Tropical wetlands: solutions for or drivers of climate change?

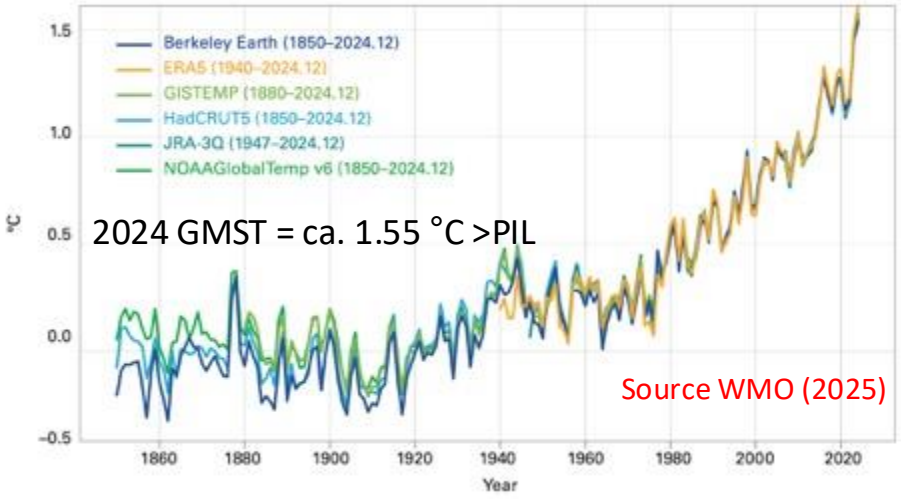
David Taylor
Department of Geography
National University of Singapore

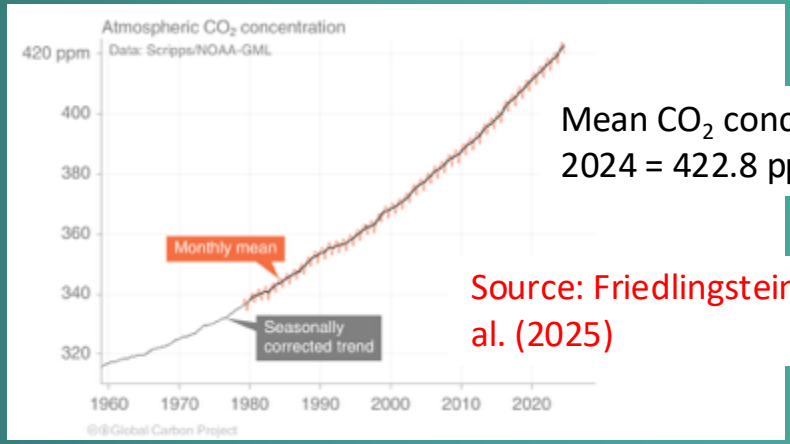
CGSEA
CARBON GOVERNANCE IN SOUTHEAST ASIA

https://cgsea.org/

INTPREP

NUS
National University of Singapore



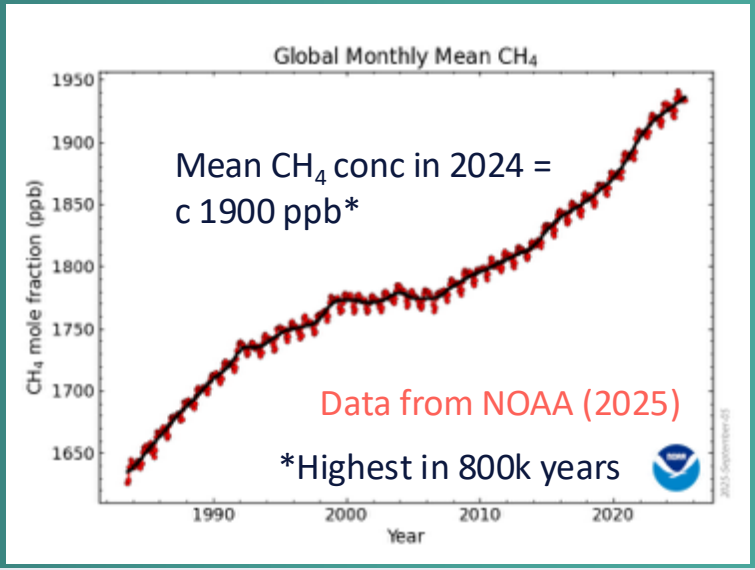


Atmospheric CH_4 concentrations now around 165% greater than PIL - highest levels in last 800,000 years

Wetlands a **major but uncertain driver of growth in atmospheric CH_4** (ca. 25% of total emissions), with **wetland modification in the tropics a predominant cause**

