Impact of fire on vegetation, soil microbes and CH$_4$ emission from a degraded tropical peatland

Hasan Akhtar$^1$, Massimo Lupascu$^{1,2}$, Omkar S. Kulkarni$^{3,7}$, Aditya Bandla$^7$, Rahayu S. Sukri$^4$, Alexander R. Cobb$^5$, Thomas E. L. Smith$^6$, Sanjay Swarup$^{2,3,7}$

$^1$Department of Geography, National University of Singapore, Singapore; $^2$NUS Environmental Research Institute, Singapore; $^3$Department of Biological Sciences, National University of Singapore, Singapore; $^4$Institute for Biodiversity and Environmental Research, Universiti Brunei Darussalam, Brunei Darussalam; $^5$Center for Environmental Sensing and Modeling, Singapore–MIT Alliance for Research and Technology, Singapore; $^6$Department of Geography and Environment, London School of Economics & Political Science, UK; $^7$Singapore Centre for Environmental Life Sciences Engineering, Singapore
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.
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$_4$m$^{-2}$hr$^{-1}$ during dry and wet period (Fig. 7), respectively, and from 1.12 ± 0.24 to 4.33 ± 0.56 mgCH$_4$m$^{-2}$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 TgCO₂-eq yr⁻¹

- At landscape level, the CH₄ emission from degraded tropical peatland areas may contribute a mean of 236.9 ± 130.6 kgCH₄ 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 TgCH₄ yr⁻¹ or 0.006–0.532 TgCO₂-equivalent yr⁻¹ (Table 3).

Table 3

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Open land* area in 2015 (in Ha)</th>
<th>Sedge basal area (m²/Ha)</th>
<th>Regional area covered by sedges (Ha)</th>
<th>CH₄ flux (mgCH₄ m² hr⁻¹)</th>
<th>CH₄ flux (kgCH₄ ha⁻¹ yr⁻¹)</th>
<th>TgCH₄ yr⁻¹</th>
<th>TgCO₂-eq yr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>1419480</td>
<td>25.9</td>
<td>3677</td>
<td>0.56</td>
<td>49.5</td>
<td>0.0002</td>
<td>0.006</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>1419480</td>
<td>176.8</td>
<td>25096</td>
<td>1.39</td>
<td>121.8</td>
<td>0.0031</td>
<td>0.104</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>1419480</td>
<td>25.9</td>
<td>3677</td>
<td>1.75</td>
<td>153.5</td>
<td>0.0006</td>
<td>0.019</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>1419480</td>
<td>176.8</td>
<td>25096</td>
<td>7.11</td>
<td>622.9</td>
<td>0.0156</td>
<td>0.532</td>
</tr>
</tbody>
</table>

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

Fig. 9: CH₄ 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 CH₄ flux in intact PSF, Brunei (Pangala et al., 2013).
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).
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 sumatrens*is) 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 hypotheses 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.
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
Acknowledgement: We thank the Ministry of Education of Singapore & NUS Graduate Research Support Scheme for funding this research; Brunei Forestry Department for entry and sampling permits; Biodiversity Research and Innovation Centre for export permits; Biosecurity Division for phytosanitary certificates; Universiti Brunei Darussalam for permission to conduct research; and all the RAs for their help in the field.
References


