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Post-Fire Carbon Emissions in Degraded Tropical Peatlands

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Introduction

- Tropical peatlands held about 88.6 Gt C or equal to 15-19% of the total global C pool (Page et al. 2011). The majority (84%) of these peatlands are situated in Indonesia, covering 21 Mha, followed by Malaysia with 2–2.5 Mha.

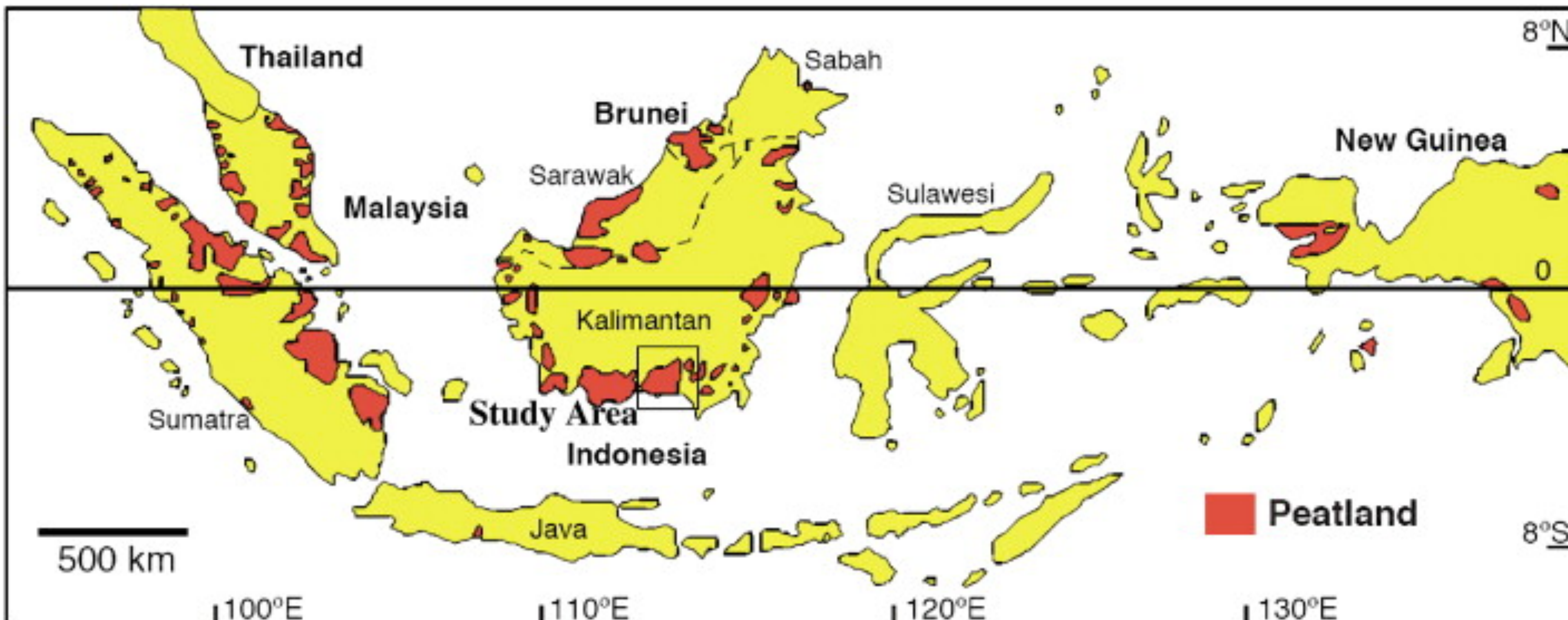
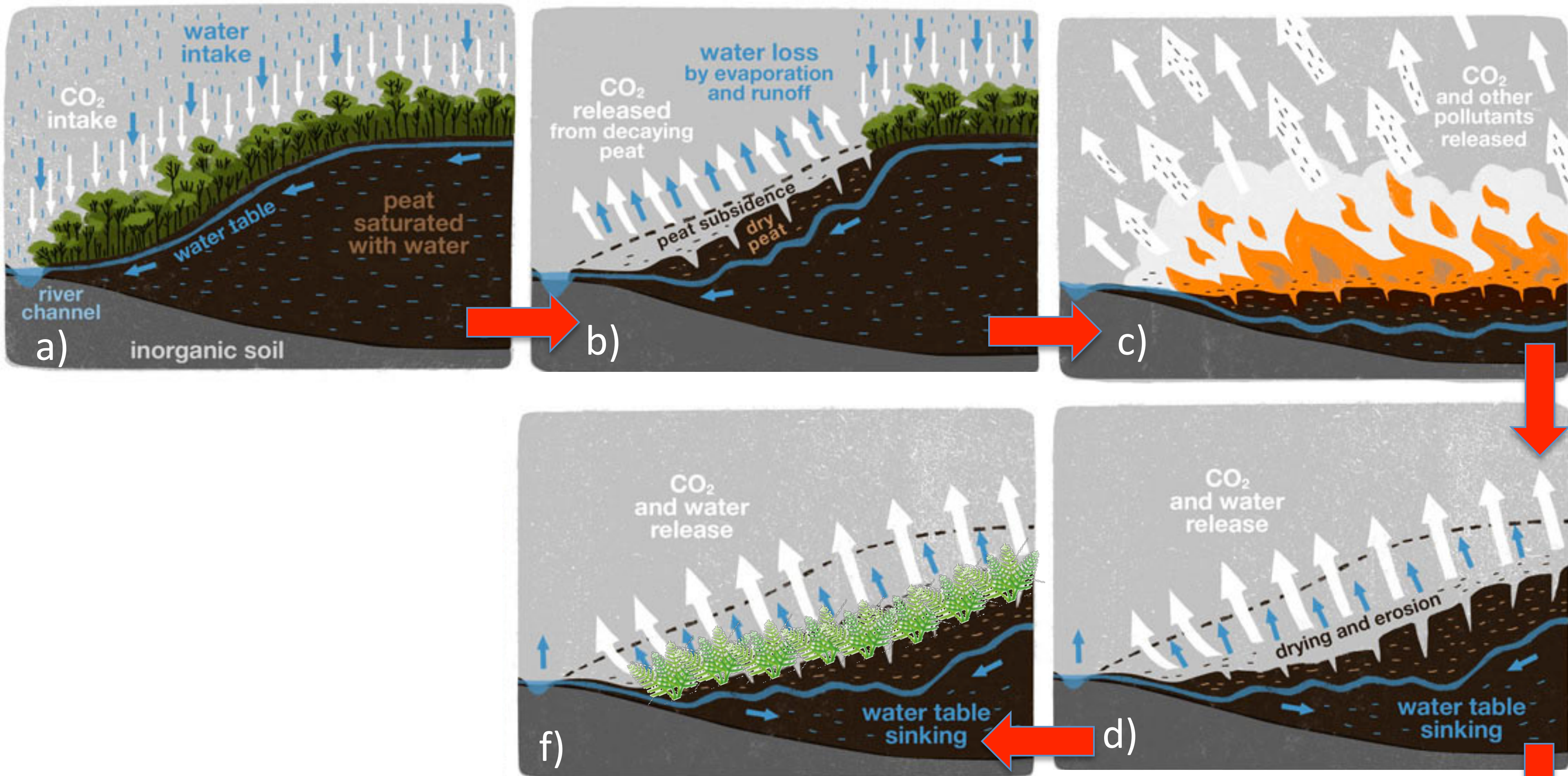
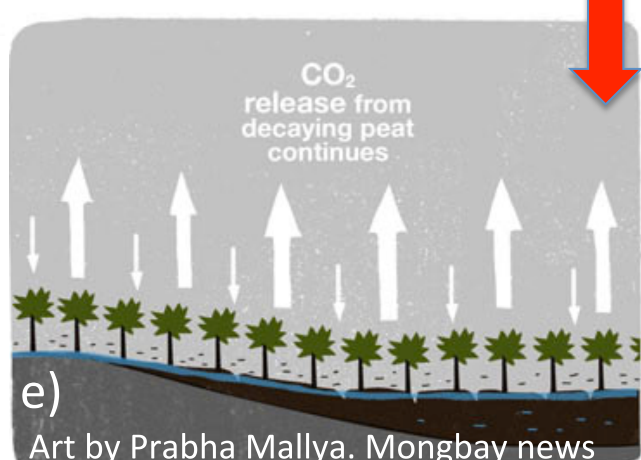