Warming potential of CH_4 >>> CO_2 over a 20-year horizon

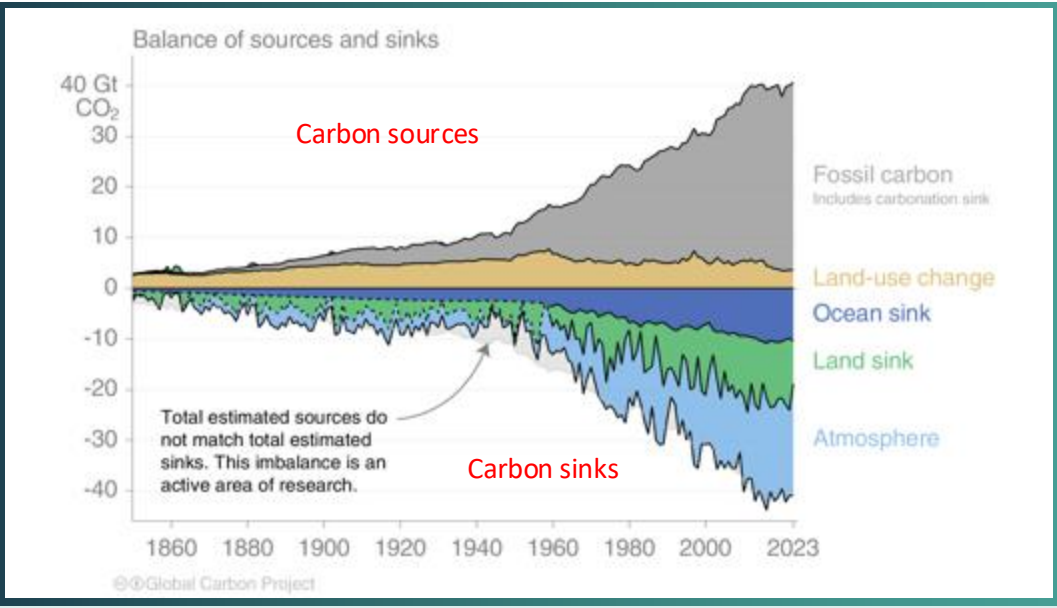
Saunois et al. (2025)



Rising carbon emissions result in an expanded atmospheric carbon sink

Annual carbon emissions & their partitioning

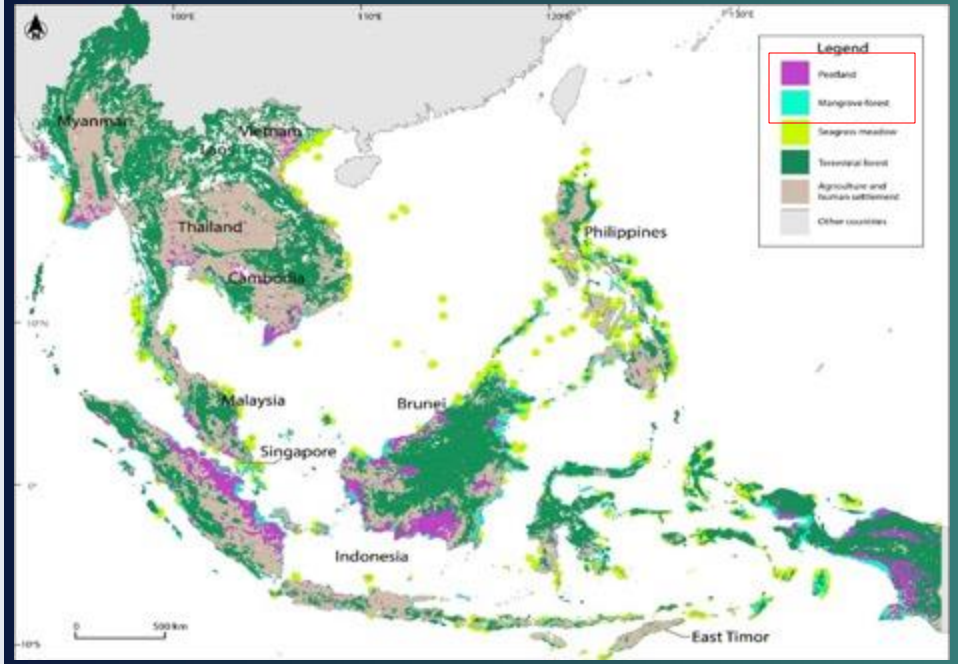
Source: Friedlingstein et al. (2025) Global Carbon Budget 2024

