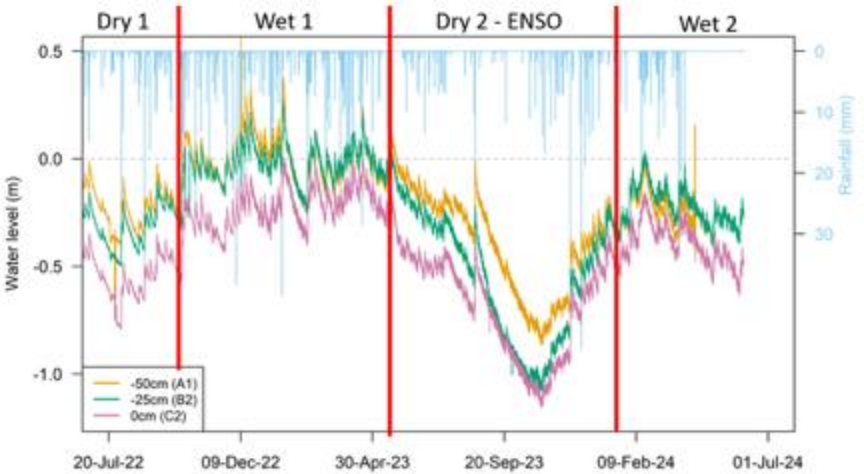


Control	Surface left intact, just cleared
0	Not lowered & top 0.25 m mixed
-0.25	Lowered 0.25m & top 0.25 m mixed
-0.5	Lowered 0.5m & top 0.25 m mixed



⚠ Log scale for CH_4

>140,000 individual CO_2 and CH_4 flux measurements (hourly data points) over 2 years.



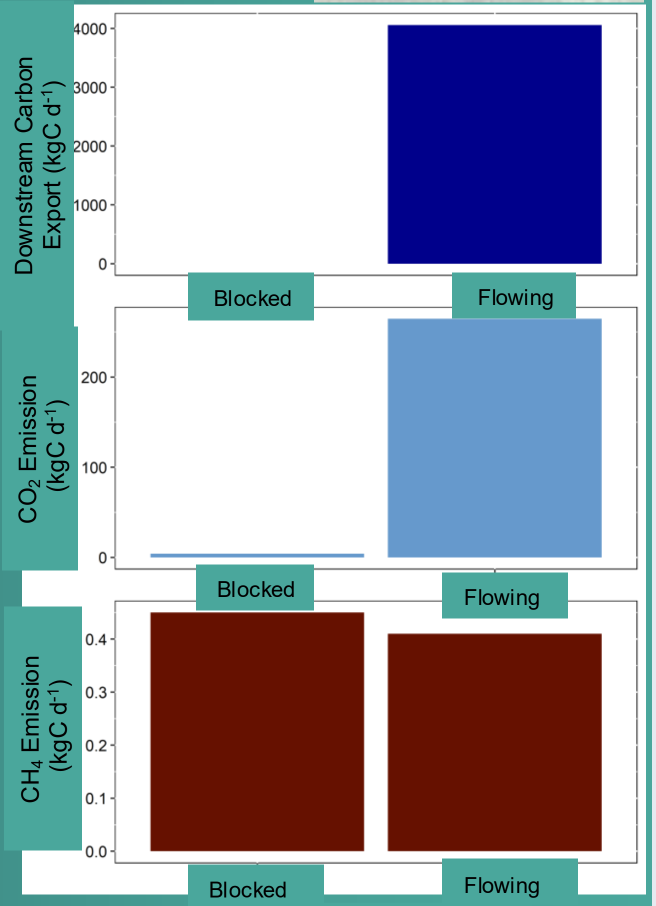
Two clear wet and dry periods, including the **2023-2024 ENSO** (Dry 2).

Water Table Level oscillated from +0.4 m (Wet 1) to -1.25 m (ENSO – Dry 2).

Blocking effects quality and quantity of fluvial export & emissions of C

Blocked canal

Flowing canal



Average $F^{14}C$ age of CO_2 measured – **from around 615 to 850 yr BP**

Taillardat et al. (2025) *GRL*

Yustina Octifanny, CGSEA PhD student

Human cost of peatland restoration (climate change mitigation)

"The Katingan Peatland Restoration and Conservation Project … seeks to protect and restore 149,800 hectares of peatland ecosystems …. based on a solid business model."
PT. Rimba Makmur Utama Project Description (2016)

Ibu Remi, repsondent ~ Mentangiai, Kapuas, Central Kalimantan

Several major companies purchased **carbon credits** ~ Shell purchased more than US$ 9 million worth of credits …

Locals such as Ibu Remi forced to give up shifting cultivation with tree planting the only replacement livelihood provided.

Poorly paid (ca US$ 400 per year) and arduous.

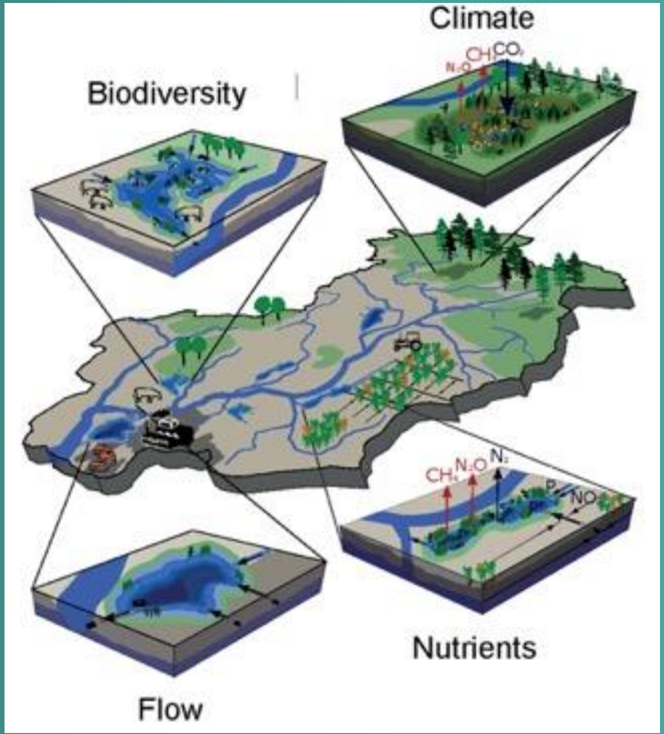
Work largely done by women – men move to find work elsewhere