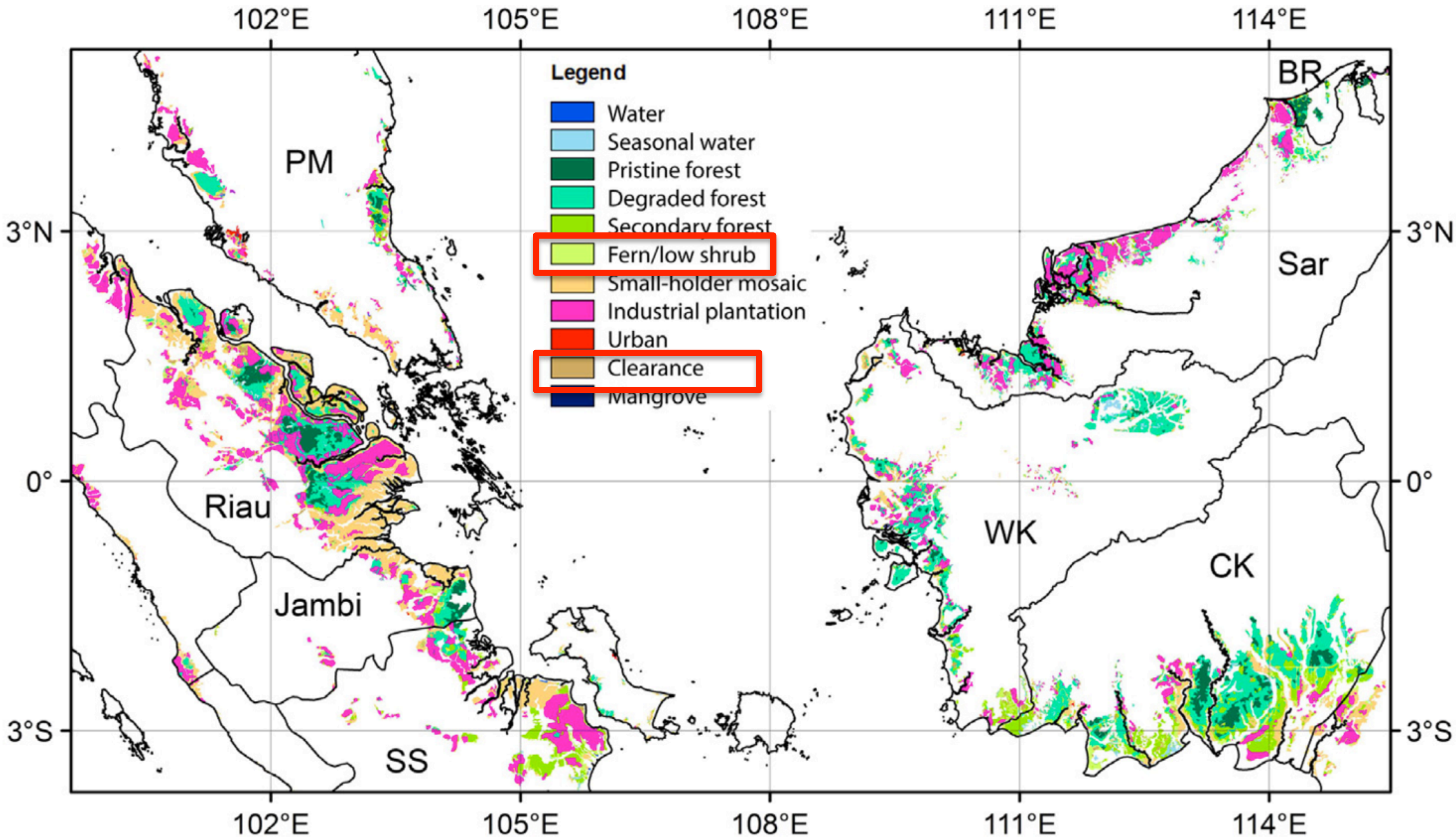
Photo: Page et al. 2010





Art by Prabha Mallya. Mongbay news

- Tropical peatlands (a) have experienced rapid deforestation and extensive drainage (b) for agriculture leading to increase chance of fires (c) and increase in C emissions (d,e,f).
- While many areas are developed for plantations (e), other open-areas covered by ferns and sedges can dominate the landscape (f).