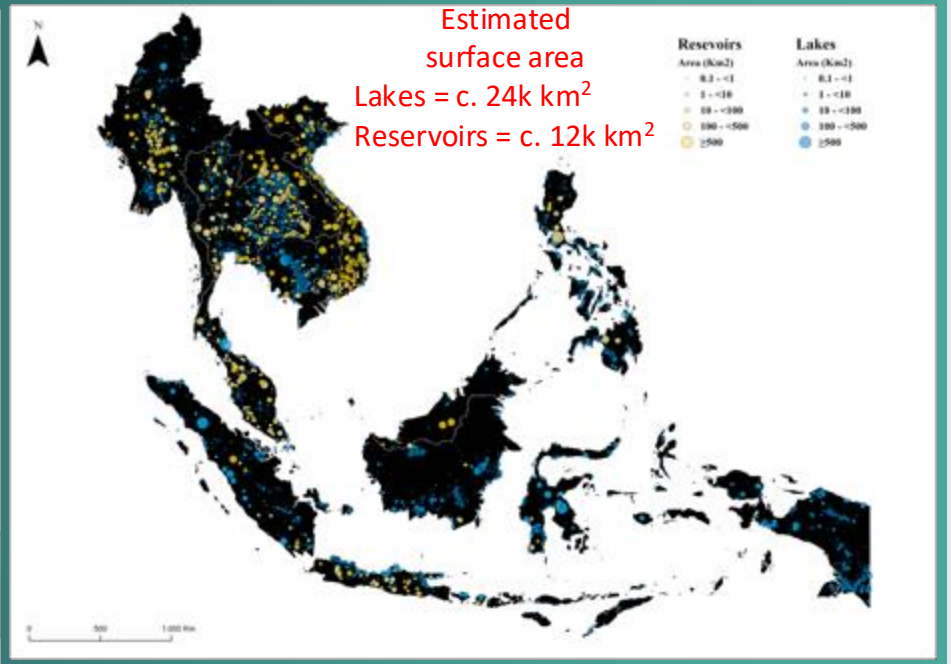


Effective climate mitigation requires achieving *at least* net zero emissions of CO_2 **by 2050** - can only be achieved by a combination of **reduced emissions** and **increased sequestration**

Countries around the world are investing in related technologies including environmental **restoration** and **rehabilitation**

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

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

Wetlands have unique attributes as nature-based carbon sinks ….

Atmospheric CO_2

Atmospheric emissions of CO_2 & CH_4

~1.1 Pg C yr^{-1}

Fluvial C (dCO_2, DOC, DIC, P-C)

Fluvial C (dCO_2, DOC, DIC, P-C)

~1.0 Pg C yr^{-1},

C flux

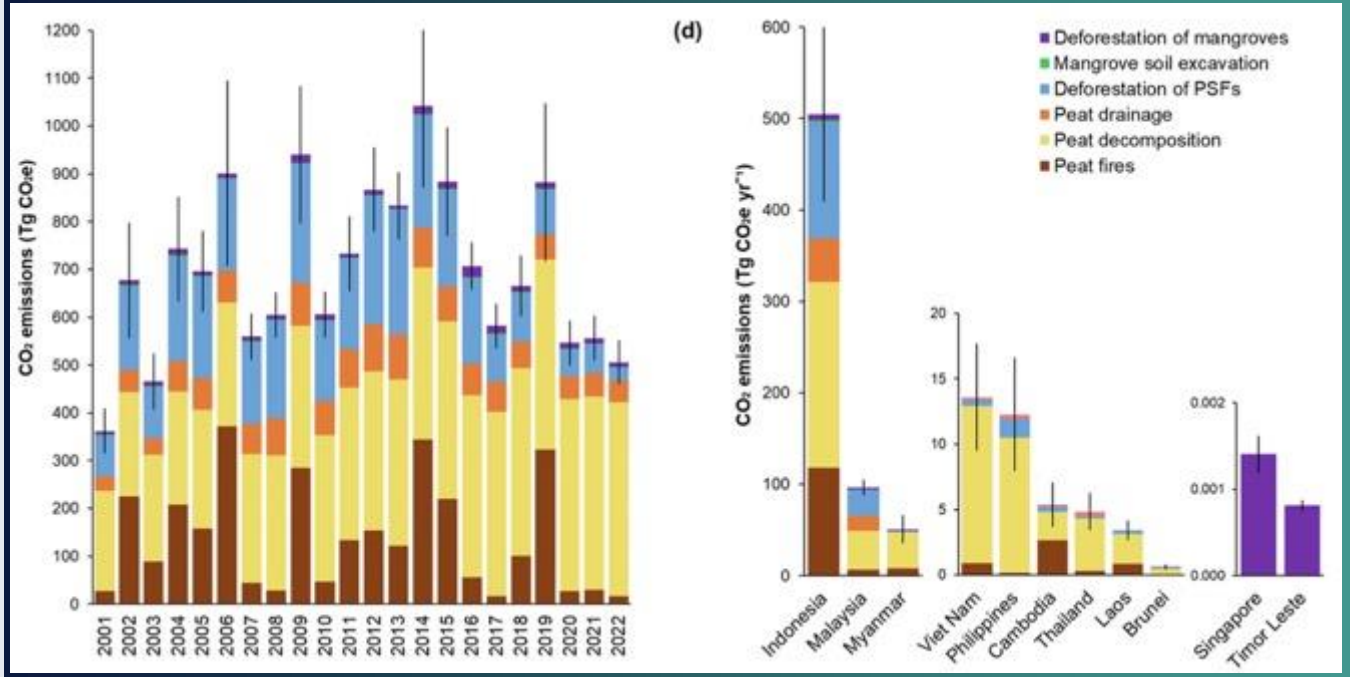
C stock

Sedimentary C (OM, IM)

0.2–1.6 Pg C yr^{-1}

Wetlands:
biogeochemical factories
C stocks >>>>>> C flux
Lateral connections
C stocks = *irrecoverable* C
High uncertainty in levels

What is the true potential of nature-based wetland carbon sinks in SE Asia?

