MoorLIFE 2020

D4 – Estimating Carbon Released from Wildfires:

A case study into the estimated amount of carbon released as a result of the wildfire that occurred on the Roaches in August 2018.

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Executive Summary

As part of the MoorLIFE 2020 project, Moors for the Future Partnership (MFFP) aims to monitor the threats to Active Blanket Bog (ABB), of which the primary threat is wildfire. The wildfire that occurred on the Roaches, Derbyshire, in August 2018 caused approximately 61ha of damage to the ABB areas located on site. Wildfires impact on a wide variety of ecosystem services, including carbon sequestration and storage, by releasing the carbon that is stored in peat *(Davies et al, 2013)*. Additionally, the monitoring of carbon emitted to deliver MoorLIFE 2020 is also another key deliverable of the project. Therefore, to understand how the MoorLIFE 2020 carbon emission fits into the wider landscape, the amount of carbon released as part of the wildfire that occurred on the Roaches was estimated, and then compared to the wider literature and how this compares to the amount of carbon released during restoration activities undertaken as part of MoorLIFE 2020.

A variety of factors affects the carbon content of soil e.g. wetness (*Hendra et al, 2018*), soil bulk density and area (*Lindsey, 2010*). This variability means that it is difficult to get an accurate assessment of the amount of carbon released as part of this event. Furthermore, due to the unpredictability of wildfires, it is difficult to find other case studies that have been undertaken using direct ground based measurements.

The wildfire on the Roaches was chosen because MFFP has an existing monitoring site located there, measuring a number of variables including peat depth. The monitoring site was located within the area of the burn scar, allowing for peat depth before and after the wildfire to be collected, a key consideration when estimating carbon released as a result of wildfire.

It should be noted that the methodology assumed that the burn depth is equal across the whole site, and therefore causing the same amount of peat loss across the area. This is unlikely to be the case, but is in line with assumptions made by other studies. Additionally, variations in burn severity could not be quantified across the whole site.

The results indicated an estimated 3,422 tonnes of carbon was released as a result of the wildfire, based upon the average figures used. Some of this carbon will be converted to pyrogenic carbon, one component of which is black carbon, which will be redeposited on site. When this is taken into account the total amount of carbon released to the atmosphere is 3,115 tonnes. Assuming MFFP standard bare peat restoration techniques are used on the site, then it will take 10 years to protect the same amount of carbon through reducing the impacts of erosion.

Carbon was primarily released in the form of carbon dioxide in smoke and fumes, therefore the figure was then converted into carbon dioxide (CO_2) indicating that 11,430 tonnes of CO_2 was released.

This is approximately 68 times more carbon dioxide than was used to deliver year 3 of the MoorLIFE 2020 project (166 tonnes of CO_2), which to date has seen the most amount of carbon released as a result of our works.

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1. Introduction

The restoration and protection of peatlands is important because peatlands represent a significant store of carbon (*Davies et al, 2013*), with close to an estimated 20 million tonnes locked up within the peatlands of the Peak District National Park alone *(PDNPA, 2009).* This accumulation of carbon has occurred due to the slow rate of decomposition experienced within this environment as a result of the anaerobic conditions present (*Reddy et al, 2015*).

A key threat to Active Blanket Bog (ABB) is wildfires which can lead to the release of the carbon that is locked up within them (*Davies et al, 2013*). The South Pennine Moors (SPM) Special Area of Conservation (SAC) has experienced a large number of wildfires in recent years, with 51 instances of wildfire recorded in 2018 *(Titterton et al, 2019)*. With significant numbers of wildfires occurring, a greater amount of carbon will be released into the atmosphere *(Santin et al, 2015).* The wildfires also damaged / destroy vegetation *(Davies et al, 2013)*, which would continue to help remove carbon from the atmosphere, creating a longer term impact on carbon emissions. The release of these emissions contribute towards global warming *(Berwyn, 2018)*. With the UK government aiming to cut greenhouse gas emissions to net zero by *2050 (UK Government, 2019)*, it is important that work is undertaken to reduce the risk and severity of wildfires through concreate conservation actions (e.g. gully blocking etc.) and education (e.g. public engagement events).

