The causes and prevention of wildfire on heathlands and peatlands in England (NEER014)

Appendix 9: Vegetation and sub-surface fire temperatures

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Appendix 9. Vegetation and sub-surface fire temperatures

Introduction

There is a wide range of studies that have investigated vegetation fire temperatures above and below ground. Dry heath and blanket bog habitats have been the subject of a number of studies that have reported maximum fire temperatures in the canopy in the range of 485 °C to 993 °C with average maximum temperatures up to 670 °C. There appears to be considerable variation in recorded temperatures within and between experiments, with soil temperatures and fires at the base of the vegetation, ranging 7–87 °C up to a maximum of 982 °C. Mean temperatures are as would be expected, considerably lower than the maximum, with the range 170–190 °C more typical. A similar range of temperatures has been reported for other habitats, although in forests surface fire temperatures up 1005 °C have been recorded.

Studies of temperatures below ground consistently find that little or no heating occurs in the soil below 1–2 cm with the exception of grass fires investigated in Africa where the soil temperatures increased by 3–4 °C. One study investigating *Miscanthus* grassland reported temperature increases of 10–15 °C at depths of up to 1 cm.

Table A9.1. Vegetation and fire temperatures in experimental studies.

Habitat	Methodology	Temperature and residence time	Source
Dry heath/blanket bog	17 prescribed fires on a moor in the Peak District, UK. Burned March–April over three years.	Maximum of 982 °C at base for 11–547 seconds and maximum of 993 °C at canopy for 6–474 seconds. Mean maximum at base was 662°C with a mean residence time of 184.5 seconds. Maximum temperature of canopy was 705.5°C with a mean residence time of 179.3 seconds.	Harris *et al.* 2011a
Dry heath and raised bog	Estate in Scotland, UK. 7 experimental fires on four separate days. Burned as head fires, each area about 25 m x 30 m. Two treatments: moss/litter layer left in place and moss/litter layer removed. Thermocouples placed 2 cm below ground.	21°C at soil surface, moss/litter layer present. 73°C soil surface, moss/litter layer removed.	Grau Andres *et al.* 2017
Blanket bog/dry heath	Estate in Scotland, UK. 15 experimental fires burned from October 2003–April 2004. Each fire c. 15 m x 20 m.	346 °C–704 °C with time above 400 °C in the canopy ranging from 0–37.5 seconds. Temperature at surface of moss/litter layer >100 °C ranging 0–100 seconds.	Davies *et al.* 2010
Two Boreal forest sites, one with areas dominated by lichen and the	Two separate forest sites in northern Sweden. Treatments over two years with 5	Lichen site, no fuel added a maximum temperature of c.400 °C, at *Vaccinium* site no fuel added, maximum temperature >600 °C. Where fuel added there was little	Schimmel & Granstrom 1996