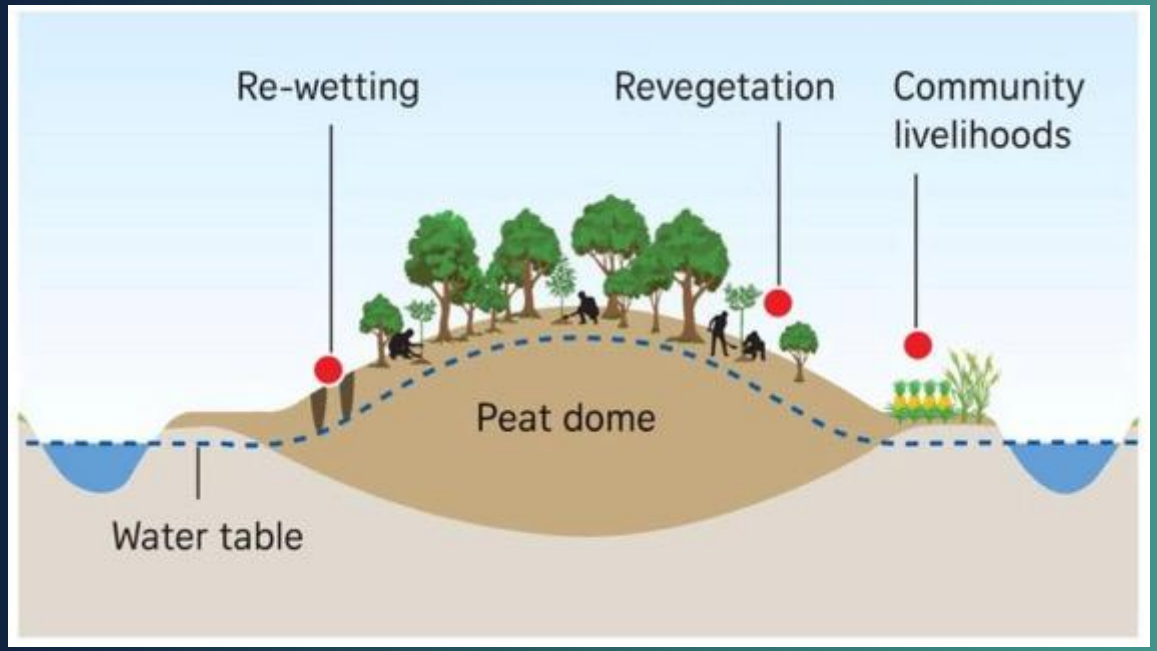


CO_2 emissions from degraded peatland and mangroves in SE Asia (from Sigit et al., *Nature Comm*, 2025)

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

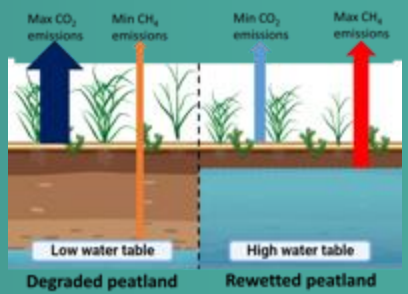
Scope for enhanced carbon sequestration through **restoration and protection**

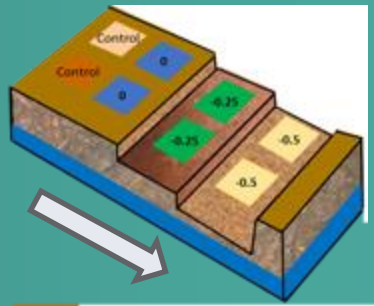
Indonesia's Peatland Restoration Agency (formed in 2016 and extended to include mangroves) had a mandate to restore @ 2 million hectares (20,000 km2) of degraded peatland and mangroves ….