During a fire, carbon is released in a number of ways, primarily as CO_2 in fumes and smoke; however, some carbon will be converted into pyrogenic carbon termed char *(Clay and Worrel, 2011)*. One component of char is black carbon (charred carbon deposited by vegetation and grassland fires). These latter components may not be lost to the atmosphere.

Due to the unpredictability of where these events occur, it is difficult to obtain empirical data on wildfires. As such, the wildfire that occurred on the Roaches in 2018 represents a unique opportunity to estimate the impact wildfire has on the amount of carbon released during a wildfire event using direct ground based measurements. This is because MFFP has a monitoring site situated within the burn scar area, collecting a variety of data including peat depth, vegetation data, water table depth and weather information. The site was established in late 2016, allowing before and after data to be collected, a key requirement for determining carbon released due to wildfire. These difficulties are represented in the literature, with it being difficult to find relevant studies looking at carbon released due to wildfires using direct ground measurements *(Ballhorn et al 2009).*

2. Aims and objectives

As part of the MoorLIFE 2020 project, action D4 aims to monitor the threats to ABB, with the primary threat being wildfire, whilst action D5 aims to monitor the carbon emitted in delivering this project. This case study contributed to the delivery of both these actions by demonstrating the carbon impact that wildfires can have on this environment and setting our work in a wider context by:

A. Identifying how much carbon is released through a wildfire event when compared to the activities required to restore an ABB site, which is the focus of action D5.
B. Emphasise the consequences of wildfire and help to reduce the number of accidently started wildfires by increasing awareness of the impact which people's actions can have.

Additionally this work gives us further evidence of the impact wildfire has on this habitat, potentially allowing MFFP to tailor restoration work in the future, e.g. increase the density of *Sphagnum moss spp* planted to increase carbon sequestration (*Harpenslager et al, 2015*).

3. Methodology

3.1 Study Area and Background

The wildfire on Friday 10th August 2018 occurred on an area of land called the Roaches, which is located within the Peak District National Park (PDNP) 4 miles North of Leek and 8 miles North West of Macclesfield, see Figure 1 below. The wildfire was started by a campfire within the forested area of the site which then spread to the ABB area, burning a total area of 65ha of which 4ha was woodland leaving 61ha of ABB habitat damaged and causing the loss of a number of moorland shrubs, herbs and mosses including *Sphagnum* Moss.

For this case study the area of woodland was excluded from the analysis as we are not able to determine the carbon content of the trees, the analysis will therefore focus on just the ABB sections.

As identified in Figure 1 all of the sampling locations were outside of the wildfire burnscar perimeter, as we are aiming to sample what the peat was like prior to it being removed / damaged as a result of the wildfire.

Figure 1 – Location map showing the outline of the burn scar perimeter for Roaches wildfire in 2018. Inset location of the Roaches in the context of the PDNPA.

3.2 Carbon Released

Equation 1 was used to determine the amount of carbon released as a result of the wildfire.

Carbon released = estimate of burned area*soil bulk density*carbon content*depth of peat burned

Equation 1: Formula for calculating carbon released (Evans, 2018)

3.3 Estimated Area Burned

The burn scar perimeter was mapped by walking the line of the area burnt using the tracks function on an Etrex 10 GPS. This mapping exercise was undertaken in September 2018. This allowed the burnt area to be calculated in hectares using MapInfo® software. Hectares was then converted into cm^2 to ensure that all units were the same type.

