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Impact of fire on vegetation, soil microbes and CH_4 emission from a degraded tropical peatland

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Introduction

- Tropical peatlands cover 0.25% of the Earth's land surface and stores 3% of the global soil carbon (C). In Southeast (SE) Asia, peatlands stores approx. 88.6 Gt C or equal to 15-19% of the global peatland C pool (Fig. 1)
- However, over decades, these have been degraded for other land use purposes, mainly by employing drainage (to lower water table) and fire (to remove vegetation)
- Such disturbances results in drying of peat surface, making these degraded tropical peatlands more fire-prone
- Importantly, **the extent of these degraded areas have increased to almost 10% (~1.42 Mha) of the total peatland area in SE Asia** (Fig. 2)

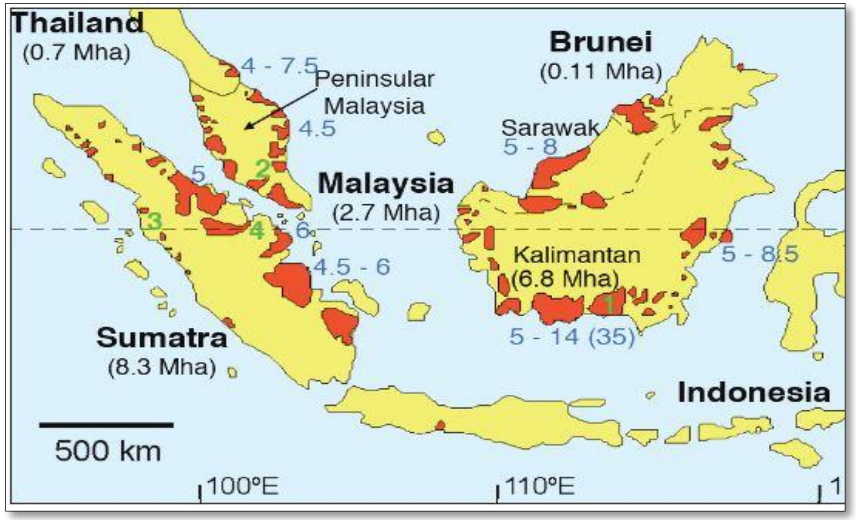


Fig. 1: Tropical peatland distribution in SE Asia (Page et al., 2004)

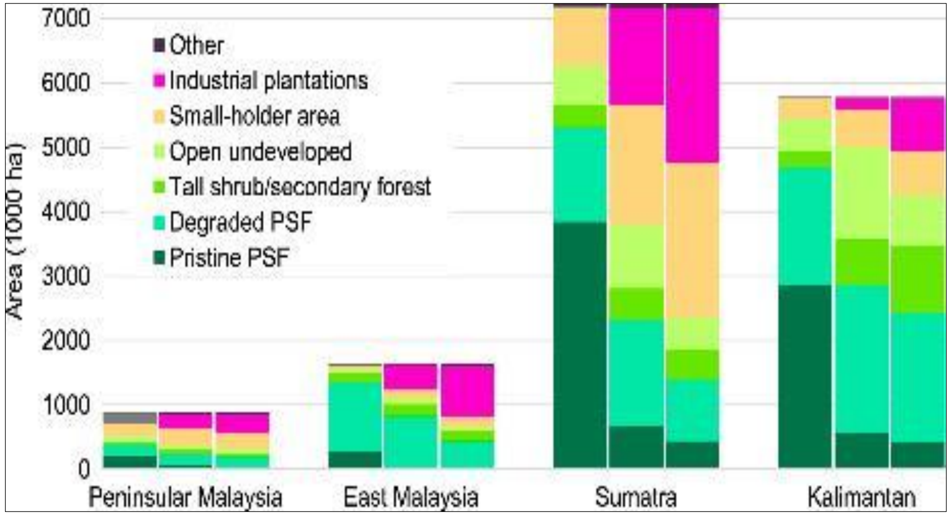


Fig. 2: Land use change during 1990-2007-2015 (left-centre-right) in tropical peatlands of SE Asia (Miettinen et al. 2016)