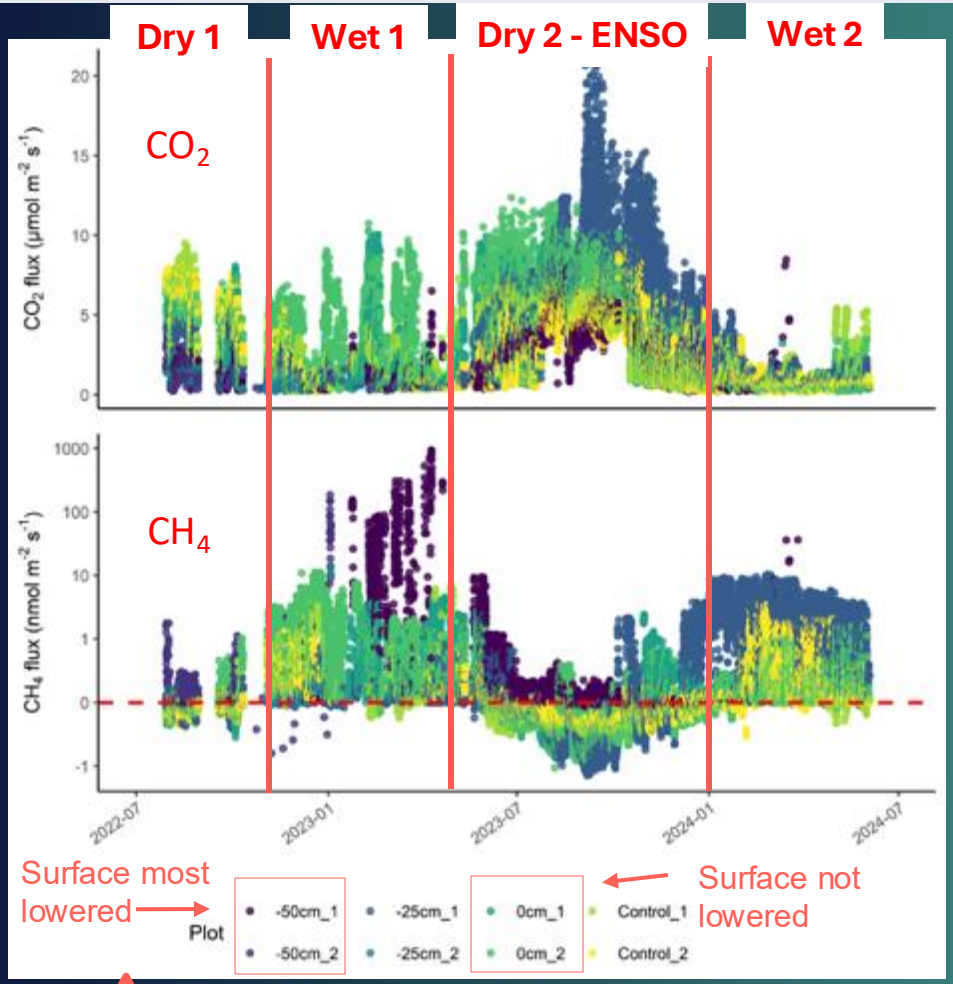
Peatland restoration based on "Hydrological unit" and largely involved raising the groundwater table level & revegetation

Peatland Mesocosm Experiment in a Retired Plantation in Sumatra



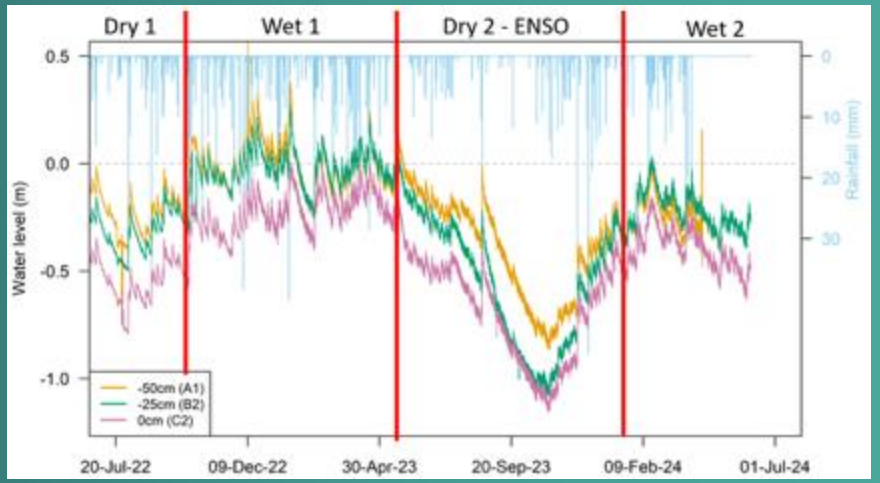


Control	Surface left intact, just cleared
0	Not lowered & top 0.25 m mixed
-0.25	Lowered 0.25m & top 0.25 m mixed
-0.5	Lowered 0.5m & top 0.25 m mixed