3.4 Soil Bulk Density

The soil bulk density was calculated using the methodology described in Rowell *(2014)*. This involved sinking a density ring, 5.5cm in diameter and 4cm in length, into the soil vertically and then digging out the density ring, being careful to leave soil hanging out of the top and bottom of the ring. The excess soil was then carefully removed using a knife leaving an intact core behind. The sample itself was confined to the top 15cm of soil *(Chaudhari et al, 2013; Wood, 2006).*

The site was split into two areas focusing on:

- Areas with less than 5 degrees of slope
- Areas with more than 5 degrees of slope

Within each of these areas 5 randomly selected sample locations were identified, which in total provided 10 samples (see Figure 1 above). The reason for sampling the site according to these parameters of slope is because soil bulk density varies by slope and depth, and according to Lindsey (*2010*) slope is one of the key factors in determining carbon content.

Prior to sampling taking place each density ring, see Figure *2* below, was weighed and numbered so that the correct weights could be attributed to the correct sample.

Density rings are metal rings that are hammered into the soil in order to create a soil core which can be used for soil bulk density calculations.

Figure 2: Photo and definition of density rings

Once collected the soil samples were dried in an oven at 105°C for 24 hours *(Rowell, 2014)* and then weighed again to obtain the dry soil mass. Next, soil bulk density was calculated using the formula identified in Equation *2* below.

Calculation of dry bulk density (using typical data)	(grams)
Mass of cylinder + caps + dry soil	224.28
Mass of cylinder + caps	77.02
Mass of oven dry soil	147.26

e.g. Volume of cylinder = $\pi r^2 L = \pi \times 5.5^2 \times 4 = 121\ cm^3$. Therefore oven-dry bulk density is:

$$147.26/121 = 1.21\ g\ cm^3$$

Equation 2: Soil bulk density calculation (Adapted from Rowell, 2014)

3.5 Carbon Content

Ten soil samples of approximately 100g of peat were collected at the same location as the soil cores and analysed using the OX/IR technique *(SAL, 2019)*. The analysis was undertaken by Scientific Analysis Laboratories (SAL).

3.6 Peat Anchor Data

Data provided from the Community Science project (*Moors for the Future Partnership*, 2018) enabled peat anchor data pre and post fire to be collected. This involved measuring the distance between the ground and the top of the peat anchor on the Northern face, for 10 different peat anchors spread out across the monitoring site (see Figure 1 on P4 for locations). The higher the number the larger the difference between the ground and the top of the peat anchor and has been used to determine the change in peat levels.

3.7 Black Carbon

A proportion of the amount of carbon calculated to have been released from the site post-burn is likely to have been converted into pyrogenic material, including black carbon, this carbon was not lost to the atmosphere. Black Carbon is the charred remains of vegetation and organic material that was not completely burnt during the wildfire. Clay and Worrall (*2011*) estimated that black carbon accounted for 4% of the total carbon released during a fire.

$$\boxed{\text{Total carbon released to the atmosphere} = \text{Total carbon produced}*0.96}$$

Equation 3: Total carbon released to the atmosphere calculation

3.8 Carbon Dioxide

Once the amount of carbon released was identified it was converted into carbon dioxide by multiplying total carbon released to the atmosphere by 3.67 (Evans, *2018*), which is the difference in atomic weight between carbon and carbon dioxide (EIA, 2020).

3.9 Assumptions

A number of assumptions have been made when calculating the carbon released as a result of the wildfire including:

Carbon content of ash and other pyrogenic by-products – This study does not calculate the amount of carbon that was re-sequestered, either on site or at locations outside the burn scar perimeter, which can be incorporated back into the soil through geological and biological processes including bioturbation, the actions of organisms like earthworms, and geological process such as freeze thaw cycles (*Bodí et al*, *2014*).

As site specific values for this type of carbon were not calculated, separate values were obtained from a study undertaken in the Peak District National Park (PDNP), specifically Edale, by Clay and Worrall (*2011*). This study looked at the amount of black carbon that was produced as a result of a fire.