Background

- The degraded tropical peatlands areas experience frequent flooding, due to enhanced peat oxidative decomposition, and gets covered mainly with flood tolerant vascular plant species such as ferns and sedges
- In particular, the **role of sedges in plant-mediated gas transport** to the atmosphere has been recognized as a significant CH_4 emission pathway in northern peatlands, however, **in the Tropics this is still unknown** (Fig. 3)
- Additionally, the carbon compounds secreted via root exudates may attract **methane producing microorganisms (methanogens) in Rhizo-compartments** (Endosphere, Rhizoplane, Rhizosphere) of sedges (Fig. 4)
- Therefore, in view of the above, our hypothesis are:
  - Sedges in degraded tropical peatlands are a significant source of CH_4, transporting it directly into the atmosphere as in northern peatlands, and
  - Rhizo-compartments of sedges harbour more methanogens compared to other plant species (ferns)

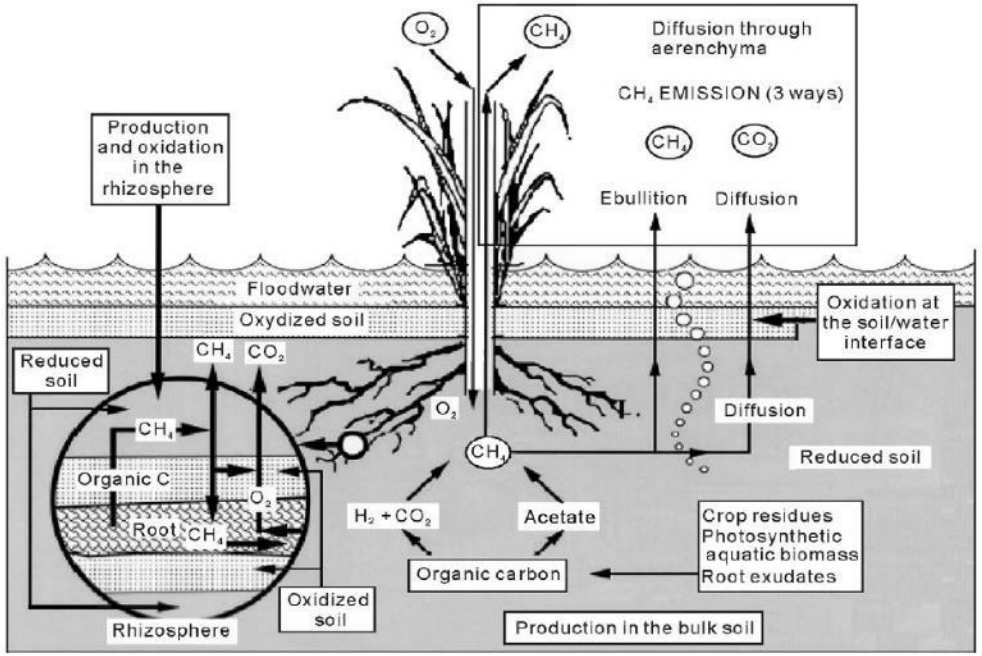


Fig. 3: Schematics for plant-mediated CH_4 emission, production & consumption in wetlands (Lai, 2009)

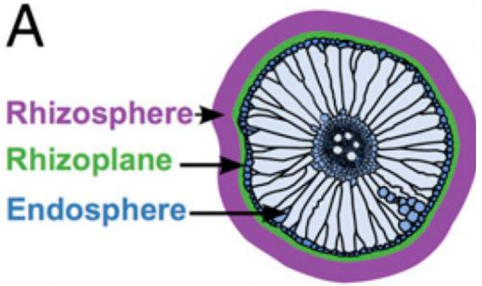


Fig. 4: Rhizo-compartments schematics (Edwards et al. 2015)

Material & Methods

- **Study site:** We identified a suitable fire degraded tropical peatland site (B1-3; Fig. 5) in Belait District, Brunei Darussalam (4°28’40” N, 114°18’19” E), primarily covered with ferns and sedges.

