nature geoscience

MATTERS ARISING

https://doi.org/10.1038/s41561-021-00769-2

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No support for carbon storage of >1,000 GtC in northern peatlands

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ARISING FROM J. E. Nichols and D. M. Peteet *Nature Geoscience* https://www.nature.com/articles/s41561-019-0454-z (2019)

Northern peatlands store large amounts of carbon: 500 ± 100 GtC, according to a consolidated estimate from a diversity of methods[1–6]. However, Nichols and Peteet[7] presented an estimate of 1,055 GtC, exceeding previous estimates of carbon stock in global peatlands[2] and in northern peatlands by a factor of two. Here we argue that this is an overestimate, caused by systematic bias introduced by their inclusion of ^{14}C dates from mineral deposits and other unsuitable sites, the use of records that lack direct measurements of carbon density, and the methodology issues. Furthermore, their estimate is difficult to reconcile within the top-down constraints imposed by ice-core and marine records, and estimated contributions from other processes that affected the terrestrial carbon storage during the Holocene epoch.

Unsuitable datasets and methodology issues

Nichols and Peteet[7] used the time-history approach[2] to estimate peatland carbon stocks and their evolution over time. Their area-specific net carbon accumulation rates (j_C), as shown in their Fig. 2c, have a Holocene mean value of 33.4–37.6 gC m^{-2} yr^{-1} (median across three methods), which is 46–102% higher than previous estimates of 18.6–22.9 gC m^{-2} yr^{-1} (refs [2,3]). Why this difference? Nichols and Peteet calculated j_C from sedimentation rates (cm yr^{-1}) and carbon density (gC cm^{-3}). We argue that both of these parameters were overestimated by the authors.

Sedimentation rates are biased by the inclusion of ^{14}C dates derived from mineral-rich non-peat deposits. Nichols and Peteet claimed to include all the sites in the Neotoma Paleoecology Database labelled as peatlands or synonyms, such as bogs or fens. However, many of these records, despite being called ‘bogs’, are deposits that developed from initial lake stages. For example, Chatsworth Bog in Illinois (Neotoma ID 364) contains >12 m sediments but was a lake for most of its 14,000-year history. Mineral lacustrine sediment had almost completely filled the basin about 3,000 years ago, when it changed from a lake to a marl fen that accumulated peat. The large difference in j_C—up to 30 gC m^{-2} yr^{-1} during the early Holocene—between Nichols and Peteet[7] and ref. [3] (using the same data compilation) was partly due to Nichols and Peteet’s inclusion of rapidly accumulating mineral deposits. In addition, many sites from Nichols and Peteet originate from low-latitude locations that are not representative of the areas where the vast majority of northern peatland areas are located (their Fig. 1a and Supplementary Fig. 1); this also compromises their estimates.

As stated by Nichols and Peteet, “rather than individual measurements of carbon density, a median carbon density (g cm^{-3}) was used to calculate the j_C from sedimentation rate (cm yr^{-1})”. Thus, Nichols and Peteet fail to account for the variability in carbon density in different regions and among different types of peatland[3,8]. For example, there is a more than twofold difference in carbon density between western European islands/continental Europe (0.028 gC cm^{-3}; n = 449) and western Canada (0.076 gC cm^{-3}; n = 3,441)[3]. Also, peat undergoes different degrees of decomposition and compaction with age, resulting in highly variable carbon density often observed along a single peat profile. Furthermore, using one median carbon density value for all sites that lack direct measurements is prone to introducing bias and greatly inflates j_C calculations, especially for mineral-rich deposits. The propagation analysis of carbon density uncertainties by Nichols and Peteet[7] does not resolve this problem.

Furthermore, we find an inherent problem in Nichols and Peteet’s algorithm that inflates the sedimentation rates and total carbon storage. Their probabilistic method was initially developed in a case study from an Alaskan peatland[9]. Using their data[9] and algorithm, we find that a composite stratigraphy of 197 cm in length (in their Table 2) would change to a 246-cm-long core. We arrived at this 24.5% increase in core length by summing the product of the sedimentation rate (as annotated on their Fig. 3d) and time duration (shown in their Fig. 3e) of their 10 core intervals. By the same argument, the observed peat carbon storage of 126.3 kgC m^{-2} (as calculated from their Table 2) would change to 155.8 kgC m^{-2}, an increase of 23.4%. This case study demonstrates that the assumptions behind their probabilistic method artificially create new carbon mass. The same problem exists in Nichols and Peteet[7], but unfortunately they did not provide their specific and complete data in order to reproduce their results and quantify the effects of this carbon mass inflation, as well as the effects of the inclusion of the erroneous data and the use of median carbon density values for filling data gaps.