An even burn across the site – The study assumed that the wildfire burned evenly across the whole site, causing the same amount of peat loss which is unlikely to be the case. This assumption has been made because data is not available for the whole burnt area, due to the unpredictability of where wildfire will occur. It should be noted that this is a common problem associated with this type of research and the same assumptions have been made by *Ballhorn et al (2009).* Based upon the location of peat anchors, there is a possibility that the depth burnt is an underestimation because all the peat anchors are located at the bottom of a slope where it is likely to be wetter due to the water pooling there from the slope, this increased wetness may inhibit the impact of the wildfire.

Total extent of burnt area – The study assumes that all areas within the burn scar perimeter were burnt, which is not the case. This is because the wildfire does not burn evenly across the whole site, leaving tufts of disparate vegetation within the burnscar perimeter. Unfortunately, the tufts of vegetation were not mapped due to their small disparate nature. Figure 3 below is a photograph of the area taken 1 month after the wildfire occurred showing some tufts of vegetation within the area.

Figure 3: An overview of the burnscar perimeter after the wildfire occurred

4. Results

4.1 Peat Anchor Data

Analysis of the peat depth data, see Table 1 below, identified that the mean distance between the top of the peat anchor and the peat surface is 328mm pre wildfire, whereas the average post wildfire peat depth is 381mm a difference of 53mm, suggesting a decrease in the height of peat pre and post wildfire.

Table 1: Distance between top of the peat anchor and the peat surface pre and post wildfire (mm)

		Peat Anchor Locations (mm)										
	Date	**P01**	**P02**	**P03**	**P04**	**P05**		**P07**	**P08**	**P09**	**P10**	**Average**
Pre wildfire	30/10/17	386	70	450	140			185	53	180	322	223
	07/08/18	420	105	500	200	1010		195	110		345	361
	23/08/18	415	100	510	275	1030		230	105	280	400	372
	24/09/18	408	80	510	300	970		225	80	270	375	358
Post wildfire	25/10/18	395	80	505	275	965		225	65	275	385	352
	29/11/18	400	80	505	270	970		225	70	270	380	352
	20/12/18	400	80	505	275	975		220	70	270	380	353
	20/06/19	395		495	290	985				270	370	468

4.2 Carbon Content

The carbon content of samples is provided in Figure 4 below. The highest carbon content recorded was in sample 10S, which had a carbon content of 0.52% per gram, whereas the lowest recorded carbon content was in sample 11F at just 0.18% per gram a range of 0.34%.

Seven out of the ten samples have a standard deviation within the all site mean, this indicates that the average site figure of 0.415% per gram would be appropriate to use for carbon content across the site, when compared to using minimum or maximum figures obtained from the analysis.