Wetlands have **multiple functions** & **interconnected across scales**

To be **effective**, govererrnance must reflect these realities – and ensure adaptive & equitable outcomes

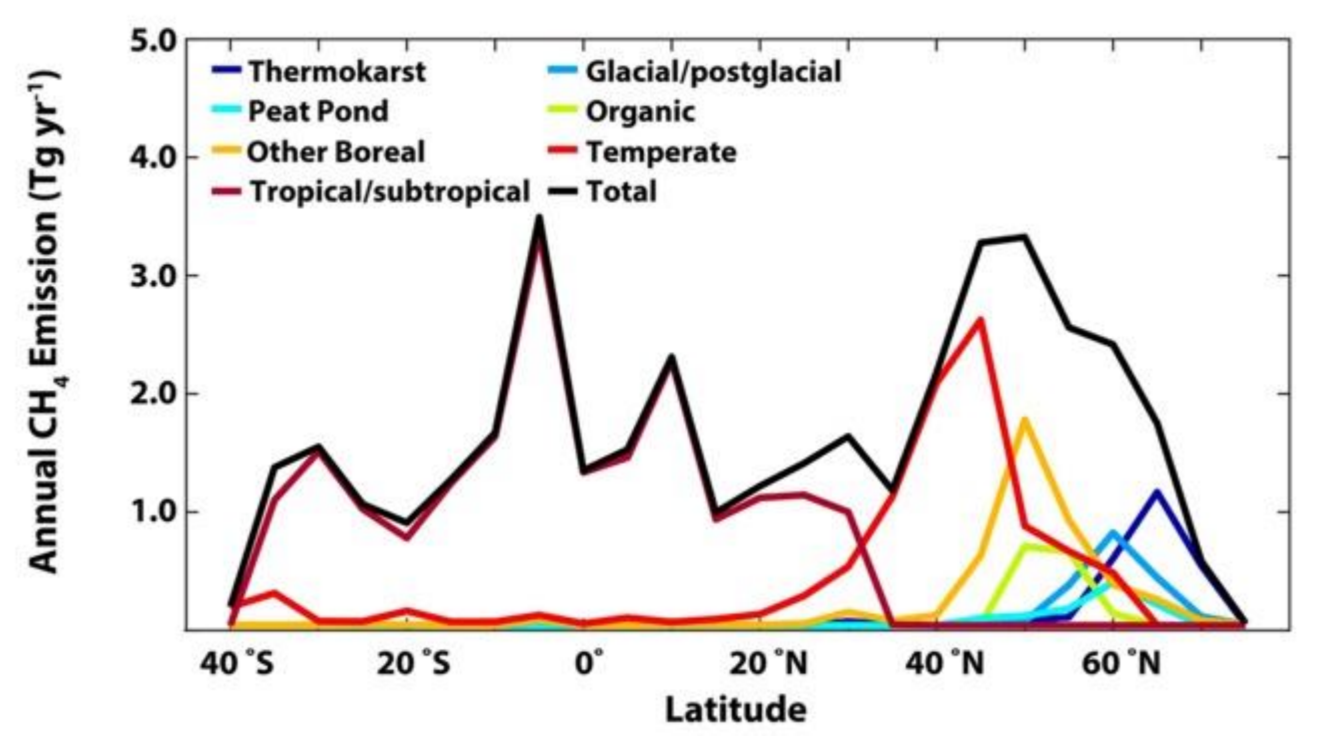
Scale is critical – must accommodate (multi)functionality and interconnectivity*, e.g. by nesting *the local* within larger spatial scales

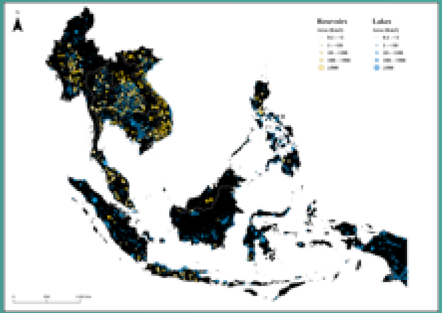
*includes telecoupling over large distances



Landscape (e.g. "**wetlandscape**") scale of governance. Figure from Hambäck et al (2023) *SoTE*

Lakes are important carbon stores – and heavily impacted by humans





Lakes and reservoirs are **major sources of CH_4 emissions – with tropical/subtropical sites accounting for ca 50% of total flux** ~ but **high uncertainty**!

Figure shows annual lake CH_4 emissions ($Tg\ yr^{-1}$) by ecoclimatic type. Note that ebullition is the predominant pathway for CH_4 emissions. From Johnson et al. (2022)

- (Tropical) wetlands are critically important, nature-based carbon sinks, **storing immense stocks of irrecoverable carbon**

- They are dynamic social-ecological systems that provide ecosystem services beyond carbon (**notably food security**!)

- Whether wetlands contribute to/mitigate global climate change is in the balance, with **understanding limited and high uncertainties**

- Need to explore ways of *governing* tropical wetlands that are **fairer, more effective and less inviting of a moral hazard** than a simple reliance on carbon markets

Thank you!