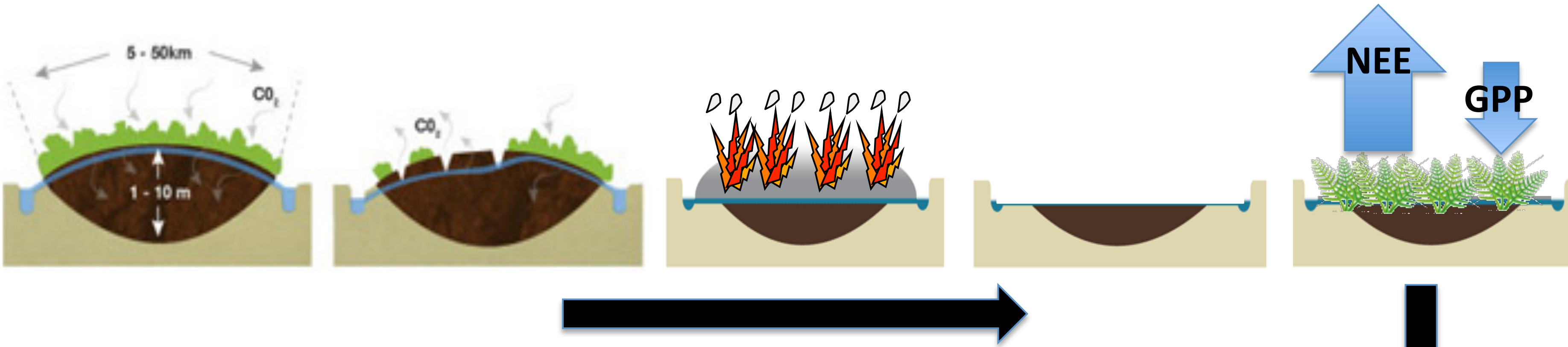
In SE Asia, the extent of open-degraded peatlands occupied by ferns and sedges account for ~10% of the total peatland area in 2015 (~1.42 Mha) (Miettinen et al. 2016).

- **While direct carbon emissions through peat combustion must be quantified to investigate the impact of peat fires on the regional and global carbon balances,**

- **it is also important to evaluate oxidative decomposition of peat after fires for a complete understanding of ecosystem-scale fire impact and for better peat restoration management.**

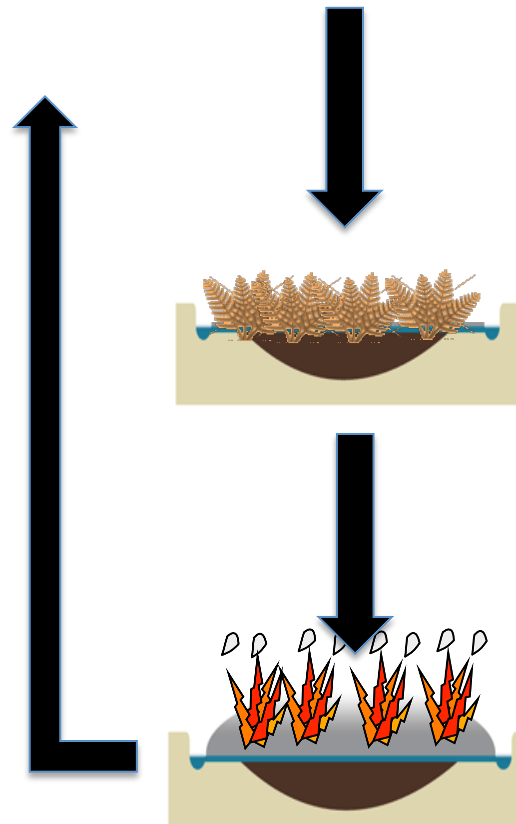
Specifically, with this study we want to address the following questions: how does fire alter peat and water geochemistry? What are the rates, sources and control mechanisms influencing post-fire R_{eco} and CH_4 emissions in tropical peat swamp forests?

Burnt Peat Swamp Forests



Overall after a fire, ecosystems act as a C-source for months to years as ecosystem-respiration (Reco) exceeds photosynthesis (Litvak et al., 2003; Bond-Lamberty et al., 2007). The reoccurrence of fires is extremely high in these degraded landscapes preventing the re-growth of the original forest.

Our general understanding of rate and age of CO2 and CH4 being released from fire-affected tropical peat swamp forest along with changes in peat geochemistry remains poorly understood.



Study Site: Brunei

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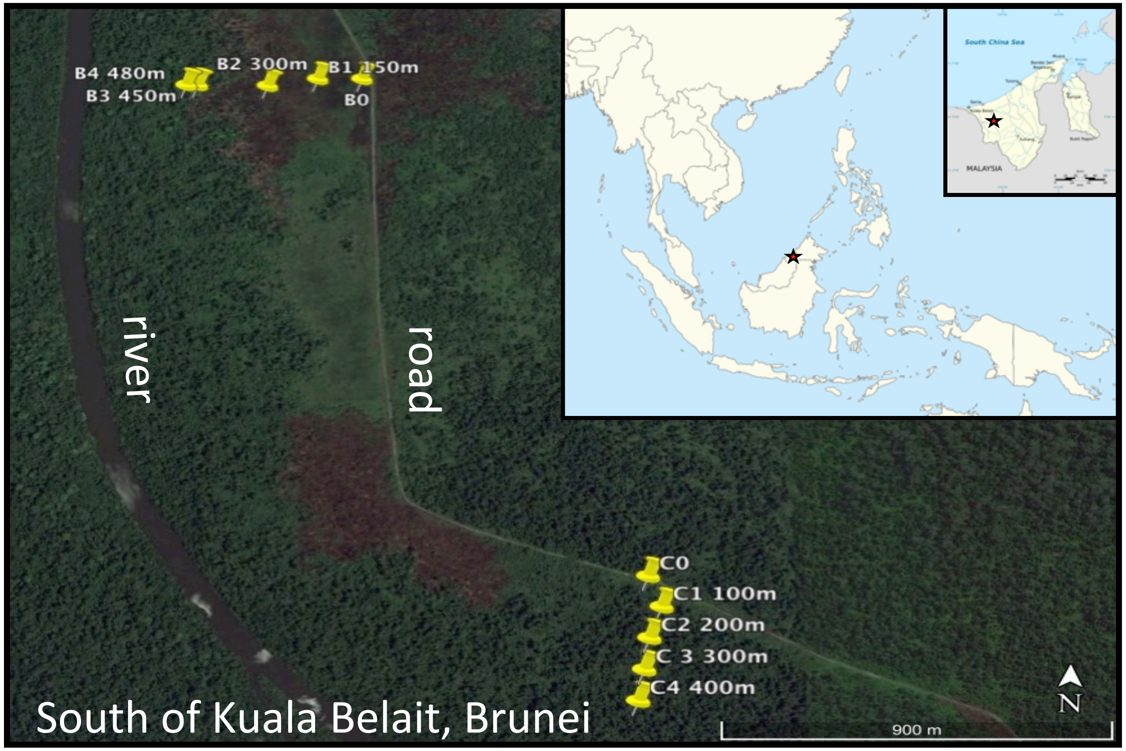

Due to road construction in the 60s, drainage canals (~1.0–1.5 m wide x ~0.5–1.0 m deep) along the road were built disrupting the original peat dome hydrology. Consequently, multiple fires (n=7) have occurred at our burnt (B) site over the last decades with the most recent one during El Niño in March 2016.

Burnt transect (B0-B4): ferns and sedges dominated; peat depth varied from a max. of 3.4 m (close to the road) to a min. of 1.2 m

Control transect (C0-C4): mixed peat swamp forest; peat depth varied from a max. of 4.1 m (close to the road) to a min. of 2 m.