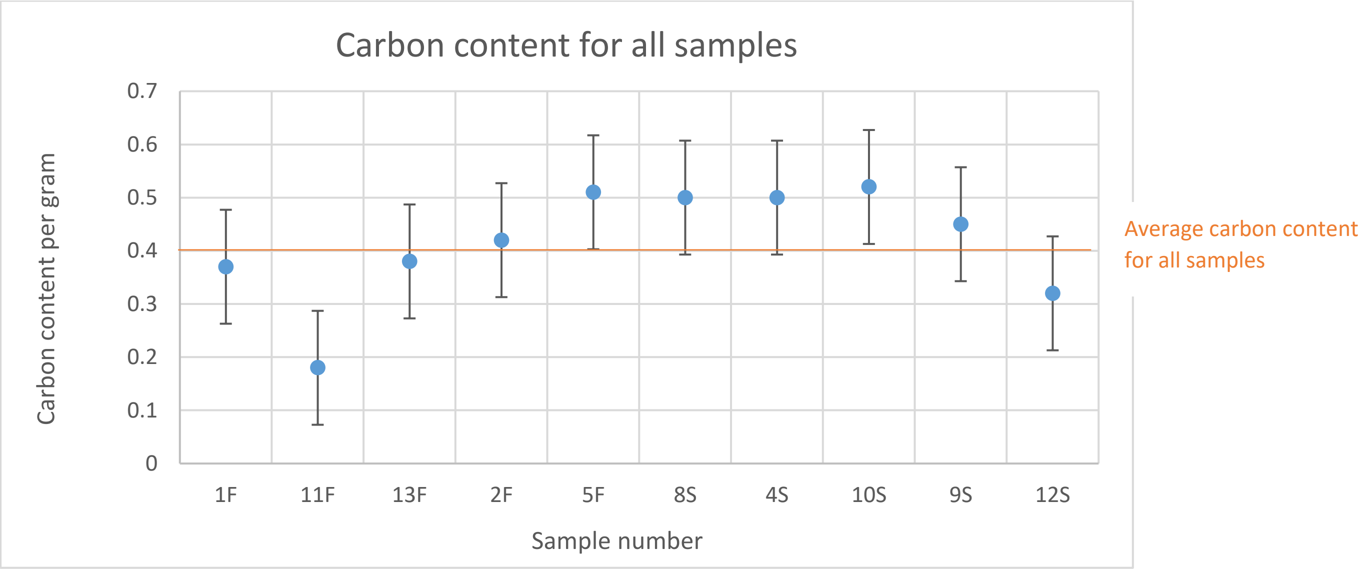

Figure 4: Carbon content per gram for sample locations that are sloped (S) and flat (F) with the error bars showing the standard deviation (P=0.05) for the mean, for the all site figure.

A Mann Whitney U Test was undertaken to determine that there is no significant difference between the sloped and flat areas where carbon content is concerned.

Table 2: Results of the Mann Whitney U Test for samples on sloped and flat area of the carbon content (P=0.005)

	Sum of ranks	**Count**	**U Value**
Flat	22	5	7
Sloped	33	5	18
Critical value	2		

4.3 Soil Bulk Density

Soil bulk density samples were analysed from 10 locations around the edge of the burn scar perimeter, with 8 out of the 10 samples within the standard deviation (0.11cm^3) of the all site average. Only two samples are significantly higher than the others suggesting there is a limited variability across the site.

The average soil bulk density for the whole site is 0.24 grams per cm^3, with the highest soil bulk density found in sample 11F, which is 0.47 grams per cm^3, whereas the lowest bulk density is 0.11 grams per cm^3 in sample 8S see Figure 5 below.

