Accepted: 22 February 2019
DOI: 10.1002/geo2.75

COMMENTARY

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Comment on: "Peatland carbon stocks and burn history: Blanket bog peat core evidence highlights charcoal impacts on peat physical properties and long-term carbon storage," by A. Heinemeyer, Q. Asena, W. L. Burn and A. L. Jones (*Geo: Geography and Environment* 2018; e00063)

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KEYWORDS: blanket bog, carbon, fire, moorland management, peatlands

A recent paper in this journal by Heinemeyer et al. (2018) considered the effects of managed burning on the carbon (C) balance of blanket peatlands in the Pennines, northern England. The study used short peat cores to compare recent C accumulation rates between three sites subject to differing frequencies of prescribed burning for grouse moor management. Using spheroidal carbonaceous particles (SCPs) for dating, they concluded that the most frequently burned site had the highest rate of C accumulation. This was attributed to the higher bulk density and charcoal content of this site, leading to the conclusion that grouse moor burning may convert otherwise decomposable organic matter into inert material, and that the presence of charcoal may suppress decomposer activity. The implication of their findings would be that – contrary to most current understanding – the use of prescribed fire on the grouse-moor-managed blanket bogs of the UK could be net beneficial for C sequestration. We believe, however, that this conclusion is flawed, due to a number of problems related to the study design, methods, and interpretation. Since these findings could have significant consequences for land-management policy regarding the use of prescribed fire on peatlands in the UK, and perhaps elsewhere, we set out our concerns here.

First, we do not believe that the study design permits the effects of grouse moor burning to be reliably tested. The study lacks an unburned control, so rates of C accumulation in burned sites cannot be compared with a natural reference.

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Inferences rely on differences in estimated burn frequency between the three sites, which were 23, 25, and 28 years on average. These differences seem rather small. Current burn rotation length is stated to be 10–15 years at all locations, suggesting no present-day differences. Furthermore, the sites were located 30–40 km apart, had different climate regimes (30% difference in mean annual rainfall between the driest and wettest site), and different land-use histories. Notably, the "frequently burned" site (Whitendale) is the only one that was not subject to historic ditch drainage. To compare burning "treatments," the authors used data from one small area of each peatland. Although they took three cores from each site, these were located within a 5 m radius, with different cores used for different measurements. It seems likely that multiple cores taken over larger areas would show greater within-treatment variability. This is not considered in the statistical analysis, the consequence of which is an inflated effect size when comparing treatments. In other words, there may not actually be significant differences between sites. The combination of rather subtle differences in burn management, potentially large differences in other site properties linked to climate and drainage history, limited replication, and the absence of a control site would appear to render conclusions regarding burning impacts uncertain.

Second, Heinemeyer et al. selectively use data from the Moor House (North Pennines, England) long-term ecological research site as a source of unburned reference data (for example, they assume that the estimated age of 1,700 at 25 cm depth for Moor House is applicable to all three of their widely separated sites, without supporting evidence) while also heavily criticising previous results from the uniquely long-term (greater than 60 year) replicated Moor House controlled burning experiment. A number of these criticisms appear to reflect misunderstandings or incomplete knowledge of both the site and previous research. For example, they state that none of the depth profiles of Garnett et al. (2000) detected the 1975 SCP peak. This is because Garnett et al. used the (more reliable) 1950s SCP take-off date to date their cores, and did not therefore analyse SCPs up to the surface of all cores, where peat is less decomposed and reliable SCP measurement difficult (Swindles, 2010). Furthermore, Heinemeyer et al. argue that charcoal layers in the Moor House cores do not match the onset of experimental burn rotation in 1954, and suggest that a lower charcoal layer at 10–11 cm corresponds to this date, thereby invalidating the SCP take-off dates of Garnett et al. Subsequent work by Garnett and Stevenson (2004), not referred to by Heinemeyer et al., combined SCP and ^{14}C data to show consistent dating of charcoal layers formed by experimental burns in the upper peat profile, and high agreement between the SCP take-off date and the first appearance of bomb-enriched ^{14}C in the peat profile, both of which occurred in the 1950s (Figure 1). Another core analysed by Garnett and Stevenson (2004) revealed the presence of a deeper pre-1954 charcoal layer (presumably the one used by Heinemeyer et al. to argue that the Garnett et al. reconstruction was incorrect), which was clearly attributable to a previous fire. Given that Moor House was part of the Appleby Castle shooting estate prior to becoming a National Nature Reserve, the occurrence of such pre-experimental fires is to be expected; indeed recent work by Marrs et al. (2018) suggests that a site-wide fire occurred in around 1923.