5 plots were established in each transect from the road to about half km into the forest with a distance of 100-150 m from each other. For each plot, we installed a piezometer and 3-4 collars (for a total n=35) for R_{eco}, CH_4 emissions measurement and ^{14}C sampling.

Sites overview videos : https://www.massimolupascu.com/gallery

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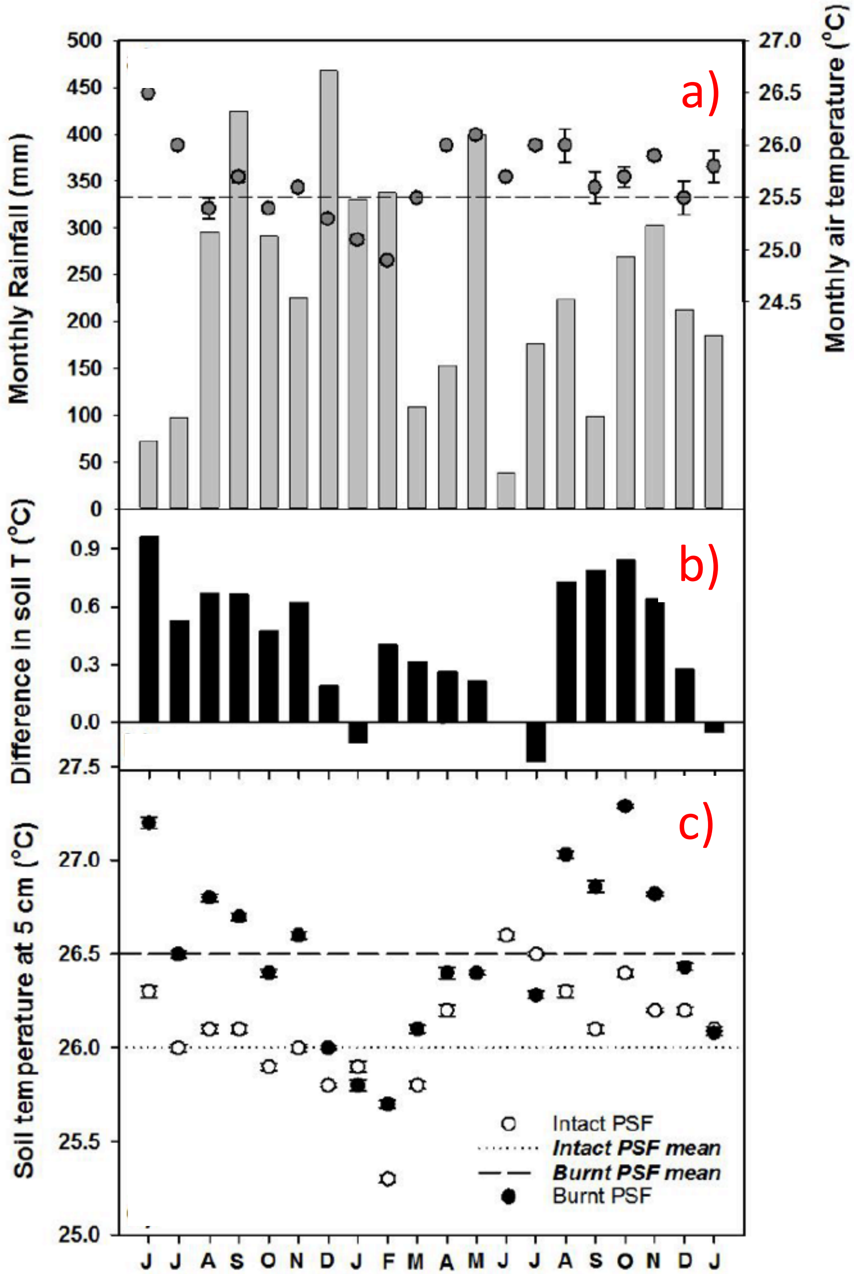
Methodology

- Ecosystem respiration and CH_4 (a) over 9 fieldwork campaigns (June 2017-January 2019)
- ^{14}C-CO_2 and ^{14}C-CH_4 and ^{14}C bulk soil (b)
- Continuous soil temp. at 5 and 10 cm and water table measurements (e)
- Soil Water Content for every flux measurement
- Porewater DOC, DO, pH, TDS, salinity for every fieldwork campaign (d)
- Peat soil characteristics (C, H, N, S) (c)

Results: Impact of fire on soil temperature



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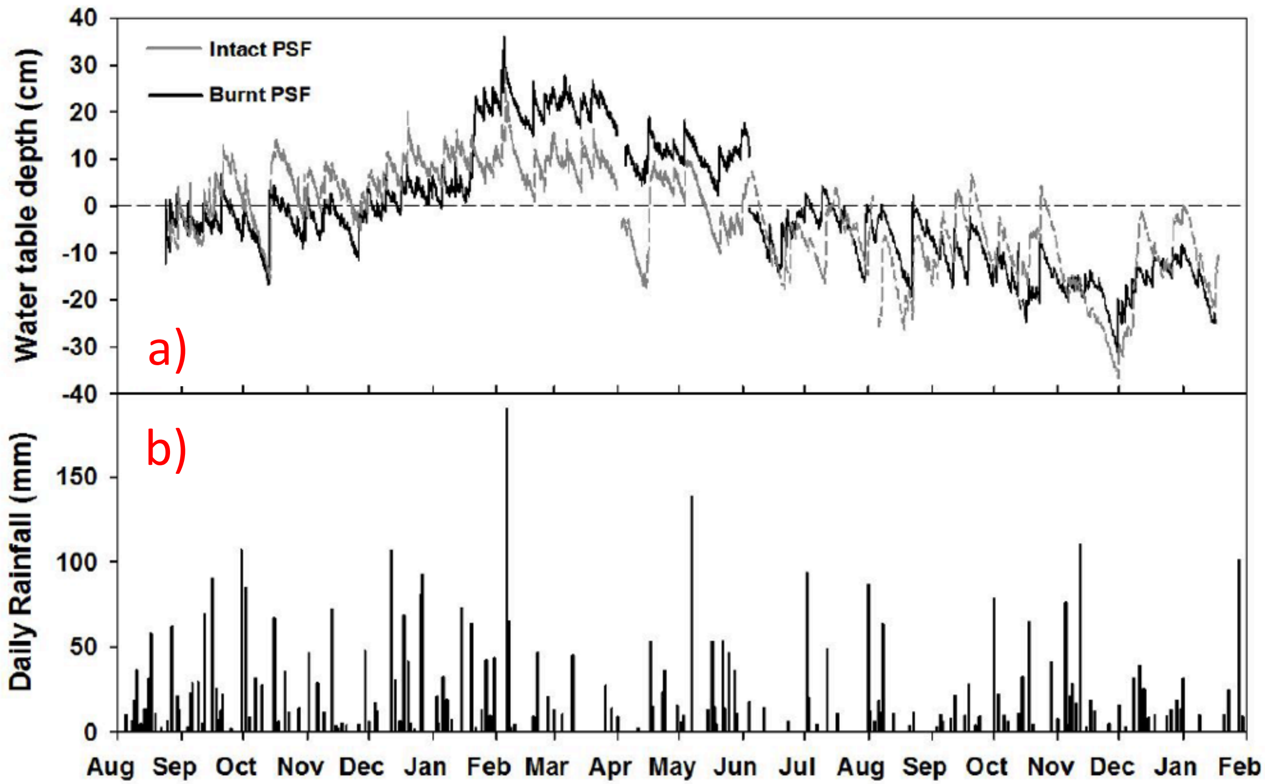
Average soil temperature (c) mirrored the air temperature trend (a) for the entire sampling period following the monsoons and inter-monsoons season with the highest value recorded in June 2017 at 27.2°C, and the lowest in February 2018 at 25.3°C.