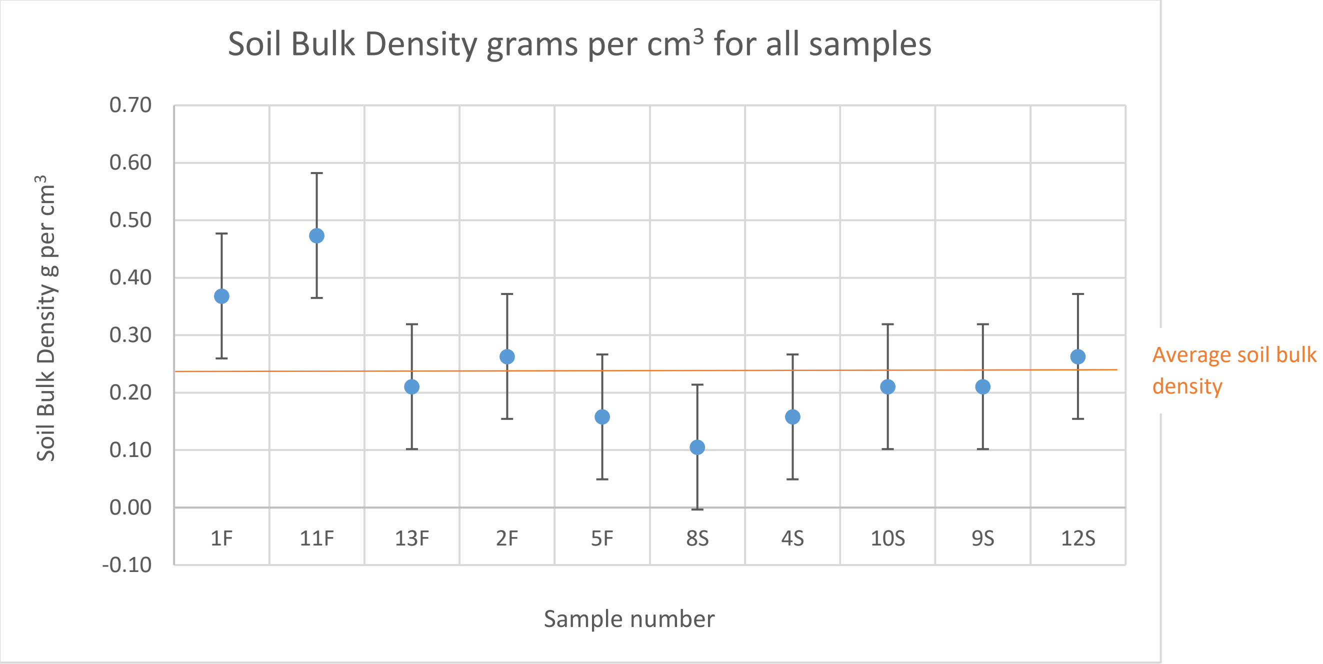

Figure 5: Soil bulk density measurements for the sloped areas (S) and flat areas (F) for the site, including the standard deviation (P=0.05) away from the mean for the whole site average.

Analysis of soil bulk density samples by gradient of slope indicated that there is no statistical difference between flat and sloped areas based upon a Mann-Whitney U test, see Table 3 below.

Table 3: Mann Whitney U test results for samples on sloped and flat areas (P=0.05)

	Sum of ranks	Count	U Value
Flat	34	5	19
Sloped	21	5	6
Critical value	2		

4.4 Total Carbon Released

The results indicated that the total average carbon released as a result of the wildfire on the Roaches was 3,244 tonnes of carbon, see Figure 6 below. Maximum and minimum values were also calculated based upon the maximum and minimum figures identified from the carbon content and soil bulk density variables identified above. This produced a range of 13,075 tonnes of carbon, highlighting the difficulty in getting accurate figures.

