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Supplementary material

Propagation probability and spread rates of self-sustained smouldering fires under controlled moisture content and bulk density conditions

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Nomenclature

c_w	Specific heat of water (kJ kg^{-1} K)
c_p	Specific heat of peat (kJ kg^{-1} K)
E	Energy required to dry and heat a mass of peat sample (kJ kg^{-1})
E'	Total energy required to dry and heat an entire sample (kJ)
E''	Energy required to dry and heat a unit volume of peat (kJ cm^{-3})
E_w	Energy required to heat and dry a mass of water (kJ kg^{-1})
E_p	Energy required to heat a mass of peat (kJ kg^{-1})
L_w	Latent heat of water evaporation (kJ kg^{-1})
p	Mass of dry peat in the peat sample (kg)
ρ	Bulk density (kg m^{-3})
T_0	Ambient temperature (K)
T_1	Temperature of water evaporation at ambient pressure (K)
T_2	Temperature of the start of peat thermal decomposition to char (K)
t^L	Time when the leading edge of the smouldering front reach a pixel (h)
w	Mass of water in the peat sample (kg)
ω	Peat sample volume (cm^3)

Detection of changes in spread rate during long burns

To detect changes in the spread rate during long burns (defined as burns lasting more than 7 h), we first calculated the median t^L for groups of pixels between distance x and x + 0.5 cm from the igniter that were more than 2 cm from the sides of the burnbox and more than 6 cm from the igniter (T), and then analyse the variation of T along the x-direction. To avoid issues of autocorrelation we analysed the spatial relationship between subsets T in each experimental burn (Legendre and Legendre 2000). Gaussian and Spherical spatial semivariogram models were fitted. Both models indicated no spatial autocorrelation beyond 1 cm (semviariogram range) for all experimental burns. We then selected values of T with 1 cm separation in distance, x. We fitted the following linear model:

$$T_j = \beta_{\delta 0} + \beta_{\delta 1} x_j + \beta_{\delta 2} x_j^2 + \varepsilon_j \tag{S1}$$

where T_j is the median of t^L for the group of pixels corresponding to the distance x_j and ε_j is a residual, assumed to be taken from a normal distribution. The coefficient of the quadratic term, $\beta_{\delta 2}$, is expected to be zero if spread is constant. The hypothesis $\beta_{\delta 1} = 0$ was tested using F-tests.

Estimation of energy required for smouldering combustion of peat

Table S1. Summary of the moisture evaporation tests for peat conditions that sustained smouldering fires for more than 7 h.

Test is the number of moisture evaporation test, *MC* treatment is the initial moisture content of the peat sample at the start of the experiment, ρ is the bulk density of the peat sample, time is the number of hours since the start of the test, propagation indicates if smouldering propagation was self-sustained (***Y***) or not (N) according to Fig. S2, *MC* is the % moisture content estimated at each hour according to the mass loss rate of the peat sample, s.d. is the standard deviation of *MC*.

Test	*MC* treatment	ρ	time	propagation	*MC*	s.d.

(num)	(%)	(kg m^{-3})	(hours)	(***Y***/N)	(%)	(%)
1	***100***	***129***	***2***	***Y***	***100.2***	***0.1***
1	***100***	***129***	***4***	***Y***	***99.7***	***0.1***
1	***100***	***129***	***6***	***Y***	***99.0***	***0.1***
1	***100***	***129***	***8***	***Y***	***98.3***	***0.1***
1	***100***	***129***	***10***	***Y***	***98.0***	***0.0***
1	100	129	12	N	97.6	0.0
1	100	129	14	N	97.3	0.1
2	***100***	***132***	***2***	***Y***	***101.0***	***0.0***
2	***100***	***132***	***4***	***Y***	***100.9***	***0.0***
2	***100***	***132***	***6***	***Y***	***100.7***	***0.0***
2	***100***	***132***	***8***	***Y***	***100.2***	***0.1***
2	***100***	***132***	***10***	***Y***	***99.7***	***0.1***
2	100	132	12	N	99.1	0.1
2	100	132	14	N	98.6	0.1
3	***100***	***138***	***2***	***Y***	***101.7***	***0.3***
3	***100***	***138***	***4***	***Y***	***102.0***	***0.0***
3	***100***	***138***	***6***	***Y***	***101.7***	***0.1***
3	***100***	***138***	***8***	***Y***	***101.3***	***0.0***
3	***100***	***138***	***10***	***Y***	***101.1***	***0.1***
3	100	138	12	N	100.7	0.1
3	100	138	14	N	100.3	0.1
4	***150***	***73***	***2***	***Y***	***148.3***	***0.3***
4	***150***	***73***	***4***	***Y***	***147.8***	***0.2***
4	***150***	***73***	***6***	***Y***	***146.7***	***0.1***
4	***150***	***73***	***8***	***Y***	***144.8***	***0.1***
4	150	73	10	N	144.2	0.1
4	150	73	12	N	143.4	0.1
4	150	73	14	N	143.0	0.1
5	***150***	***81***	***2***	***Y***	***152.2***	***0.1***
5	***150***	***81***	***4***	***Y***	***152.5***	***0.0***
5	***150***	***81***	***6***	***Y***	***152.4***	***0.0***
5	***150***	***81***	***8***	***Y***	***152.1***	***0.0***
5	150	81	10	N	151.8	0.1
5	150	81	12	N	151.5	0.1
5	150	81	14	N	151.0	0.1
6	***150***	***82***	***2***	***Y***	***150.9***	***0.0***
6	***150***	***82***	***4***	***Y***	***150.7***	***0.1***
6	***150***	***82***	***6***	***Y***	***150.2***	***0.1***
6	***150***	***82***	***8***	***Y***	***149.6***	***0.1***
6	150	82	10	N	149.1	0.1
6	150	82	12	N	148.8	0.1
6	150	82	14	N	148.3	0.1