Log scale for CH_4

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



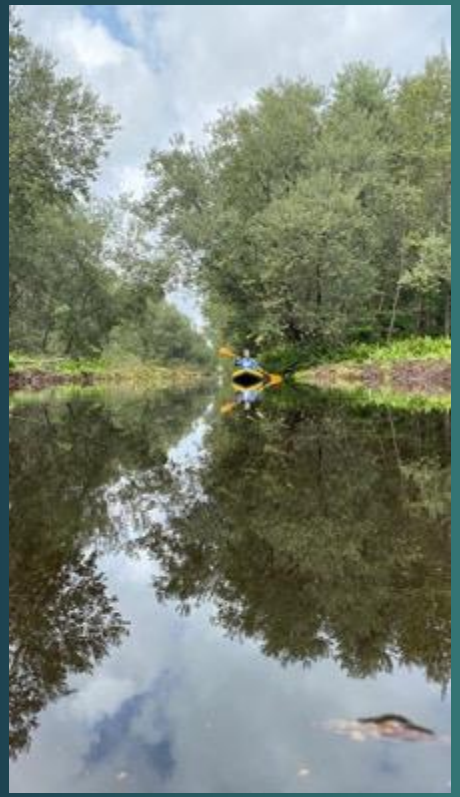
Two clear wet and dry periods, including the **2023-2024 ENSO** (Dry 2).

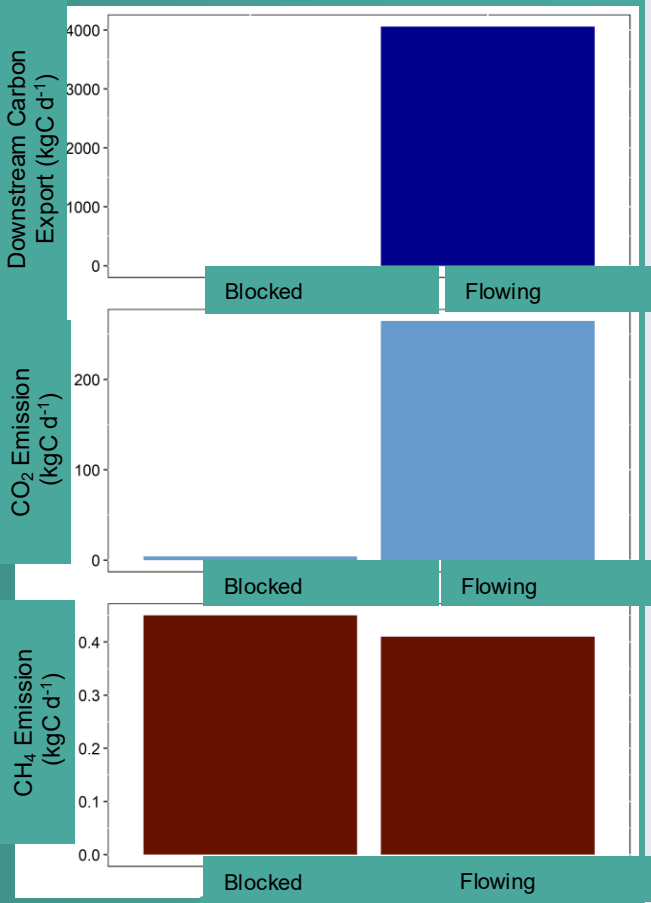
Water Table Level oscillated from +0.4 m (Wet 1) to -1.25 m (ENSO – Dry 2).

Fluvial export of C is considerable. Blocking effects quality and quantity of C emissions