Mean soil temperature for the study period was 26.5±0.2°C in the **burnt transect, which was on average 0.5°C warmer compared to the intact PSF** transect (26.0±0.2°C).

During the dry season, monthly mean soil temperature difference was more evident (up to 1°C difference) compared to the rainy season (0.2^{o}C) (b)

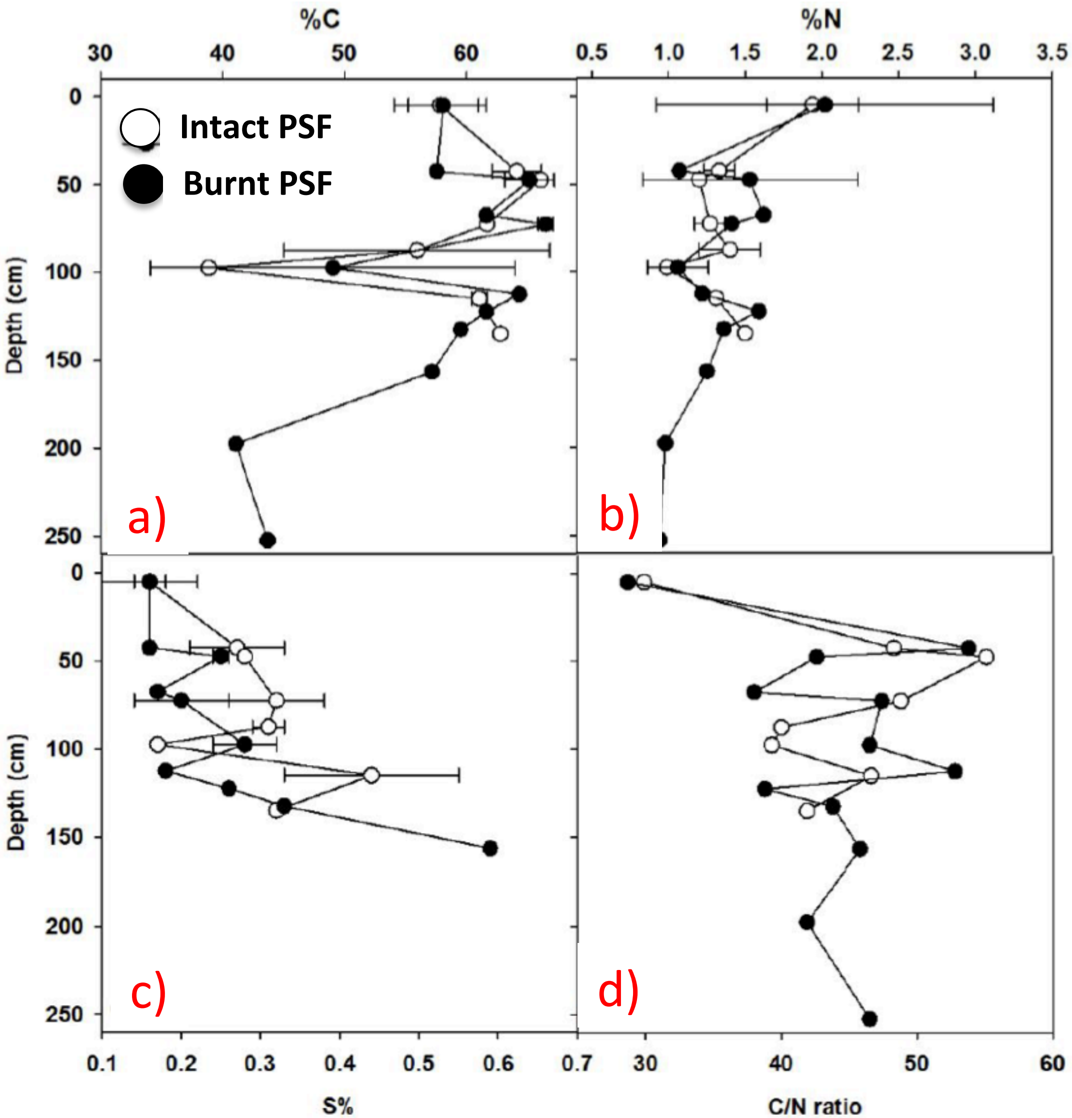
Results: Impact of fire on water table level



Water table variations followed precipitation patterns with the highest level at +30 cm above the mean peat surface between January to March 2018, and the lowest registered at -30 cm between September to December 2018.

Based on manual and continuous measurements from the other piezometers**, the burnt site had on average 5-10 cm higher water tables than the intact PSF during the wet season**.

Results: Impact of fire on peat geochemistry



Overall C% and N% showed a decreasing trend with depth ranging from a maximum of 66% to a minimum of 38% for C and 2% to 0.9% for N, respectively (a,b). S% increased from 0.2% near the surface to 4% at 2.5 m depth (c). C/N ratio varied from ~29 at the surface level to 46 at the bottom (d). **No significant difference between intact and burnt peat PSF was recorded**.

Bulk density: No significant differences were recorded between cores from the two transects with the exception of the top 5 cm, where BD was on average higher in the burnt PSF (0.15±0.06 g cm-3) compared to the intact PSF transect (0.12±0.05 g cm-3; $p<0.05$)

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Results: Impact of fire on peatwater geochemistry

	pH	*DO* %	*CDV* mV	*W Temp.* °C	*TDS* µS/cm	*Salinity*	*ORP* mV
Intact PSF	3.0±0.1	27.4±6.0	96.8±5.9	25.6±0.1	0.055±0.003	0.04±0.002	729±135
Burnt PSF	3.6±0.1	16.4±3.5	74.8±5.5	26.4±0.1	0.043±0.003	0.03±0.002	812±131

Mean values for the study period showed higher pH ($p<0.05$), lower dissolved oxygen ($p<0.05$) and water temperature ($p<0.05$) in the burnt transect compared to the intact PSF (Table 2). On the other hand, EC ($p<0.05$), TDS ($p<0.05$), and salinity ($p<0.05$), were higher in the intact PSF transect.