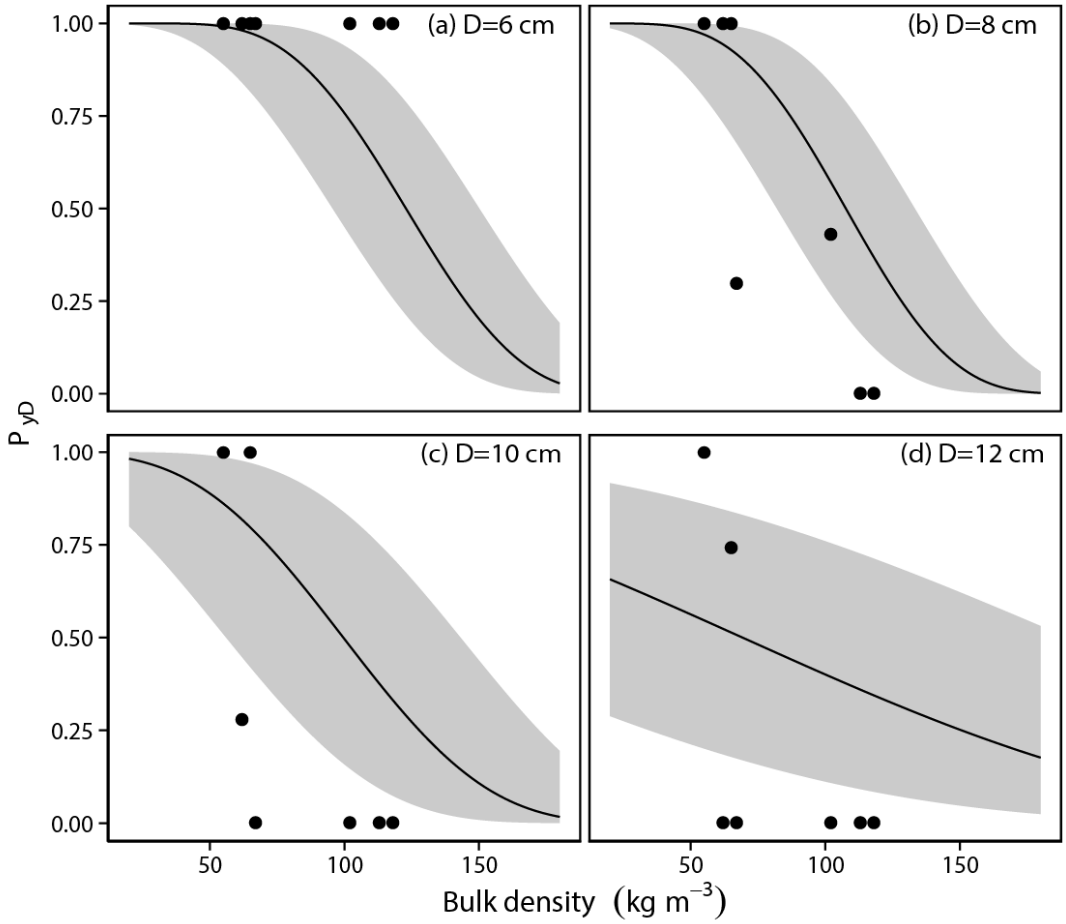

Fig. S1. Expected fraction of peat burnt (P_{yD}) for peats with 150% moisture content (Eqn S1, Table S1). Panels are predictions for distance *D* away from the ignition region of (a) 6 cm, (b) 8 cm, (c) 10 cm and (d) 12 cm. Line shows mean prediction and shaded areas are quantile = 25% and quantile = 75%. Points are fractions of peat burnt (*y*) along a transect at distance *D*.