- **CH_4 flux:** Using manual dynamic chamber (transparent clear acrylic tube) method and a portable GHG analyser (Picarro, GasScouter, USA), we measured CH_4 emission (with & without vegetation; Fig. 6) in each plots (B1-3) as well as plots along the transect (Burnt transect as in Lupascu et al.) during each field campaigns (in Aug’18, Oct’18, Jan’19, and July’19) to capture the seasonal and spatial variation (n=180).

- **Porewater parameters:** pH, Temperature, Electrical conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), and Salinity were measured with a YSI 556 MPS in piezometers during each field campaigns.

- **Peat samples for microbial analysis:** Peat samples from burnt and nearby non-burnt site were collected from different depths (0-5cm, 35-40cm, 95-100 cm below the surface) in Oct’18. At the same time, sample from Rhizo-compartments (Endosphere, Rhizoplane, Rhizosphere) of plants (sedge, ferns) were extracted using sonication method modified from Edwards et al. 2015. Thereafter, DNA sample were extracted using Zymo DNA extraction kit as per manufacturers protocol, and 16s rRNA (V4-5 region) were amplified using universal primer and PCR. Amplified product were sequenced using Illumina MiSeq platform, and the read count sequences were processed using DADA2 and PICRUST pipeline.

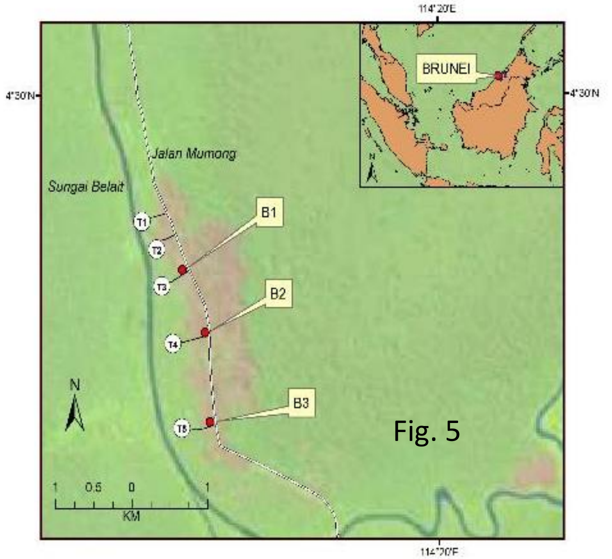


Fig. 5

Fig. 6

Results

- We found that the **sedge contributed >70% of total CH_4 emissions**, **with significant seasonal** ($p<0.001$) **and spatial** ($p<0.001$) **variation** (Akhtar et al. submitted to PNAS)
- Values ranged from 1.22 ± 0.13 to 6.15 ± 0.57 $mgCH_4m^{-2}hr^{-1}$ during dry and wet period (Fig. 7), respectively, and from 1.12 ± 0.24 to 4.33 ± 0.56 $mgCH_4m^{-2}hr^{-1}$ along the transect (Fig. 8)