Intact PSF	**pH**	**DO**	**Temp**	**EC**	**TDS**	**Sal**
pH	1					
DO (%)	-0.072	1				
Temp (°C)	-0.040	**0.525***	1			
EC (µS/cm)	0.187	0.098	**-0.505***	1		
TDS (mg/L)	-0.254	0.261	-0.321	**0.990***	1	
Sal (‰)	-0.174	0.184	-0.183	**0.873***	**0.860***	1

Burnt PSF	**pH**	**DO**	**Temp**	**EC**	**TDS**	**Sal**
pH	1					
DO (%)	-0.229	1				
Temp (°C)	0.154	**0.685***	1			
EC (µS/cm)	**0.414***	-0.221	0.014	1		
TDS (mg/L)	0.271	-0.144	-0.040	**0.951***	1	
Sal (‰)	0.069	-0.053	-0.106	**0.891***	**0.897***	1

*- significant at $p < 0.05$

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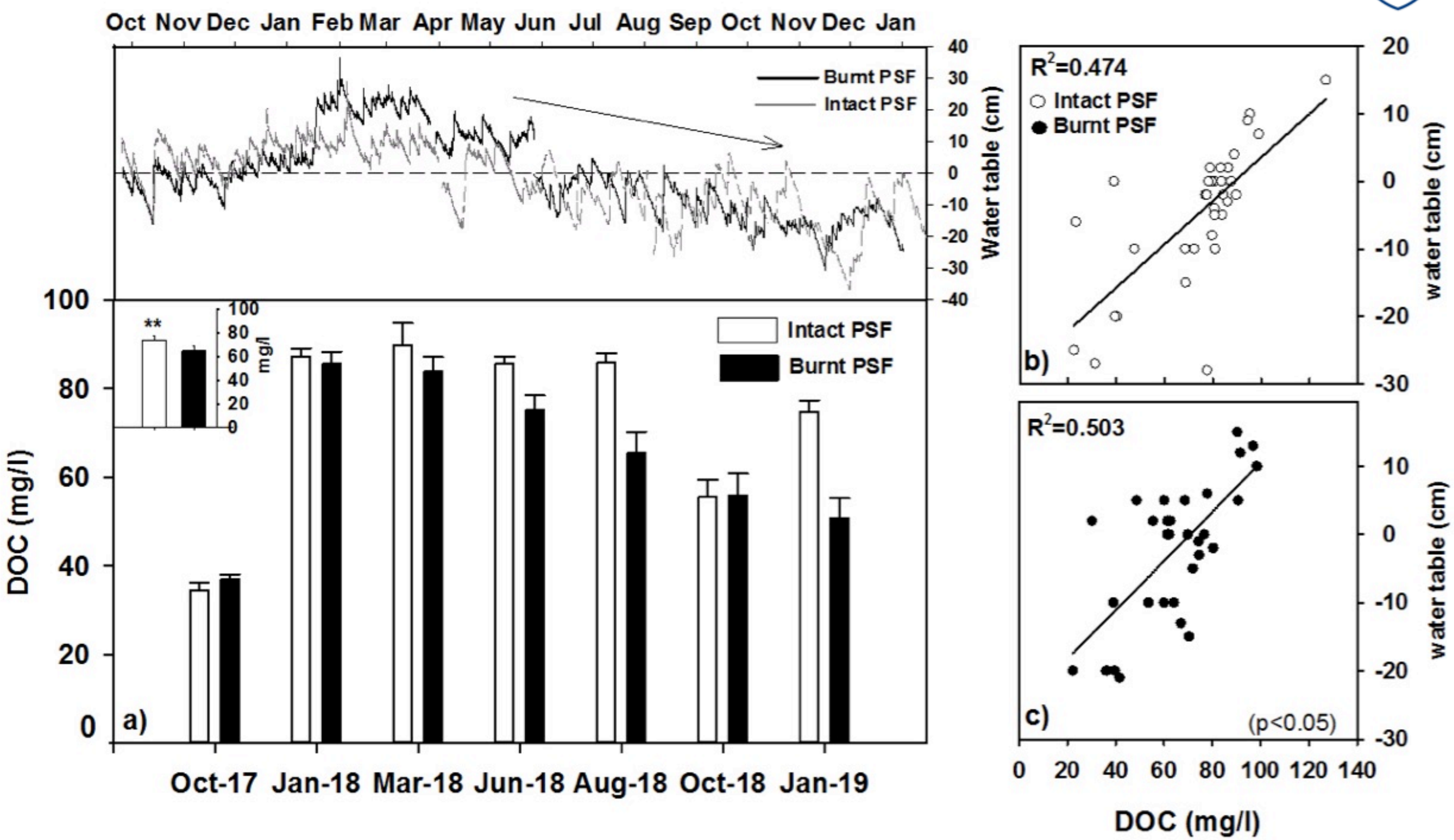
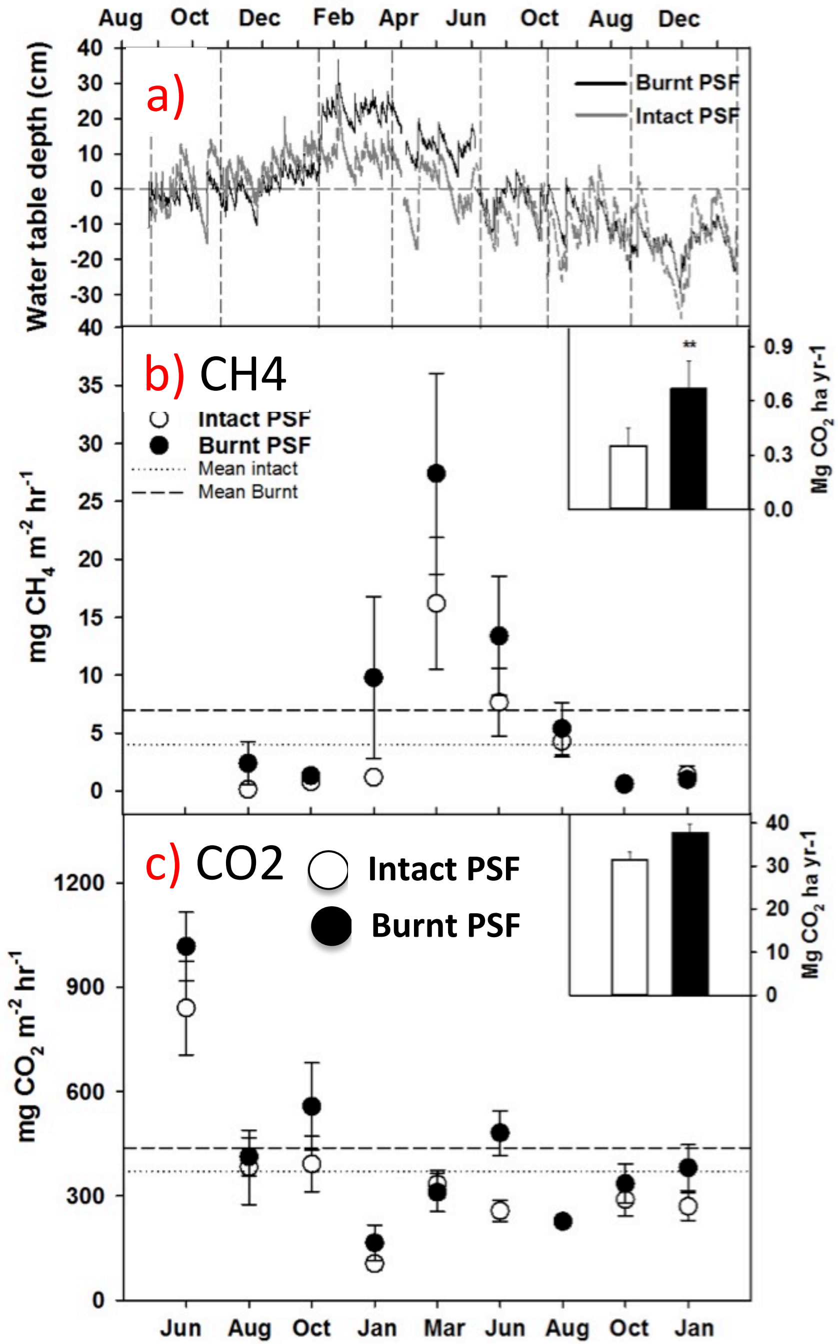
Results: Dissolved Organic Carbon (DOC)