Although critical of previous work, Heinemeyer et al. provide rather little information on how they dated their cores using SCPs, other than referring to a previous paper by Swindles (2010), which was in turn based on the method of Rose and Appleby (2005). It appears that they assigned the sample with the highest SCP concentration a date of 1975 (Swindles (2010) suggested 1979 for this peak) but did not consider the 1950s take-off date used by Garnett et al. (2000), even though this is generally considered to be the most reliable, hemispheric-scale signal (Rose, 2015). Figure 3c of Heinemeyer et al. shows extremely noisy SCP concentrations in the upper peat profile, without a clearly defined multiple-sample peak in any of the cores collected. This is also evident in Figure 1, suggesting that assignment of the 1970s peak to a single sample within a noisy record carries high uncertainty. Furthermore, there is no indication that Heinemeyer et al. considered the potential effects of short-term variations in acrotelm growth and decomposition on SCP concentrations, which Swindles (2010) described as "problematic" for the use of the 1970s SCP peak as a dating horizon. Of particular concern in the context of this study is the likelihood that a fire which consumes part of the peat mass but leaves the (intrinsically fire resistant) SCPs intact will produce an SCP peak that has little or no relation to the timing of the peak in SCP deposition. These issues have a major bearing on the study results: the assignment of the 1975 dated horizon to a large extent determines the subsequent estimates of peat C accumulation, and therefore burning impacts. If the dates are unreliable, then all subsequent results and interpretation – including the key finding that managed burning increases carbon accumulation – will also be unreliable.

Heinemeyer et al. also conclude that, alongside more frequent burning since 1950, C accumulation rates have increased compared with the preceding 250 years. This conclusion appears to be a function of the "acrotelm effect": deeper peat layers are older, which means that (other things being equal) they will have undergone more decay, and thus record apparent lower rates of C accumulation than shallower layers. This artefactual increase in C accumulation rates towards the top of peat cores is well known in palaeoecology (Clymo et al., 1998; Turner et al., 2014).