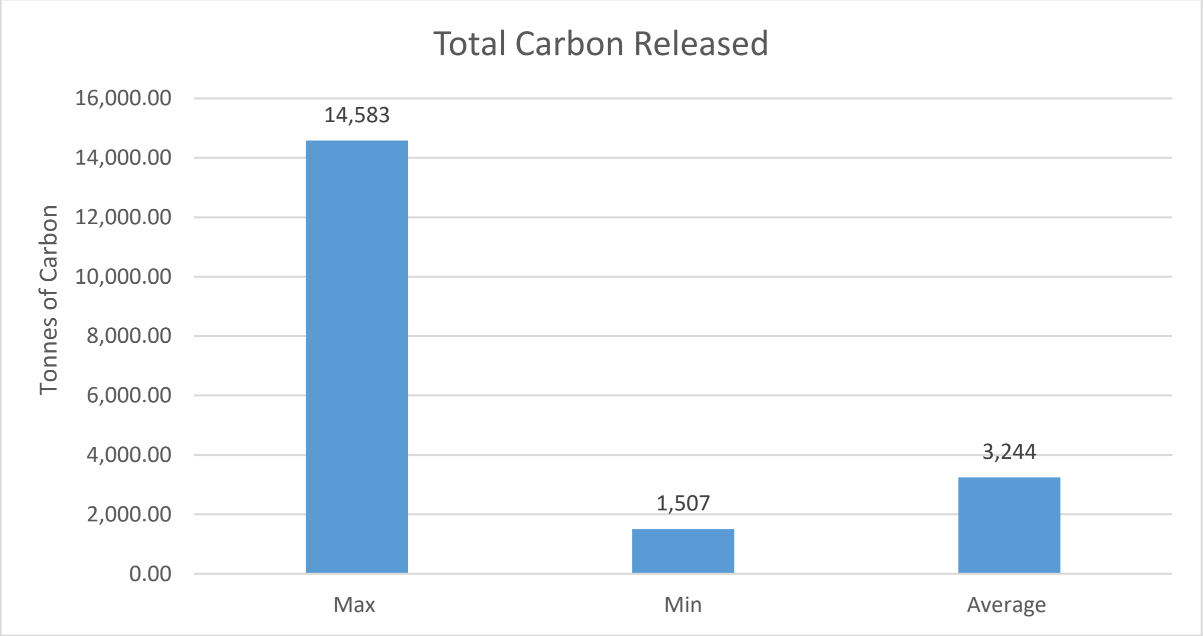

Figure 6: Total tonnes of carbon produced as a result of the wildfire

4.5. Total Carbon Released to the Atmosphere

Taking into account the amount of carbon that was converted into black carbon identifies that on average 3,114 tonnes of carbon (see

Table *4* below) was released into the atmosphere. The maximum amount of carbon released into the atmosphere was 13,999 tonnes whereas it could be as low as 1,447 tonnes of carbon released.

Table 4: Total Carbon released to the atmosphere

	Max	Min	Average
Total Carbon released to the atmosphere (T)	13,999	1,447	3,115

4.5 Carbon Dioxide Released to the Atmosphere

Using the average figures for all variables outlined above, indicates that 11,192 tonnes of carbon dioxide was released into the atmosphere as a result of the wildfire (see Figure 7 below). Due to the variability of the different factors involved in calculating the figure a minimum and maximum amount of carbon released was also calculated (5,200 and 50,307 tonnes respectively) (see Figure 7 below).