The energy required to dry and heat a mass of peat sample (*E*), the entire peat sample (*E'*) and a unit volume (*E''*) were estimated for each combination of peat moisture content (*MC*) and bulk density (ρ). The energy required to heat and dry the water from the peat is

$$E_w = \left(c_w(T_1 - T_0)\right)\ L_w\left(\frac{MC}{100+MC}\right) \tag{S2}$$

where c_w is a constant 4.186 kJ kg^{-1} K^{-1}, T_0 is assumed to be constant at 288.15 K, T_1 is assumed to be 373.15 K and L_w is 2260 kJ kg^{-1} K^{-1} (Huang et al., 2014). The energy required to heat the peat from T_0 to T_2 is

$$E_p = \left(c_p(T_2 - T_1)\right)\left(1 - \frac{MC}{100+MC}\right) \tag{S3}$$

where c_p is a constant 1.84 kJ kg^{-1} K^{-1}, T_0 is assumed to be constant at 288 K and T_2 is 423 K, which is considered the temperature at which peat starts the thermal decomposition to char (Rein 2013). E_p was calculated for a higher T_2 (473 K), however the temperature increase of 50 K did not have a qualitative effect on E (Eqn S4). The total energy required to evaporate all water from a unit mass of peat sample and heat the peat to a temperature T_2 is

$$E = E_w + E_p \tag{S4}$$

The values were estimated for each moisture content treatment (Fig. S2).

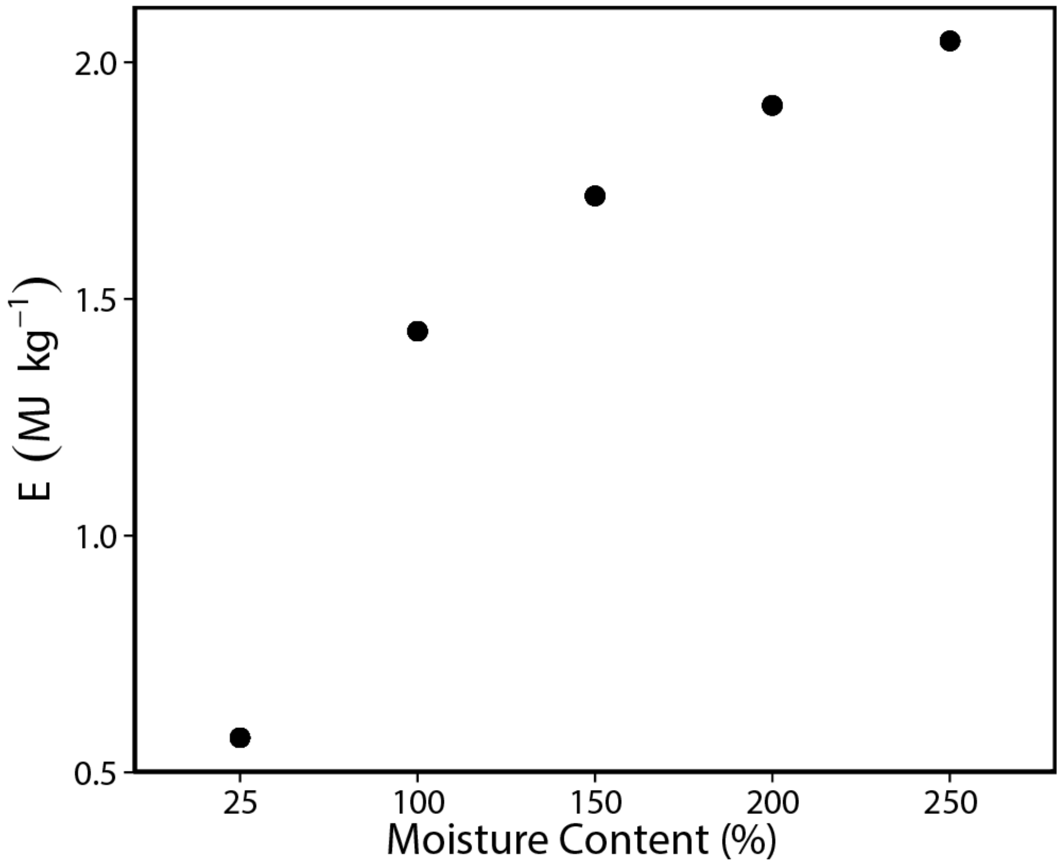

Fig. S2. Energy required (E, Eqn S3) to heat 1 kg of peat to 423 K as a function of peat moisture content.