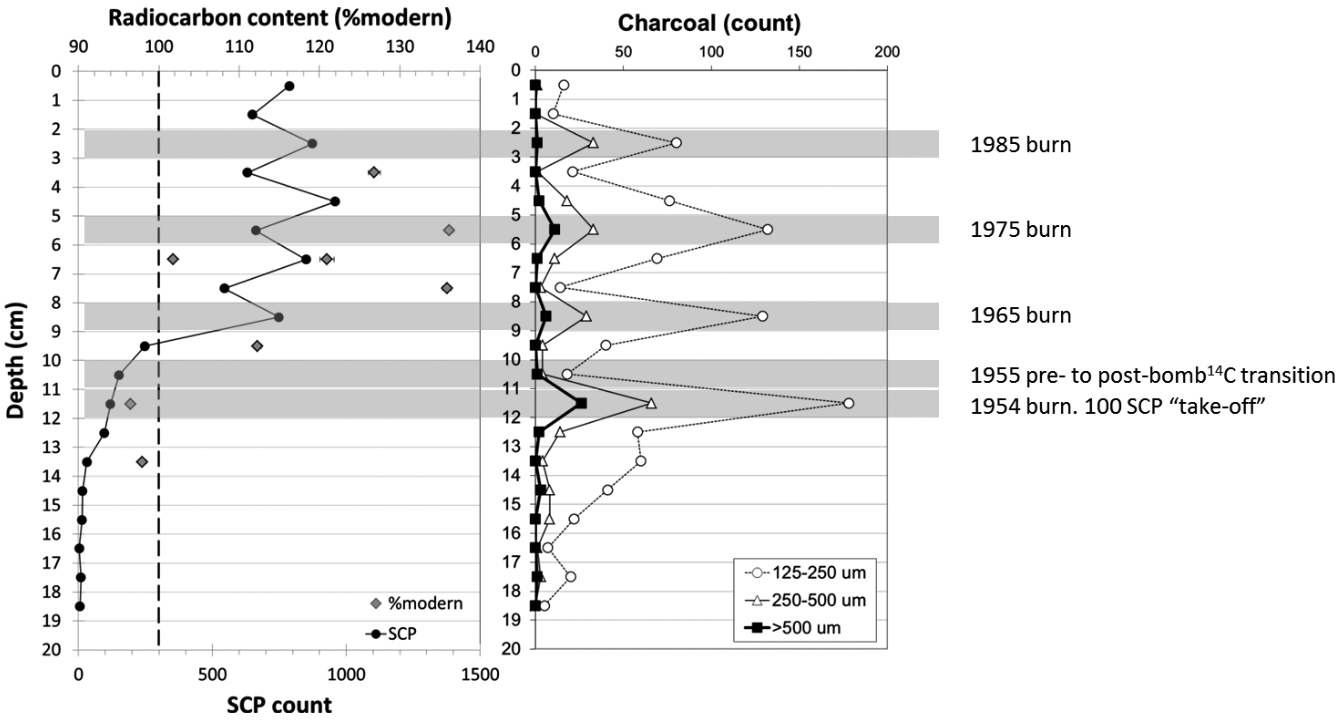

FIGURE 1 Spheroidal Carbonaceous Particle (SCP), radiocarbon (^{14}C) and charcoal content of a peat core collected at the Moor House Hard Hill experimental site. Data are taken from Garnett and Stevenson (2004). SCP and charcoal data are given in counts as originally presented. Counts were determined using 0.2 g air-dried peat samples and a standardised microscope counting procedure; counts can be converted to concentrations (number SCPs or number charcoal fragments g^{-1} dry peat) by multiplying by 16.7 (SCP) and 10.0 (charcoal). The cored site was located next to the experimentally burned plots and thus received charcoal inputs following each burn but was not burned directly after 1954. Of note are: (1) the consistency of the 1954 charcoal horizon, the 1950s SCP take-off point and the 1950s pre- to post-bomb ^{14}C transition; and (2) the variability of SCP concentrations in the upper layers, rendering correct assignment of the "1975 SCP peak" extremely difficult.

Finally, we note that the results of the peat core study appear to directly contradict chamber-based CO_2 flux measurements made during the same study at the same locations (Heinemeyer et al., 2019). These data suggest that the site with the lowest burn frequency, Mossdale, was acting as a net CO_2 sink from 2012 to 2015 (-122 g C m^2 $year^{-1}$), while the two more frequently burned sites were close to CO_2 neutral (Whitendale -34 g C m^2 $year^{-1}$, Nidderdale $+19$ g C m^2 $year^{-1}$). Although they do not refer to their own data, Heinemeyer et al. suggest that any discrepancies in results obtained using the two approaches may be due to a "major disadvantage" of the flux-based approach, that it "does not capture long-term incorporation of C as charcoal … while capturing decomposition from deeper, older layers, which affects the C budget calculations of recent periods." We agree that surface flux measurements cannot isolate the specific gain or loss of charcoal C, but disagree with the suggestion that that flux measurements somehow fail to capture the overall C balance of the system. The net exchange of CO_2 across the ground surface is what the atmosphere "sees," and encompasses the net effect of all internal peat C cycling, including any effects of charcoal (positive or negative) on decomposition processes. The inclusion of CO_2 derived from decomposition in deeper layers is indeed a vital component of the contemporary C balance in systems where organic matter that was previously protected from anaerobic decomposition by waterlogging has been exposed to oxygen via drainage or other disturbance (e.g., Moore et al., 2013; Turetsky et al., 2014). Fluxes that are not captured using chamber methods, notably the release of CO_2 via combustion of biomass during fire events, will further add to CO_2 emissions, thus exacerbating the discrepancy noted above between core and chamber-derived C balance estimates.