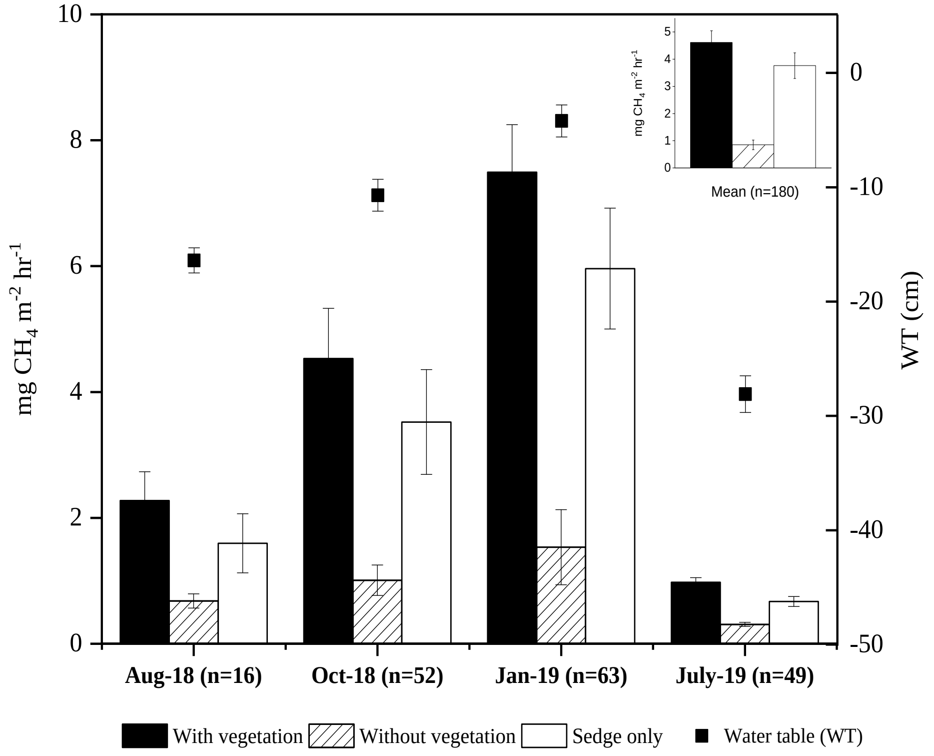


Fig. 7: Seasonal variation in Sedge-mediated CH_4 emissions and water table level between dry (August 2018 and July 2019) and wet period (October 2018 and January 2019). Inset graph is the overall mean for CH_4 flux over the sampling period

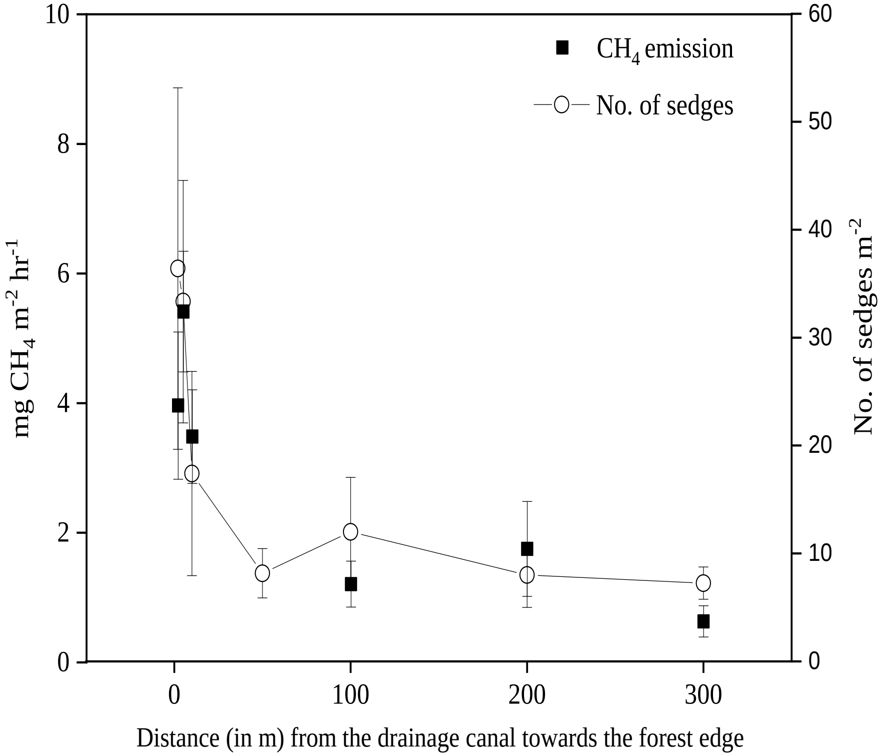


Fig. 8: Spatial variation in sedge-mediated CH_4 emissions and number of sedges per m^2 along the transect (at 2m, 5m, 10m, 100m, 200m, 300m away from the drainage canal)