other dominated by *Vaccinium myrtillus.*	treatments on each site. Plots were 100 m x 50 m.	difference between sites with range of 650–750 °C. The residence time at the mor level varied by amount of fuel and was <1 minute >60 °C where no fuel added up to 50–75 minutes where maximum fuel added. No lethal temperatures were recorded 20–30mm beneath the burn boundary.	
Dry heath and Valley Bog/wet heath	One estate in Scotland, UK. 7 burns with 40 temperature recordings (20 at ground level, 20 at 20 cm height).	At 20 cm above ground, the maximum temperature was 840 °C. The maximum temperature at ground level was 715 °C. The most frequent temperatures were in the range 300–500 °C at ground level whilst the minimum temperature at 20 cm above ground was 500 °C. Suggestion that residence time was <2.5 minutes.	Whittaker 1961
Heather	One estate in Scotland, UK. 35 fires sampled with temperature recording made “in the leafy parts of the plants”.	Maximum temperature was 940 °C but the average maximum from 35 fires was 670 °C. The average residence time above 400 °C increased with age of heather and varied from 20–60 seconds.	Kenworthy 1963
Dry heath	Estate in Scotland, UK. 2 fires set in Autumn and 5 fires set in Spring.	In autumn fires, maximum temperature in crown was 485 °C (22 cm above ground surface). Highest maximum temperature in mid-crown was 545 °C at 10 cm above the ground surface. Residence times were not clear but appear to be less than 40 seconds for upper crown but more for mid-crown. In spring, maximum canopy temperature was 360°C but the typical temperatures were around 170–190 °C.	Kayll 1966
Forest and grasslands	Review of the ecological effects of forest and brush fires from around the world.	Slash burns involving Douglas Fir, Cedar and Hemlock could reach 454 °C. Other work in a similar location recorded temperatures up to 1005 °C above the forest floor. In Spruce and Pine slash burns in Russia, ground temperatures reached 260 °C. Vegetation on sandy-topped soils in Australia reached temperatures up to 213 °C. Grassland with light litter reached up to 121°C and brushland over a mineral soil recorded temperatures up to 177 °C.	Ahlgren & Ahlgren 1960
Savanna/forest	Forest reserve in the guinea savanna zone of Nigeria, Western Africa. Investigated temperatures at different heights. Three plots used with	All soil surface records were over 538 °C. This temperature extended up to 3 m from the ground. Temperatures >100 °C were	Hopkins 1965

	fire sensitive paint on aluminium placed 2 m apart vertically, up to 6 m.	recorded up to 6–7 m from the ground.	
Bush and Grassland	Quotes research from Senegal and Sudan, Africa.	Grass fires in Senegal found that maximum temperature at the ground surface 140 °C with a residence of 2 minutes, at one half meter above the soil the temperature was noted to be 500 °C. On grassy savanna 40–60 cm in height in Sudan, soil surface temperatures varied from 105–213°C depending upon whether there was a wind. On the surface of the ground beneath 1 m high grass, a maximum temperature of 714 °C was recorded. The soil surface temperature remained between 120–715 °C for about 6 minutes. With grass 1.5 m tall, a temperature of 850 °C was recorded. Additional wok on Chaparral bush reported above surface temperatures of 160–290 °C.	Guilloteau 1956
Japanese Lawn Grass (*Zoisia japonica*)	Sendai, Japan. Burned plots at 11 am and 5 pm and measured temperatures at a range of heights between 2 cm above ground to 100 cm above ground.	At 11 am, the highest temperature was 367 °C at 14 cm above ground. Temperatures at 0, 2, 30, 50 and 100 cm did not exceed 200 °C. At 5 pm, the maximum temperature was 234 °C at a height of 11 cm above ground. The temperatures at the height of 0, 2, 5, 50 and 100 cm did not exceed 100 °C. In both treatments, the time that the temperature was above 200 °C did not exceed 1 minute and the time at the soil surface where the temperature was >50 °C lasted for more than 3 minutes.	Iwanami *et al.* 1969
Miscanthus grassland	Tohoku, Japan. Randomized block method replicated 2 times. Each plot 6 m x 6 m. Temperature measurements taken 0, 2, 5, 8, 11, 14, 17, 20, 25, 30, 100 and 200 cm above the soil surface. Burning carried out in Spring and Autumn. Some treatments received sodium chlorate powder spread over the vegetation prior to burning.	Maximum temperature in autumn 1964 was 483 °C at a height of 50 cm. In autumn 1966, the maximum temperatures recorded were 776 °C at a height of 20 cm and 767 °C at a height of 14 cm respectively. Fire residence times varied around the 200 °C mark with some lasting >1 minute and other <1 minute. In the 2–50 cm height category, fire residence time above 400 °C was >30 seconds. In the Spring, maximum temperatures were 789, 712 and 652 °C at the height of 11–17 cm respectively. At the height levels 8–30 cm, the temperature exceeded 600 °C in all the experimental plots. The vertical	Iwanami 1969