DOC followed water table trend with mean lowest concentrations recorded in October 2017 (34.5±1.8 mg C l-1), and highest by the end of March 2018 (89.8±5.0 mg C l^{-1}). This trend was more evident in the burnt PSF, compared to the intact PSF transect, which showed more stable values over time. Overall, DOC values were **lower in the burnt PSF** (64.8±3.9 mg C l^{-1}) compared to the intact PSF areas (73.9±3.9 mg C l^{-1}; $p<0.05$).

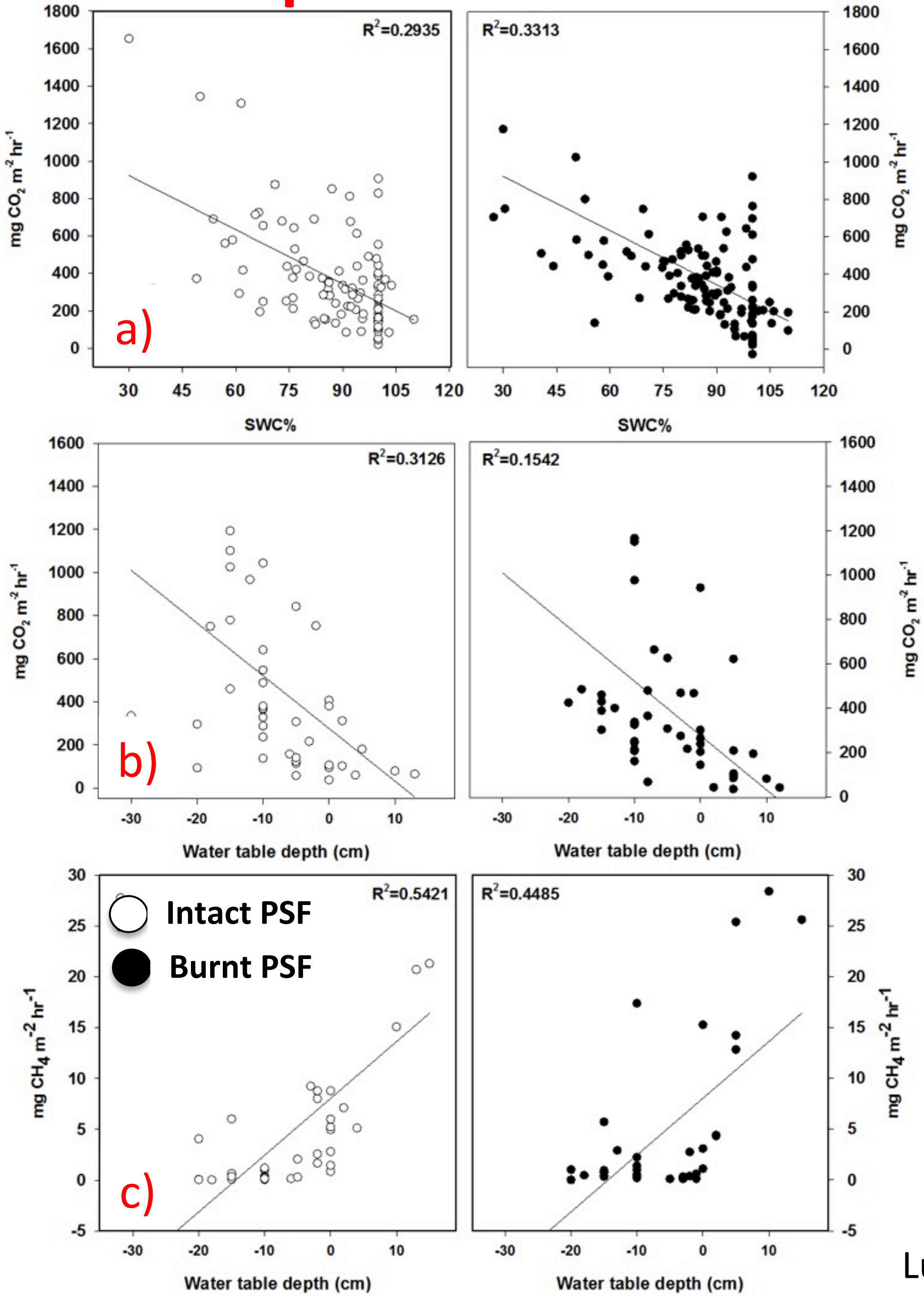
Results: Impact of fire on C emissions



CO_2 emissions at our transects showed a seasonal pattern following soil temperature and groundwater table level with the highest values in June 2017 (1110±98 mg CO_2 m^{-2} hr^{-1}), and the lowest in January 2018 (105±17 mg CO_2 m^{-2} hr^{-1}; c). Both **transects showed a similar trend and mean values for the burnt** (431±83 mg CO_2 m^{-2} hr^{-1}) **and intact PSF sites** (359±76 mg CO_2 m^{-2} hr^{-1}) over the sampling period.