Sedge-mediated CH_4 emission correlates with

- Spatially, sedge-mediated CH_4 emission strongly correlated with **number of sedges** ($p<0.001$) **water table** ($p<0.001$) and **distance from drainage canal** ($p<0.001$) (Table 1)
- Porewater parameters also affected CH_4 emissions where **pH** ($p<0.001$) and **Salinity** ($p<0.05$) showed strong significant correlations (Table 2)

Table 1

	CH_4	**Ns**	**Hs**	**SWC**	**T**	**WT**
Number of sedges (Ns)	0.49**					
Height of sedges (Hs)	0.19*	-0.12				
Soil Water Content (SWC)	0.41**	0.09	-0.06			
Soil temp. at 5 cm depth (T)	0.08	0.24*	-0.18*	-0.03		
Water table (WT)	0.78**	0.44**	0.22*	0.25*	-0.03	
Distance from canal (D)	-0.45**	-0.29**	-0.11	0.01	-0.03	-0.50**

significant at *p < 0.05, **p < 0.001

Table 2

	CH_4	**pH**	**Temp.**	**DO**	**EC**	**TDS**	**Salinity**
pH	-0.67**						
Water Temp.	-0.41	0.56*					
DO	0.01	0.07	0.43*				
EC	-0.39	-0.07	0.05	-0.03			
TDS	-0.37	-0.03	0.07	-0.02	0.97**		
Salinity	-0.51*	0.20	0.21	-0.06	0.80**	0.83**	
DOC	-0.17	0.19	0.18	-0.44*	0.13	0.16	0.22

significant at *p < 0.05, **p < 0.001

Sedges may contribute 0.01–0.53 $TgCO_2$-eq yr^{-1}

- At landscape level, the CH_4 emission from degraded tropical peatland areas may contribute a mean of **236.9 ± 130.6 $kgCH_4$ ha^{-1} yr^{-1}** (Fig. 9), which is **2–6 times higher** when compared to intact peat-swamp forests and almost **34 times higher** when compared to similar land-use

- At regional level, as per our back of the envelope calculation, sedges on degraded tropical peatland in Southeast Asia may contribute an estimated 0.002–0.020 $TgCH_4$ yr^{-1} or 0.006–0.532 $TgCO_2$-equivalent yr^{-1} (Table 3)

Table 3

Scenarios	Open land* area in 2015 (in Ha)	Sedge basal-area (m^2/Ha)	Regional area covered by sedges (Ha)	CH_4 flux ($mgCH_4$ m^{-2} hr^{-1})	CH_4 flux ($kgCH_4$ ha^{-1} yr^{-1})	$TgCH_4$ yr^{-1}	$TgCO_2$-eq yr^{-1}
Scenario 1	1419480	25.9	3677	0.56	49.5	0.0002	0.006
Scenario 2	1419480	176.8	25096	1.39	121.8	0.0031	0.104
Scenario 3	1419480	25.9	3677	1.75	153.5	0.0006	0.019
Scenario 4	1419480	176.8	25096	7.11	622.9	0.0156	0.532

*Open-undeveloped class includes Ferns/shrubs, seasonal water, clearance cover as in Miettinen et al. 2016