		temperatures of spring and autumn fires were similar.	
Mediterranean scrub	Valencia, Spain. Investigated spatial distribution of fire temperatures on plots that had fuel added. The added fuel amounted to 2 kg m^{-2} (F1) or 4 kg m^{-2} (F2).	50% of the temperatures in the plots with 2 kg m^{-2} of fuel added were in the range 170–235 °C. The mean values for these plots were 240, 239 and 218 °C with the highest recorded temperature being 621 °C. In plots where 4 kg m^{-2} of fuel added the values ranged from 322–543 °C with mean values of 418 m 448 and 435 °C. The highest temperature recorded was 677 °C.	Gimeno-Garcia *et al.* 2004
Forest	Montana/Idaho, USA. 43 plots with undisturbed duff layers and diverse load of surface fuel split between 2 slash sites and one site (West Side) where there had been no recent disturbance and a lack of downed woody surface materials. All burns were conducted in August at dusk.	Maximum temperatures of the litter surface in the slash sites was 690 and 460 °C respectively and in the soil surface <80 °C. The maximum temperature on the non-slash site 300 °C at the litter surface, 515 °C at in the duff and 400 °C at the soil surface. Maximum flame heights on slash plots reached 3 m high and flaming lasted up to 30 minutes. On the non-slash plot flame height was only a few cm in height and had a duration of less than 3 minutes. Duration of temperature >100 °C was 1 and 2.5 hr for the slash sites and 16+ hr for the non-slash site.	Hartford & Fransden 1992
Grassland	Serengeti, Africa. 18 grass swards burned at 5 locations within the Park. Temperature was measured at 2–7, 5–29 and 20–72 cm above the ground. The areas burned varied from 10–25 m^2.	The maximum temperatures recorded ranged 540–905 °C with a mean maximum for any site from 407–830 °C. Residence times were generally only a few seconds in length which then declined to ambient within 2 minutes.	Stronach & McNaughton 1989
Forest slash	Evo, Finland. Burned 2 m by 2 m plots on three sites with fuel loading varying from 0, 1, 2, 4, 6 and 8 kg/m^2, with each being replicated 3 times. Burning took place in the afternoon.	Maximum temperatures with addition of 4–6 kg/m^2 fresh weight varied from 410–809 °C with a fire residence time above 100 °C of 14.9 +/- 8.5 minutes and a fire residence time above 400 °C 4 +/- 3.9 minutes. At the second site, the maximum temperature recorded was 869 °C with a range of 701–869 °C and a mean of 779 °C. The mean duration of temperature above 100 °C was 20.7 +/- 0.2 minutes and above 400 °C 1.6 +/- 4.2 minutes.	Vasander & Lindholm 1985
Heather, Gorse, Bilberry, Crowberry and *Sphagnum*	Material collected from North Wales, Peak District and the Wirral, UK. Investigated smouldering/ignition in laboratory conditions.	Time above 300 °C for peat fuel bed was >4500 seconds, Bilberry was >3000 seconds, Heather c. 1500 seconds. The maximum recorded temperatures were:	Santana & Marrs 2014

		heather, 900 °C, Peat >9000C, gorse and bilberry >900 °C, Sphagnum and crowberry, c. 600 °C.	
Heather/Raised Mire	Estate in Scotland, UK. 19 experimental fires, 10 on heath and 9 on raised mire. Some of the plots were subject to experimental drought that combined with weather-induced variation in burning conditions allowed a variety of severity of fire effects to be investigated so that the treatments were split into Low Severity fire and High Severity fire.	Dry heath low severity had a mean ground temperature of 31 °C with a range of 7–87 °C. The high severity fire on dry heath had a mean temperature of 189 °C with a range of 9–661 °C. The low severity fire on the raised mire had a mean ground temperature of 10°C with a range of 8–17 °C and a high severity mean ground temperature of 15 °C with a range of 6–48 °C. At 2 cm depth, the dry heath site had a mean of 13°C with a range of 4–27 °C with low severity fire and a mean of 40 °C with a range of 5–254 °C. On the raised mire site at 2 cm depth, the low severity mean temperature was 9 °C (range 7–11 °C) and at the high severity fire a mean of 10 °C with a range of 6–12 °C.	Grau-Andres *et al.* 2019

Table A9.2. Fire and sub-surface temperatures in experimental studies.