Blocked canal

Flowing canal

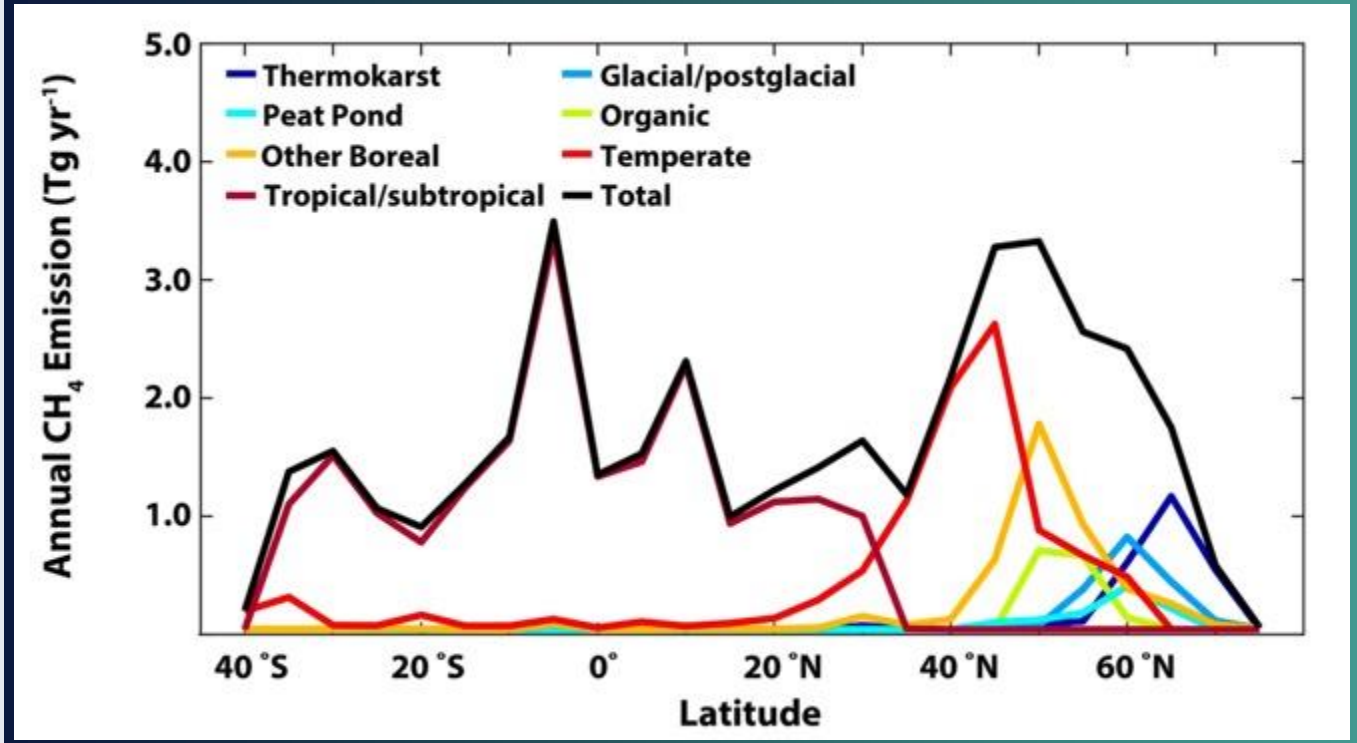


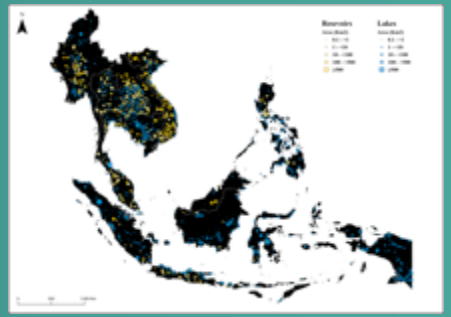


Average $F^{14}C$ age of CO_2 measured – from around 615 to 850 yr BP

Taillardat et al. (2025) *GRL*

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)

What if lakes in higher latitudes are becoming more like tropical lakes?

As drivers of lake water quality (temperature, nutrient availability, degree of stratification, biotic composition, direct anthropogenic pressures) cohere …..

Are the responses of lakes becoming increasingly synchronized (the Moran effect)?

Is the modularity of lakes declining?

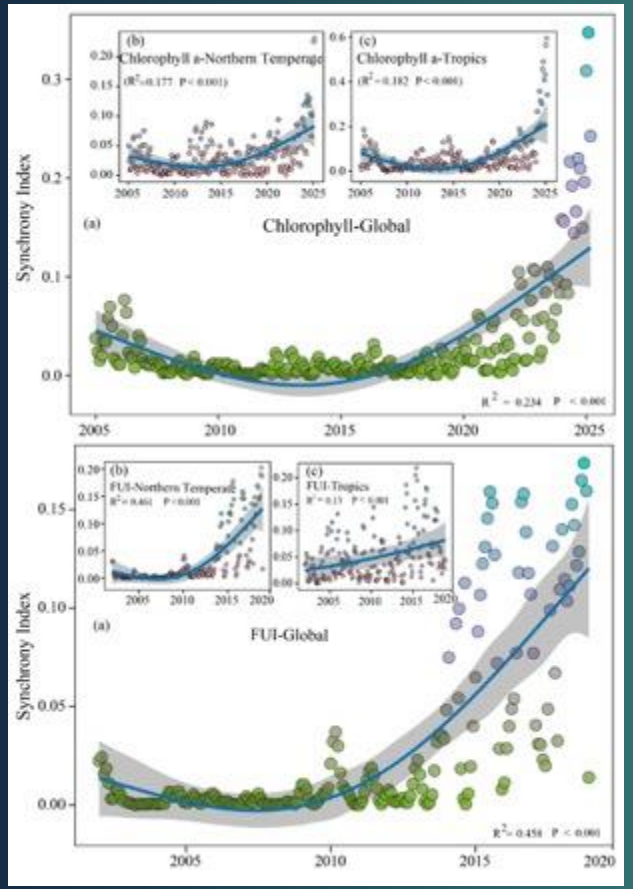
If so, what are the implications for

C (especially CH_4) fluxes and stores (& thus the climate change PB), and

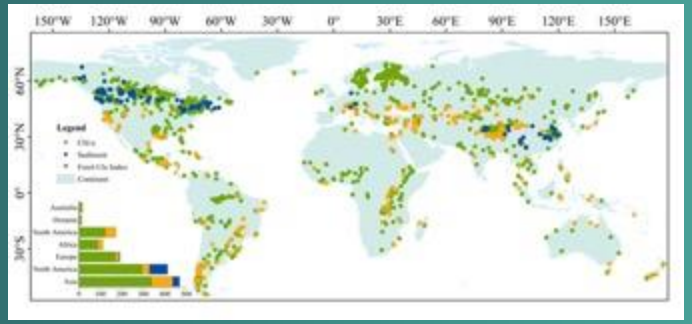
governance ~ lakes as interlinked, wetland planetary commons?