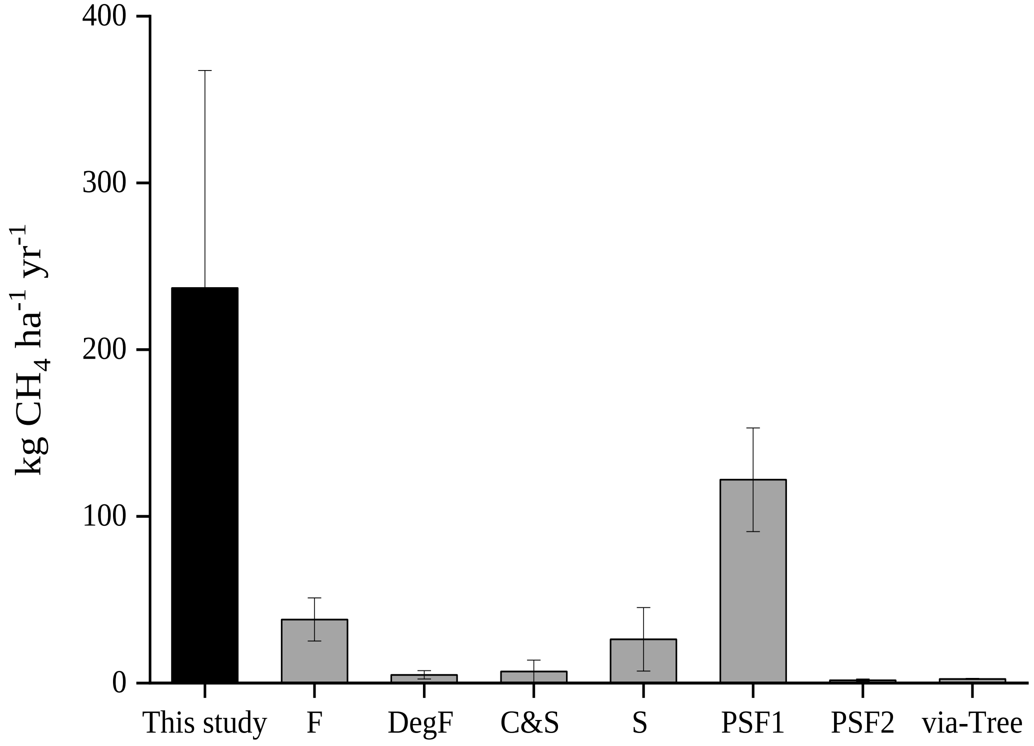
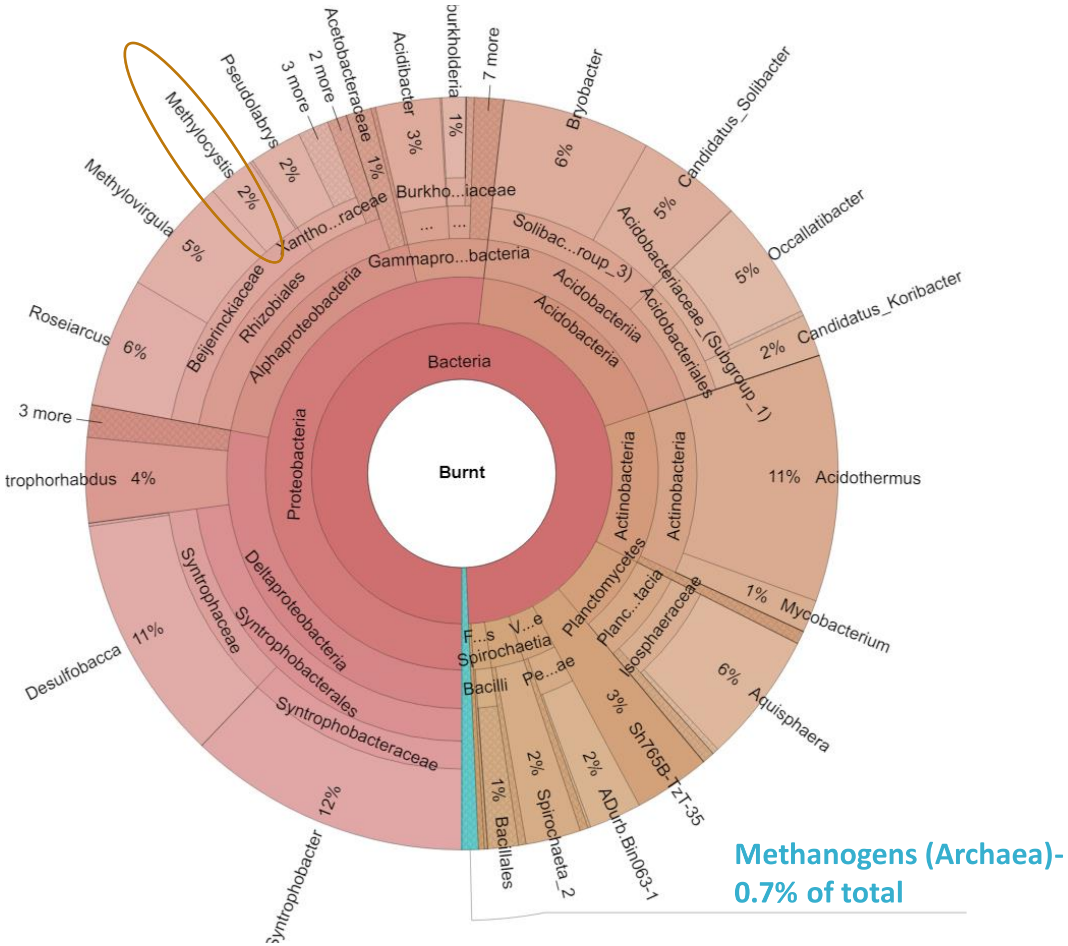