The energy required to start thermal decomposition of the entire sample is

$$E' = E_w \times w + E_p \times p \tag{S5}$$

where p is the mass of peat and w is the mass of water of the entire sample. Assuming homogeneous peat conditions within the burnbox, the energy required to start thermal decomposition per unit volume is

$$E'' = \frac{E'}{\omega} \tag{S6}$$

where ω is a constant volume of 1800 cm^3. The values were estimated for each peat moisture content and bulk density treatment (Fig. S3).

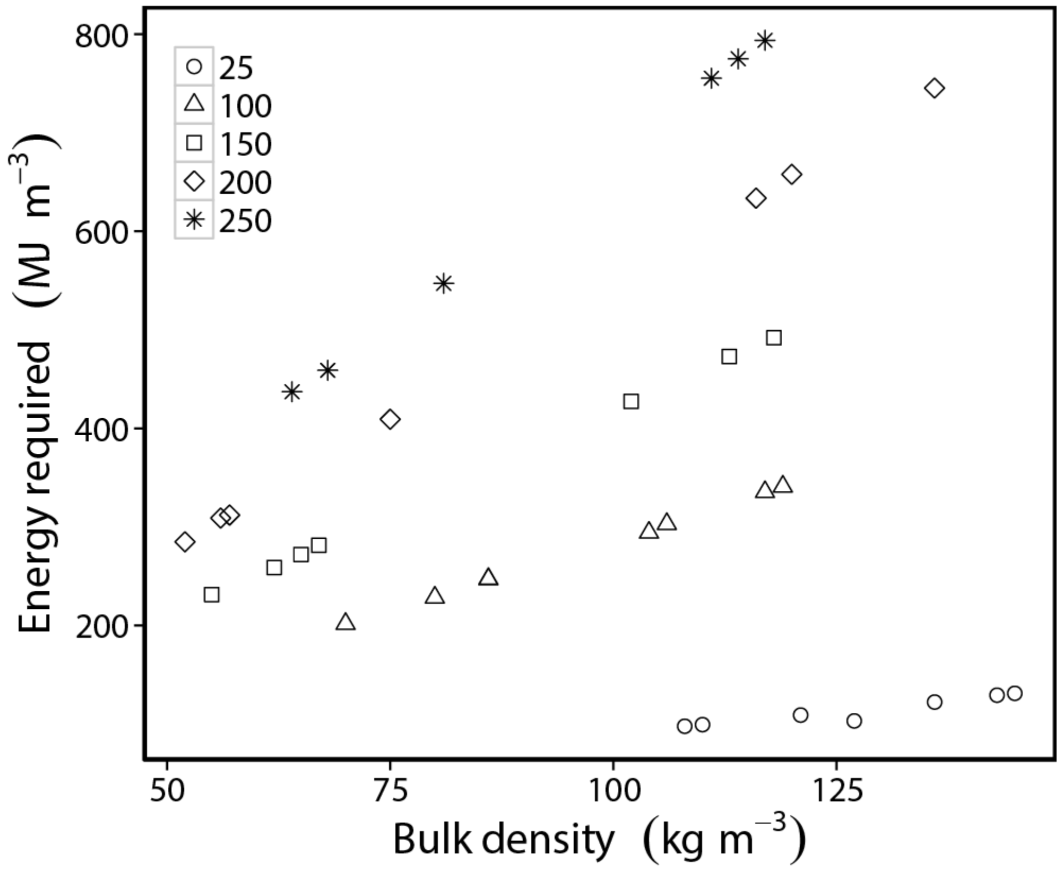

Fig. S3. Energy required per unit volume of peat sample (*E''*, Eqn S5) as a function of peat bulk density. Circle, triangle, square, diamond and star correspond to 25%, 100%, 150%, 200% and 250% moisture content, respectively.

References

Huang X, Rein G (2014) Smouldering combustion of peat: inverse modelling of the drying and the thermal and decomposition kinetics. *Combustion and Flame* **161**, 1633–1644.

Legendre P, Legendre L (2000) Numerical ecology (Elsevier: Amsterdam)

Rein G (2013) Smouldering Fires and Natural Fuels. In 'Fire phenomena and the earth system: an interdisciplinary approach to fire sicence'. (Eds CM Belcher) pp. 15–34. (Wiley-Blackwell: West Sussex)