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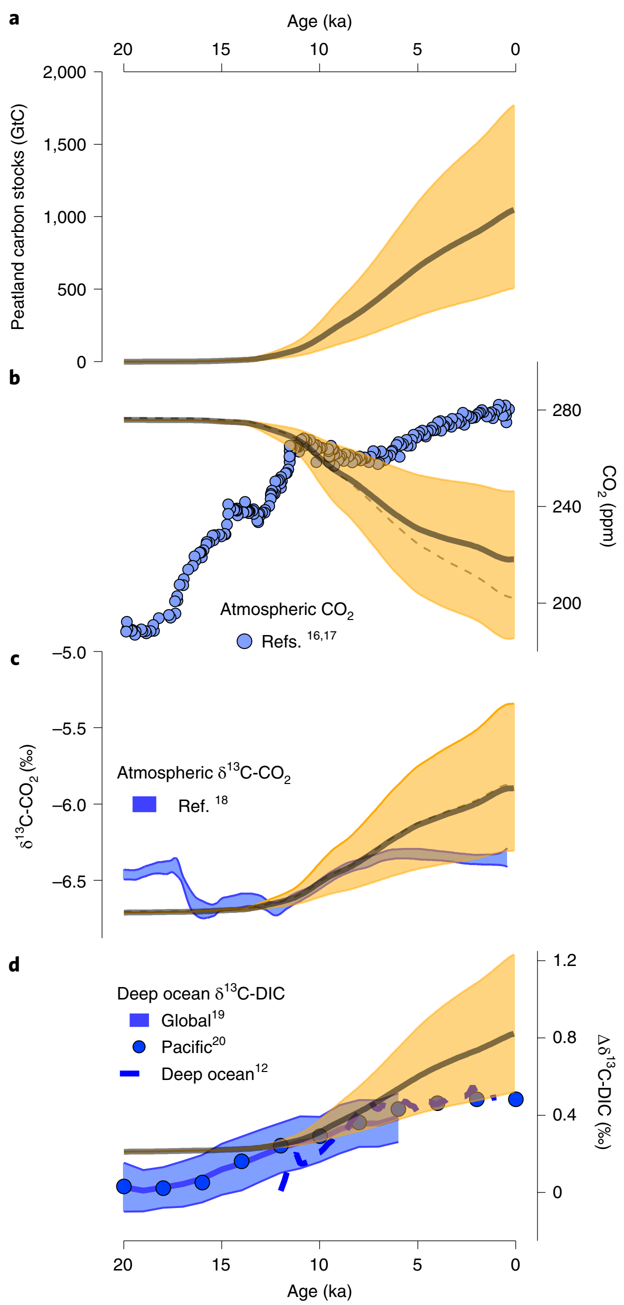

Fig. 1 | Unrealistic consequences of large peat carbon storage. a, Peat carbon storage change (line) over time with uncertainties (orange shading)[7]. **b**, Observed atmospheric CO_2 concentration from ice-core (circles) and box-model-calculated CO_2 concentration. The dashed line represents the outcome without 'carbonate compensation' mechanism in the model. **c**, Observed atmospheric $\delta^{13}CO_2$ from ice-core (blue shading) and model-calculated value. **d**, Observed deep ocean δ^{13}C-DIC from the global ocean (blue shading), deep Pacific (circles) and a stack of 33 deep-ocean cores (dashed blue line) and model-calculated values. The δ^{13}C values are plotted as anomalies relative to model results. Data from refs. [12,16–20].

Lack of support from global carbon budget constraints

The exceptionally large peat carbon storage[7] is not supported by top-down constraints from the global carbon budget reconstructions. Our model simulation results show that an increase in peat carbon storage of >1,000 GtC during the Holocene would induce a decrease in atmospheric CO_2 to below 220 ppm, an increase in atmospheric $\delta^{13}CO_2$ to a value more than 0.8‰ higher than the observed and a steady rise in deep ocean δ^{13}C of dissolved inorganic carbon (δ^{13}C-DIC) throughout the Holocene (Fig. 1).