CH_4 emissions values exhibited the highest value in March 2018 (27±5 mg CH_4 m^{-2} hr^{-1}) and the lowest in August 2017 (0.16±0.05 mg CH_4 m^{-2} hr^{-1}), mainly following water table trends (a). Over the sampling period, the burnt PSF site (7.8±2.2 mg CH_4 m^{-2} hr^{-1}) showed overall higher values ($p<0.05$) for the sampling period compared to the intact PSF (4.0±2.0 mg CH_4 m^{-2} hr^{-1}) (b). **Difference in CH4 emissions between the two transects were evident mainly during the wet season but not during the dry season.**

Results: Impact of fire on C emissions



CO2 emissions: stronger correlation with soil water content (r^2=0.29-0.33) than water table level (r^2=0.15-0.31; a,b), where R_{eco} fluxes decreased as water content increased (i.e., the water table rose).

This difference, however, was likely due to the more accurate spatial cover of the SWC data (1 for every R_{eco} measurement taken) compared to the water table data (one for every plot, hence n=3-4 R_{eco} measurements).

CH4 emissions: stronger correlation with water table (r^2=0.44-0.54).

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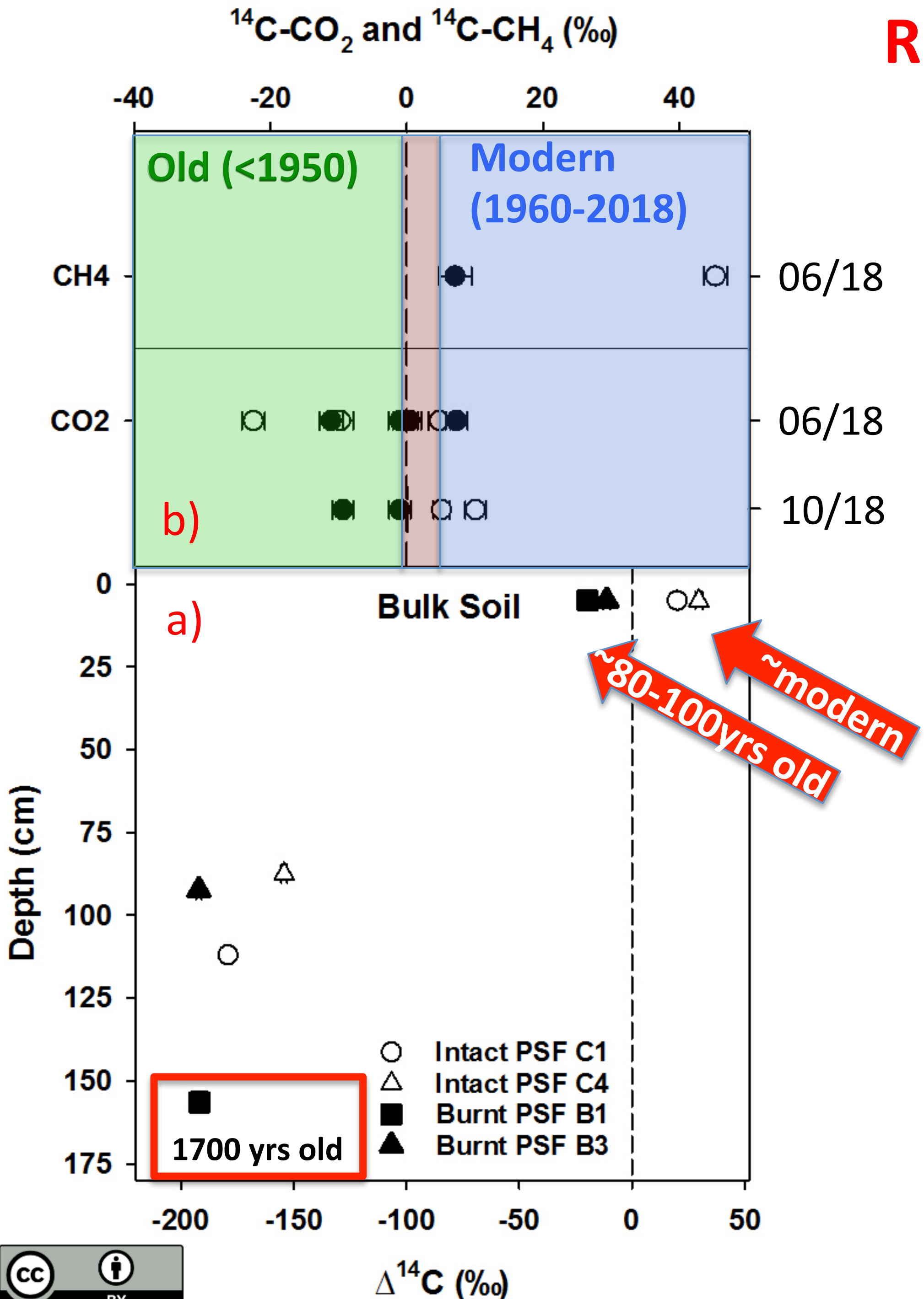
Results: Impact of fire on C sources



^{14}C-bulk soil showed marked difference in the top peat layer (0-10 cm) between the intact and burnt PSF sites (a).
Burnt areas exhibited a [^{14}C] of up to -19.7±5‰ (146±94 yrs BP) in the top layer, compared to modern C present in the intact PSF. The bottom peat layers for all cores showed similar values with a mean of -189±17‰ with the oldest sample equivalent to C that was fixed 1550±11 yrs BP.

^{14}C-R$_{eco}$ (b) collected in the month of June and October did now show a statistical significant difference between the burnt and intact PSF with a mean value of −3.3±4.2‰ and -0.9±2.0‰ for the two transects and months, respectively. **^{14}C-CH$_4$** samples were modern exhibiting a value of 45.3±1.7‰ and 7.1±2.4‰ for the intact and burnt PSF, respectively (b).

Conclusions

- In degraded tropical PSF areas where there have been repeated fires and substantial combustive loss of peat, the ecosystem is still deeply affected, decades past the fire event due to changes in peat, water properties and hydrology.
- Our data showed an increase in pH and a decrease in key parameters such as EC, DO and TDS in the burnt PSF areas. All these changes in turn affected C dynamics, mainly CH_4.
- Ecosystem respiration emissions did not show significant differences between burnt and intact PSF in terms of magnitude and sources. Even though the age of the surface peat layers were older in the burnt transect, CO_2 emitted was mainly from recent C fixed over the last 50 years, probably from C present in solution.
- CH_4 emissions showed significant higher fluxes from the burnt PSF site compared to the intact site (and literature), due to higher water table levels, lower DO, an increase in pH and a decrease in electrical conductivity, which led to better conditions for methanogenesis to occur.

Thank you!

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