Study of global lake synchrony and modularity

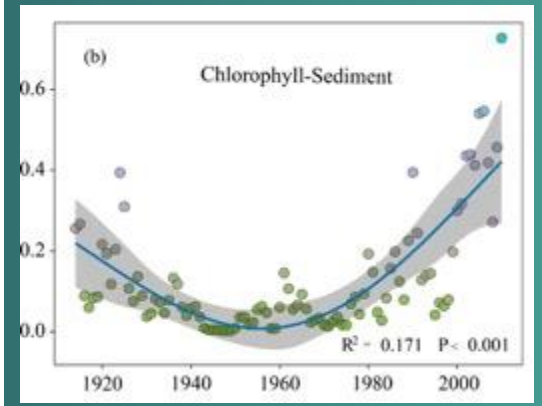
Rising synchrony of lake ecosystems from satellite records. Shaded areas denote 95% confidence intervals. Together, these records demonstrate accelerating ecological coherence in lake systems, indicating that local variability is giving way to globally coupled dynamics.

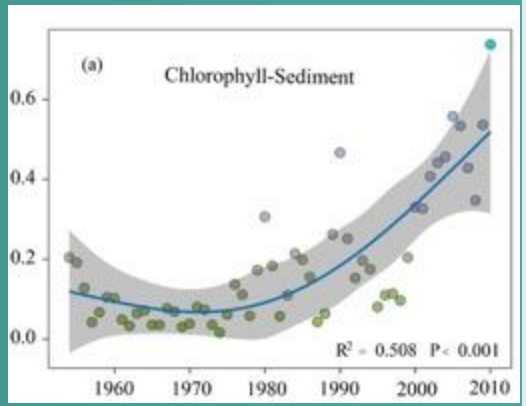


Synchrony index = Loreau ϕ (phi) metric



Locations of ca 2000 lake-based data. Note notable gaps remain..





Synchrony changes in sedimentary Chl-a
Since ca 1910 (left) and since ca 1950 (right)

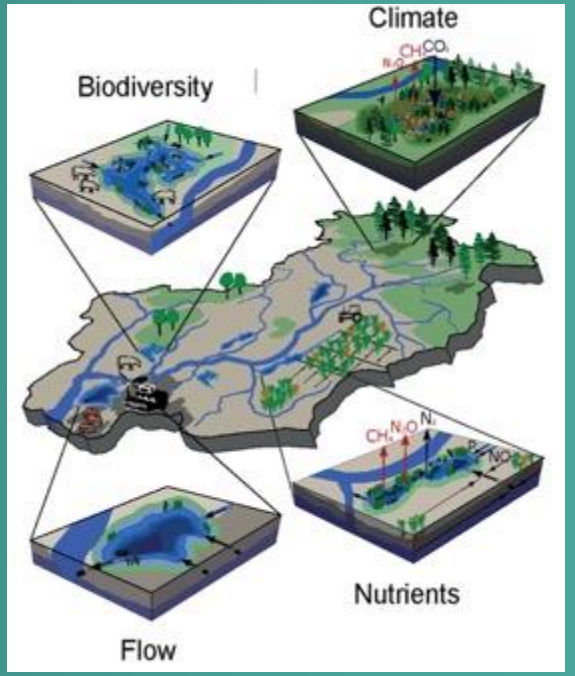
Work in progress by Zhang Ke, Han Yaoyao *et al*

Nature-based carbon sinks: **multiple functions** & **interconnected**

Particularly true of wetlands

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

E.g., *wetlandscapes* approach better accommodates (multi)functionality and interconnectivity*, enables a predictive approach and allows nesting within larger scales of governance (“Matryoshka dolls”)



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

*NB interconnections – including rivers - are also sites of C flux and accumulation, enable transfer of biota, pollutants etc

- (Tropical) wetlands are critically important, nature-based carbon sinks, storing immense stocks of irrecoverable carbon
- They are dynamic social-ecological systems (but perhaps becoming less distinctive)
- They are planetary commons, with the potential to contribute to/mitigate global climate change
- To ensure sustainability, restoration should reflect wetland interconnectivity & importance across scales & should be mindful of C-sink properties


Thank you!