First, our box-model calculations demonstrate that the simplified conversion of peat carbon uptake into an atmospheric signal of >600 ppm, as shown in their Fig. 2f, was erroneous due to the neglection of the compensating effect by the ocean that acts to reduce any atmospheric perturbation by up to 80% on the millennial time scale relevant here[10]. We assume that Nichols and Peteet instead converted their estimated terrestrial carbon stock increase by a division factor of 2.12 GtC per ppm to arrive at the claimed peat carbon uptake-related decrease in atmospheric CO_2 of >300 ppm during the Holocene. Translating the same peat carbon uptake into an atmospheric CO_2 signal with our model yielded a decrease of about 60 ppm (Fig. 1b).

Second, our simulations suggest that exceptionally large peat carbon storage is difficult to reconcile with the atmospheric and oceanic carbon budgets. Previously, the observed changes in atmospheric CO_2 concentration and in δ^{13}C from ice cores have been used to partition the contributions from the land biosphere and ocean, providing a global constraint on land carbon budget during the Holocene. The measured increase in CO_2 concentration from 265 ppm 11 kyr ago (ka) to 278 ppm in 1750 CE and the small change in δ^{13}C (Fig. 1b,c) were used to reconstruct the preindustrial terrestrial net carbon uptake over the Holocene epoch to be about 250 GtC (ref. [11]). This total Holocene land carbon balance reflects a strong uptake in the early Holocene through the growth of boreal forests and early peat buildup—consistent with the observed early Holocene increase in atmospheric and oceanic δ^{13}C values[12]—and a carbon release of 50 GtC during the late Holocene[11]. The small decrease in land carbon storage in the past 5 kyr contrasts with the large estimated increase in peat carbon storage of ~400 GtC during the same time period as in their Fig. 2e. A compensating carbon source of 400–500 GtC with a biogenic δ^{13}C signature would have to be invoked to close the budget. A detailed analysis of this budget concluded that CO_2 emissions from land use change by early agriculturalists were not sufficient to close the gap[13]. The twofold higher estimates of peat carbon storage by Nichols and Peteet[7]—compared with the one used[13]—make it even harder to reconcile the budget. This conflict is not discussed in Nichols and Peteet[7].

Rather than balancing the carbon budget with terrestrial carbon sources, Nichols and Peteet suggest that the "most important mechanism for balancing the peatland sink" is a continued carbon release from the deep ocean by the wind-driven upwelling during the Holocene. This mechanism requires an even greater loss of carbon from the deep ocean than implied by the peatland carbon sink alone, and is not supported by observation and simulation of marine δ^{13}C and carbonate ion changes. For example, an increase in Southern Ocean upwelling would further increase δ^{13}C-DIC in the deep ocean[14] from the already untenable increase in δ^{13}C-DIC from peatland regrowth (Fig. 1d), yet δ^{13}C values remained constant after 7 ka, as observed from a stack of benthic δ^{13}C data from 33 deep-ocean (>3,000 m) cores around the world oceans[12] (Fig. 1d). Furthermore, the CO_2 release from the deep ocean would lead to an increase in the carbonate ion concentration and enhanced preservation of carbonates in the deep ocean, but deep-ocean cores show the opposite—a reduction in the carbonate ion and an increase in carbonate dissolution during the Holocene[15].

In summary, we conclude that the evidence presented by Nichols and Peteet[7] is not sufficient to support their claim of doubled carbon storage in northern peatlands compared with earlier estimates.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41561-021-00769-2.

Received: 26 November 2019; Accepted: 6 May 2021;
Published online: 28 June 2021

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Methods

To illustrate the effect of such large peat carbon perturbations on the global carbon cycle we carried out a sensitivity analysis using a simple carbon-cycle box model[21]. The model considers the carbon exchange among the atmosphere, land biosphere, oceans and marine sediments. We used the ranges (median $\pm$ 1σ) from all three scenarios (literature, combined, grid box) in Nichols and Peteet[7] as model inputs. All scenarios essentially yielded the same solutions. Therefore, we show the results from only the 'combined' approach here. We also ran a separate sensitivity experiment by turning off the simple 'carbonate compensation' mechanism using just the median scenario.

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Author contributions

Z.Y. and F.J. designed the research, T.K.B. carried out the box-model simulation and created the figure, and all authors were involved in writing and revising the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41561-021-00769-2.

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Peer review information Primary Handling Editor: James Super.