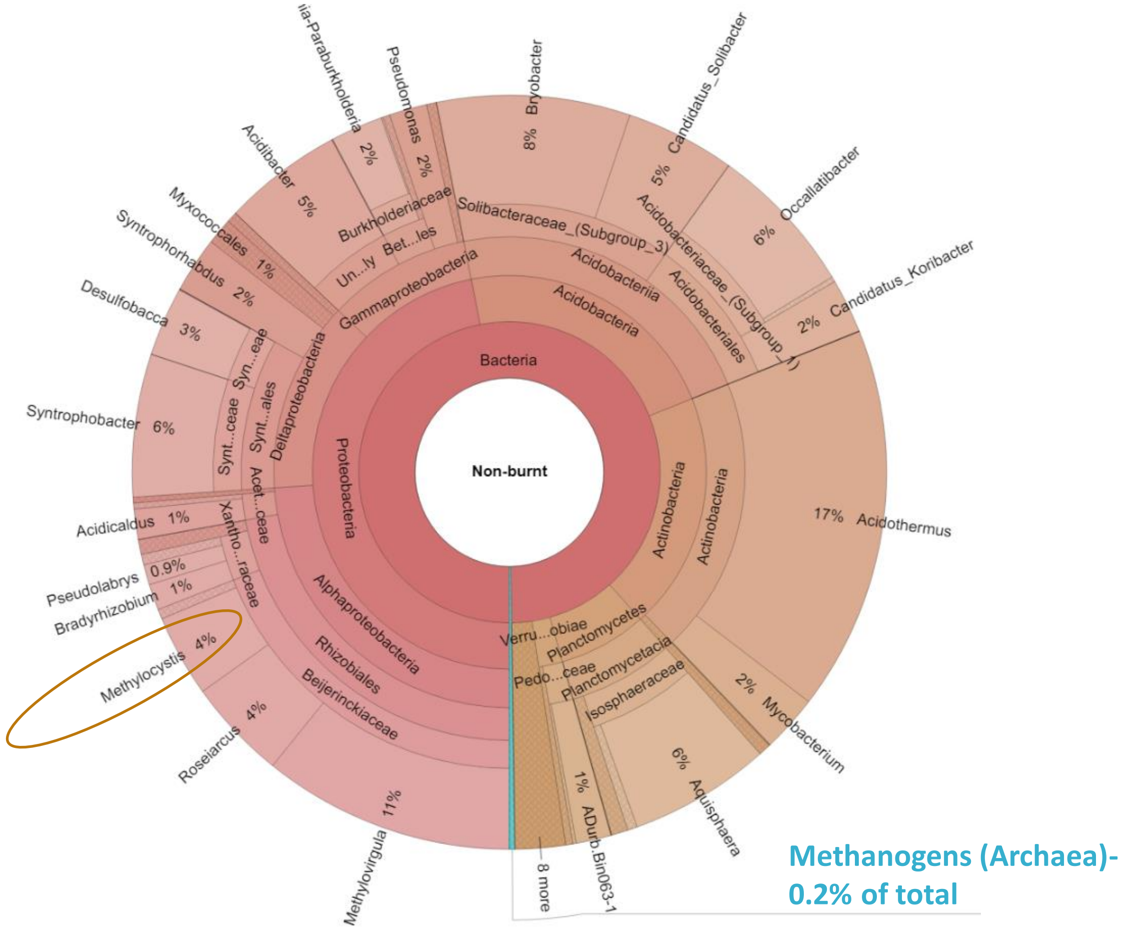


