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Lateral expansion of northern peatlands calls into question a 1,055 GtC estimate of carbon storage

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Both the size of the peatland carbon pool and its development over time are poorly constrained[1]. In a recent analysis, Nichols and Peteet[2] proposed that the northern peatland carbon store is 1,055 GtC, two to three times higher than previously thought[3]. We argue that such a large figure is inconsistent with measured peat depth and physical properties. The 1,055 GtC estimate was produced using an incorrect assumption of how peatlands expand, a methodology that is vulnerable to outliers, and using a dataset that lacks the necessary reproducibility and context for quality control.

Underpinning the time-history approach used by Nichols and Peteet[2] is the assumption that peatlands expand linearly in time after initiation. Thus the increase in peatland area is proportional to the summed frequency of peat initiation[1]. This assumption has been repeatedly called into question[1,4] and runs contrary to the overwhelming majority of evidence available from the literature[4–8], spanning a considerable number of peatlands across a diverse range of regions. Notably, the assumption that lateral expansion rates are linear is untenable as the literature points to nonlinear, initially restricted, lateral peatland expansion being the rule rather than the exception.

The reason for restricted lateral expansion rates is that the underlying and surrounding topography strongly controls peatland lateral expansion[5,6,8]. Even a relatively shallow slope (0.5%) may halt lateral expansion entirely[6]. After deglaciation, peat predominantly initiated in hollows and steep-sided basins[9]. In a practical sense this means that peat formation was often constrained, with little to no lateral growth for a long period of time. This was demonstrated as early as 1923 for a Swedish peatland[10], for example. Importantly, neglecting the influence of topography will result in a systematic bias towards the earlier expansion of peatlands, hence an overestimate of the peatland carbon stock. Notably, in studies that have directly investigated peatland expansion rather than initiation, lateral expansion is consistently most rapid in the mid-Holocene[4,11], even though initiation may have been much earlier.

It is important to note that when basal radiocarbon dates have previously been used to calculate peatland carbon stocks, the results have been more comparable to alternative approaches, such as measured inventories of carbon. For example, 612 GtC (ref. [3]) compared with an inventory-based estimate of 445 GtC (ref. [12]), both estimates of global peatland carbon content. We argue that it is specifically the combination of the methodology of Nichols and Peteet with the Neotoma dataset[13] that makes the new 1,055 GtC estimate particularly prone to error. In their approach undue weight was given to the oldest date in a region, making the method highly vulnerable to outliers. It has been previously demonstrated that a more conservative requirement of the average of the three oldest dates per region considerably changed the shape of peatland initiation and projected expansion, leading to later initiation and a reduced rate of lateral expansion[1].

A bold claim, such as the near doubling of the northern peatland carbon stocks[2], needs to be supported by primary data sources that can be assessed for quality, as other estimates have provided[3,14]. The Neotoma dataset is complex, with no consistent definition of what constitutes a 'peatland', and the database changes over time as new sites are added. As such, it does not meet basic expectations of reproducibility. It has proved impossible for us to reproduce the data used in the original estimate by Nichols and Peteet[2]. This is all the more problematic as poor-quality radiocarbon dates, which lack stratigraphic context or are otherwise unsuitable for dating peatland initiation, have in the past inflated carbon stock estimates owing to a bias towards earlier initiation[15], as could only be determined later from access to the primary data sources[15].

While Nichols and Peteet make a welcome attempt to include a more intellectually rigorous estimate of error than earlier estimates, the standard deviation (σ) of their 1,055 GtC estimate is extremely large, with a $\pm 1\sigma$ range of 511–1,782 GtC. As such, they state that their 1,055 GtC estimate is consistent with earlier studies, including the alternative inventory approach, and the peat depths derived from these two methods. However, our analysis of their data strongly suggests this is not the case (Supplementary Information). Using the same peatland area, bulk density and carbon content data as Nichols and Peteet, northern peatlands would require a mean depth of 7.1 m to store 1,055 GtC. To date, one of the largest published compilations of northern peat depth measurements[14] ($n = 7{,}111$) lists a mean depth of 2.5 m, with an upper 95% confidence interval of 3.5 m. The mean peat depth in major peatland regions in North America and Siberia is consistently found to be 2–3 m (refs. [14,16]). This demonstrates that the peat depth, and hence the double carbon stock estimate[2], is unrealistic and inconsistent with observed peat depth and physical peat properties. Furthermore, a recent inventory-based estimate of northern peatland carbon stocks[14], including a similar range of error sources, produced a more tightly confined estimate of 268–562 GtC, better reconciled with physical peat properties and global peat depth measurements[14].

Following the well-known Occam's razor philosophy or principle of parsimony, models should be made more complex only if the result leads to more realistic estimates. The increased complexity in the approach used by Nichols and Peteet does not increase the realism of carbon stock estimates nor reduce their uncertainty. Unless realistic models of lateral peatland expansion can be incorporated

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into estimates of peatland carbon stocks, the time-history approach will remain severely flawed.

The solution to modelling lateral expansion may lie in using process-based models, or the topography surrounding peatlands to estimate topography underneath them, based on digital elevation information in combination with geostatistical and/or machine-learning approaches, for example. Additionally, we strongly recommend that future peatland carbon stock estimates use independent measurements of peat depth and carbon accumulation to evaluate their realism and uncertainty.

Online content

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Data availability
The authors declare that the data supporting the findings of this study are available within the paper and its Supplementary Information files.

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J.L.R. and H.P. conceived the study, and all authors were involved in writing and revising the manuscript.

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