Overall, we must conclude that the interpretation of managed burn impacts on peat C accumulation by Heinemeyer et al. is not robust. Our key concerns are that (1) the study lacks replication or an effective unburned control; (2) the burn-frequency "treatments" are at high risk of being confounded by climatic, management, and within-site variations; (3) calculated C accumulation rates are critically dependent on correct estimation of SCP peak dates based on noisy data subject to confounding factors that have not been considered; and (4) the grounds on which the authors dismiss conflicting results from the only available long-term, replicated, and controlled UK burning experiment are not substantiated. Moreover, while we do not dispute the observed correlations between peat C content, bulk density, and charcoal content, we note that a compacted peat is almost invariably also a degraded peat, and a source of CO_2 emissions. For example, the regularly burned peatlands of Indonesia, which are composed of dense, recalcitrant, and charcoal-rich residual organic matter (Könönen et al., 2016), are also among the most intense hotspots of land-use-related CO_2 emissions on the planet (Page et al., 2002; Turetsky et al., 2014). The Intergovernmental Panel on Climate Change reported annual CO_2 emissions from peat fires of 0.12 Pg C/year, equivalent to 1.5% of all CO_2 emissions from fossil fuel burning (Ciais et al., 2013). While Indonesian peatlands and UK blanket bogs differ in many respects, they share the common features that (1) most fires are started deliberately, with the aim of modifying vegetation cover; and (2) peat in burned areas is compacted and charcoal enriched. To suggest that these characteristics are associated with increased net CO_2 uptake in the UK, when they are so clearly associated with large CO_2 release in Indonesia and elsewhere, would seem to be at odds with our broader understanding of the effects of fire on peatland ecosystems.

With the likely exit of the UK from the European Common Agricultural Policy and the eventual transfer of EU nature conservation legislation (e.g., Habitats Directive) into UK law, land management in the UK uplands is likely to go through a period of significant change. Activities that provide climate change mitigation benefits may be favoured by future public subsidy schemes (https://www.gov.uk/government/speeches/michael-gove-speech-on-uk-climate-change-projections; Committee on Climate Change, 2018), while those that generate emissions may be penalised. Recent papers suggesting that fire is an essential tool for peatland management (Davies et al., 2016), that the carbon implication of current practices of peat burning may be "not as bad as previously thought" (Marrs et al., 2018), or that they may even deliver carbon benefits (Heinemeyer et al., 2018) thus have the potential to significantly influence policy. With the impending publication of the UK Department of Environment, Food and Rural Affairs' 25-year England Peat Strategy, the forthcoming inclusion of peatlands in the UK's national greenhouse gas emissions inventory, and the need to reduce and – where feasible – reverse greenhouse gas emissions from the land to the atmosphere in order to achieve the "zero net emissions" target of the Paris Agreement, it is imperative that evolving policies are based on a robust and reliable scientific evidence base. For the reasons stated, we do not believe that the study by Heinemeyer et al. meets these criteria.

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How to cite this article: Evans CD, Baird AJ, Green SM, et al. Comment on: “Peatland carbon stocks and burn history: Blanket bog peat core evidence highlights charcoal impacts on peat physical properties and long-term carbon storage,” by A. Heinemeyer, Q. Asena, W. L. Burn and A. L. Jones (*Geo: Geography and Environment* 2018; e00063). *Geo: Geography and Environment*. 2019;e00075. https://doi.org/10.1002/geo2.75