Fig. 9: CH_4 emission from different land-use types. F is intact peat-swamp forest, DegF is degraded forest, C&S is croplands and shrublands, S is Sago palm plantation (as in Hergoualc'h & Verchot, 2014; IPCC, 2013); PSF1 and PSF2 are intact peat-swamp forest in Sarawak (Wong et al., 2018) and Kalimantan (Sakabe et al., 2018), via-Tree is Tree-mediated CH_4 flux in intact PSF, Brunei (Pangala et al., 2013).

Higher methanogens in burnt areas

Using 16S rRNA high-throughput sequencing (Illumina MiSeq), we found that the peat in **burnt areas have higher methanogens (0.7%)** and **lesser methanotrophs (2%)** compared to non-burnt areas which has lesser methanogens (0.2%) and higher methanotrophs (4%) (Krona plots below for overall microbial diversity for peat samples from burnt & non-burnt sites)





Sedges harbour more methanogens in rhizo-compartments

- Since we already found that sedges are a significant source of plant-mediated CH_4 emission, we further investigated the mechanistic understanding of methane production by analysing the microbial community composition in root zones of plant species
- We found that Rhizo-compartments (Endosphere, Rhizoplane, Rhizosphere) of sedges *(Scleria sumatrensis)* harboured higher number of methanogens compared to other plant species (Ferns) present in the areas (Fig. 10)
- Additionally, sedges had relatively lesser methanotrophs in rhizo-compartments compared to ferns
- These further supports our hypothesises that the succession towards more flood-tolerant sedges may enhance CH_4 emission from degraded tropical peatland areas

Fig. 10: Relative abundance of methanogens and methanotrophs in rhizo-compartments of plant species

Methanogens
Methanobacterium
Methanocella
Methanomassiliicoccus
Methanoregula
Methanosaeta
Methanosarcina

Methanotrophs
Methylobacterium
Methylocapsa
Methylocella
Methylocystis
Methylomonas

Conclusion

- Sedge-mediated transport contributed >70% of total CH_4 emission and may contribute 0.01–0.53 $TgCO_2$-equivalent yr^{-1} from degraded tropical peatlands in Southeast Asia
- These numbers are 2–6 times higher when compared to intact peat-swamp forests, and almost 34 times higher when compared to similar land-use
- Further, microbial community composition and its variation due to altered vegetation structure (i.e. shift from ferns towards more flood tolerant sedges) may play an important role in rate of CH_4 production and emissions
- As the **degraded tropical peatland areas are projected to expand due to more frequent fire episodes and flooding, ecological succession towards more flood tolerant sedges may eventually increase CH_4 emissions in the future**

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THANK YOU

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