Habitat	**Methodology**	**Temperatures**	**Source**
Dry heath and raised bog	Estate in Scotland, UK. 7 experimental fires on four separate days. Burned as head fires, each area about 25 x 30 m. Two treatments: moss/litter layer left in place and moss/litter layer removed. Thermocouples placed 2 cm below ground	Time above 50°C for both treatments was 0 seconds.	Grau Andres *et al.* 2017
Blanket bog/dry heath	Estate in Scotland, UK. 15 experimental fires burned from October 2003–April 2004. Each fire c. 15 m x 20 m.	Thermocouples buried in moss layer and only one registered a temperature >500 °C so buried probes dropped from further analysis.	Davies *et al.* 2010
Two Boreal forest sites, one with areas dominated by lichen and the other dominated by *Vaccinium myrtillus.*	Two separate forest sites in northern Sweden. Treatments over two years with 5 treatments on each site. Plots were 100 m x 50 m. Thermocouples placed 2 cm below the surface of the mineral soil.	No temperatures >100 °C were recorded.	Schimmel & Granstrom 1996
Dry heath and valley bog/wet heath	One estate in Scotland, UK. 7 burns with 40 temperature recordings (20 at ground level, 20 at 20 cm height).	Found that little change in temperature 1 cm below surface of peat so investigations ceased. Later reported that increases in temperature below 1cm in the peat surface was “probably less than 28	Whittaker 1961

		°C" compared to the recorded accompanying temperature of the burning heather of 440 °C.	
Bush and grassland	Quotes research from Senegal and Sudan, Africa.	Grass fires in Senegal recorded an increase in temperature of 3–4 °C at depths of 2 cm and below. These increases occurred slowly but persisted for around 30 minutes raising the temperatures in the soil layer from 30, 33, 36 and 37 °C to 36, 38, 42 and 46 °C respectively. Similar work in the Sudan on grassy savannah found that the increases in temperature 2 cm below the surface amounted to a maximum of 14.4 °C (in sandy soil) as against an increase of approximately 700 °C at a few mm above the soil surface.	Guilloteau 1956
Miscanthus grassland	Tohoku, Japan. Randomized block method replicated 2 times. Each plot 6 m x 6 m. Temperature measurements taken 1, 2, 3 and 4 cm below the soil surface. Burning carried out in Spring and Autumn. Some treatments received sodium chlorate powder spread over the vegetation prior to burning.	Readings limited to spring burns. At 1 cm below the soil surface the temperature was 10–15 ˚C higher than the temperature before burning. At 4 cm below the soil surface there was a negligible change in temperature.	Iwanami 1969
Forest	Montana/Idaho, USA. 43 plots with undisturbed duff layers and diverse load of surface fuel split between 2 slash sites and one site (West Side) where there had been no recent disturbance and a lack of downed woody surface materials. All burns were conducted in August at dusk.	"about 4–7 cm below the duff/mineral soil interface, the mineral soil was barely warmed."	Hartford & Fransden 1992
Heather/raised bog	Estate in Scotland, UK. 19 experimental fires, 10 on heath and 9 on raised mire. Some of the plots were subject to experimental drought which combined with weather induced variation in burning conditions allowed a variety of severity of fire effects to be investigated so that the treatments were split into Low Severity fire and High Severity fire. Temperatures recorded at 2 cm below soil surface.	The mean temperature on the low fire severity heathland plots was 13 ˚C (range of 4–27 ˚C) and 40 ˚C (range of 5–254 ˚C) on the high fire severity plot. On the mire low fire severity plots, the mean temperature 2 cm below the surface was 9 ˚C (range 7–11 ˚C) and 10 ˚C (range of 6–12 ˚C) on the high fire severity plots.	Grau-Andres 2019

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