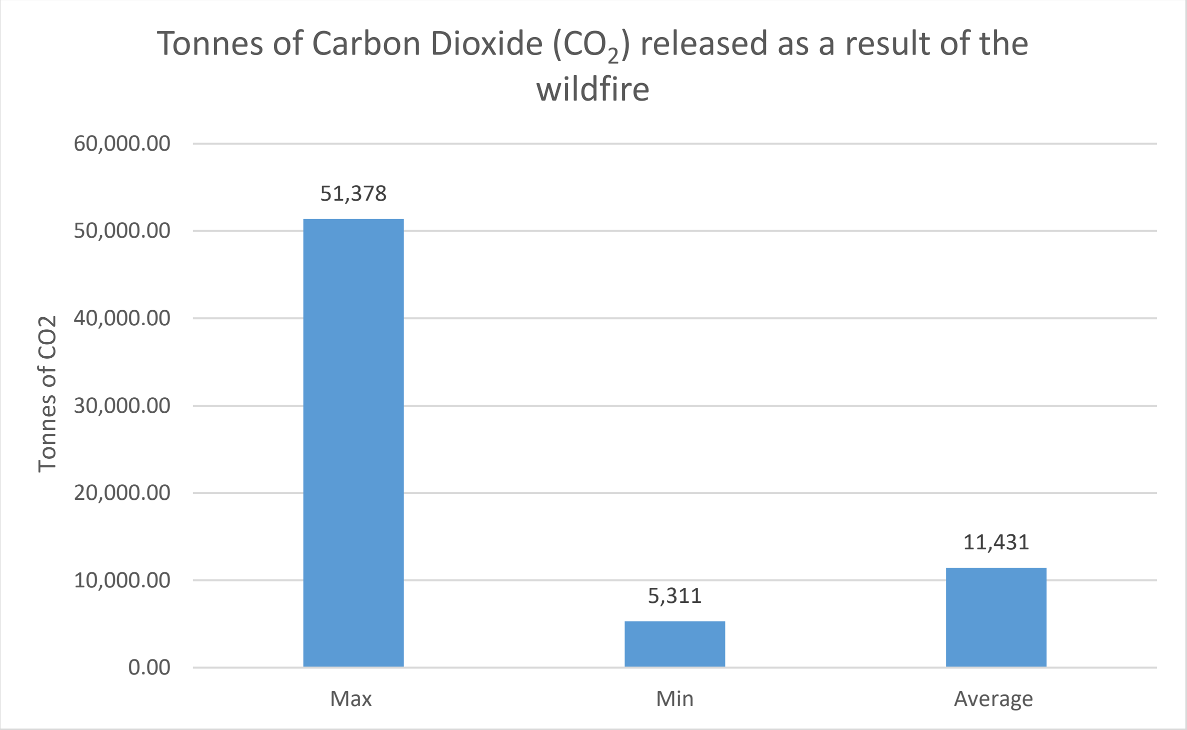

Figure 7: Tonnes of carbon dioxide (CO_2) released as a result of the wildfire

5. Discussion

This research looked at the quantity of carbon released from an area of blanket bog following a wildfire. It demonstrates that approximately 11,431 tonnes of carbon dioxide was released into the atmosphere.

This average figure more accurately represents the carbon released from the site when compared to the minimum and maximum figures calculated in this report. This is because the majority of the samples fell within the standard deviation away from the mean for both the carbon content and the soil bulk density. Furthermore the Mann Whitney U test indicated that there was no statistical significance between the gradient for both factors. As noted by Warren *et al* (2012) this figure can only be an estimate as all the factors (e.g. soil bulk density etc.) will vary across the site and it is beyond the scope of the study to identify these variations across the whole site.

The average figure for the amount of carbon released as a result of the wildfire is 3,244 tonnes which is the equivalent of 52 tonnes per hectare. This is approximately half way between the minimum (2 t C ha-1) and maximum values (110 t C ha^{-1}) in Poulter *et al* (2006) study, which examines smouldering wildfires in temperate peatlands of America, but below the 96 tonnes per hectare calculated by a similar study undertaken by Davies *et al* (2006) focussing on Scottish peatlands. It should be noted that it is higher than those figures calculated for Boreal peatlands (15 – 28 t C ha-1) of Canada *(Davies et al, 2006)*. However, the lack of comparable studies using actual before and after peat depth data highlights the difficulty in drawing accurate comparisons between this study and the wider literature.

Taking into account the amount of pyrogenic material left behind as a result of wildfire, the average amount of carbon released to the atmosphere is 3,115 tonnes, which when converted into carbon dioxide is 11,431 tonnes. A comparison to the MoorLIFE 2020 project, identifies that approximately 68 times more carbon was released in this one event than the 166.2 tonnes of carbon dioxide released in the whole third year of MoorLIFE2020, which involved 4,122ha of gully blocking, 851ha of Sphagnum Moss plugs planted, 1,635m of re-profiling, and over 400,000km of travel. This amount of carbon released is the equivalent to running 1,426 homes for one year.

The work undertaken by Worrall *et al* (2011) indicates that the bare peat restoration work MFFP undertakes protects 4.48 tonnes of carbon per hectare per year. Therefore, it would take 10 years to protect the same amount of carbon released in this wildfire. This emphasises the importance of the work that MFFP does, helping to re-wet moorlands and by communicating the importance of reducing wildfires.

It should also be noted that the wildfire also caused other impacts, including loss of vegetation, which can have impacts on other ecosystem services such as flood attenuation by reducing surface roughness and loss of biodiversity.

6. Summary

This study investigated carbon loss on the roaches. Key findings were:

- 3,115 tC (11,431 tCO2) lost from roaches fire
- The is a significant difference when compared with emissions from large project such as ML2020
- It will take a long time for the amount of carbon to recover the amount of material lost

7. Further Research

The current methodology only focuses on the carbon released from the peat, whereas further investigations could also consider the carbon released from the vegetation layer. This would allow a fuller picture of the amount of carbon released because of the wildfire.

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