Matters arising

Black carbon attribution

https://doi.org/10.1038/s41586-022-05518-y

Received: 3 August 2022

Accepted: 2 November 2022

Published online: 21 December 2022

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ARISING FROM J. R. McConnell et al. *Nature* https://doi.org/10.1038/s41586-021-03858-9 (2021).

Refracted black carbon (rBC), measured in polar ice cores, can be used to infer historical levels of biomass burning from terrestrial sources. McConnell et al.[1] compared rBC levels from Antarctic ice-core records with selected palaeoecological records from nearby Patagonia and more-distant Tasmania and southern New Zealand, and concluded that burning by early Polynesian (Māori) settlers in New Zealand dwarfed other preindustrial carbon emissions in the mid-latitudes of the Southern Hemisphere during the past 2,000 years. However, closer scrutiny of existing palaeoecological records shows that all of these regions probably contributed to the peak rBC levels. This distinction is important, because it enables the hemispheric-scale environmental impacts on the remote Southern Hemisphere to be attributed to multiple societies that engaged in biomass burning, rather than to a single cultural phase.

Although early forest burning by Māori peoples was widespread in southern New Zealand, and introduced a new source of carbon emissions to the wider region, the most-extensive damage and maximum emissions are likely to be confined to a comparatively brief 'initial burning period'[2], which commenced in the late thirteenth century and lasted around 50 years. This brief, intense burning phase is evident in the representative New Zealand record shown in figure 1 of McConnell et al.[1], with charcoal concentrations from the initial burnings peaking in the first 100 years and declining thereafter, until the arrival of European people in the early nineteenth century. These and other changes in Māori land use during the brief course of New Zealand prehistory are well established in archaeological and palaeoecological records[2]. More recently, other studies[3,4] have revitalized a previous argument that climate change during the pre-European era may have strongly influenced early Māori settlement patterns and land-use practices during a 'transitional' phase of New Zealand prehistory. This phase, commencing around AD 1400 and coinciding broadly with the Little Ice Age, represents the abandonment of conventional settlements in the southern regions of New Zealand in response to less-hospitable climates, which is consistent with the decreasing charcoal curves of that time[4]. This depopulating of southern New Zealand and the associated reduction in burning coincides with the peak Antarctic rBC levels that were nevertheless attributed to Māori burning by McConnell et al.[1].

Furthermore, in figure 1, McConnell et al.[1] use a single charcoal record from Patagonia that shows decreasing levels at the time of peak rBC levels, with an implicit presumption that this record is representative of the wider region. However, a large number of published records and historical accounts reveal that this presumption is incorrect. In northern and central Patagonia (40–49° S), records from Lake Shaman[5], Mallín El Embudo[6], Lago Melli[7], Lago Espejo[8], Lago Teo[9] and Mallín Fontanito[10] show higher charcoal values and inferred fire frequency during the second half of the last millennium, coinciding with the arrival of European people around AD 1600. In southern Patagonia (50–54° S)—the closest of all of the putative burning regions to the Antarctic Peninsula—the environmental impact from the time of arrival of European people, which started about AD 1600, was unprecedented in the context of the late Holocene epoch[11–15]. For example, a charcoal record from Rio Rubens bog (around 52° S) shows that local fires did not occur for more than 900 calibrated years before European contact, but then became frequent from approximately AD 1600 (ref. [15]). At nearby Laguna Potrok Aike, charcoal levels similarly increased from around AD 1600 (ref. [16]). The inferred palaeofire records from all of these studies in Patagonia show that the historical pattern for the past millennium is actually opposite to that of the Lago Cipreses record, which was presented as representative of Patagonia by McConnell et al.[1]. The pattern of increased burning accompanying European settlement is consistently seen in palaeoecological records elsewhere, including New Zealand from the 1800s. In this regard, the Lago Cipreses record[1],— showing a sustained decrease in charcoal levels for the second half of the millennium during the European settlement era—is anomalous not just in the context of Patagonia. Given the relative proximity of the Patagonian source region to the Antarctic ice-core depositional sites, it is perplexing that these other palaeoecological and historical observations for early European burning have not been considered (especially in light of the rather brief period of early Māori burning in New Zealand noted above).

Diversity in the fire regimes in Patagonia is not unexpected, because of its complex topography and interactions with the prevailing and shifting Southern Hemisphere westerly winds, along with scattered human settlement patterns. As a consequence, no single palaeofire record is likely to be representative of the entire region. This is also true for Tasmania, for which a single record (Lake Vera) was again selected by McConnell et al.[1] to represent the regional fire history. This record was used to eliminate Tasmania as a candidate for the peak rBC emissions. However, a composite palaeofire record from 14 sites in southwest Tasmania shows higher levels at the time of peak rBC levels, from AD 1600 to AD 1800, than at any other time during the preceding 600 years[17].

In summary, the peak rBC levels of the Antarctic Peninsula from AD 1600 to AD 1700 coincide with increased burning across nearby Patagonia at the time of early European settlement there, increasing burning in southwest Tasmania and decreased burning across southern New Zealand. Yet McConnell et al.[1] attribute these peak rBC levels exclusively to early Māori emissions. The discrepancy between the palaeofire record in New Zealand and the rBC records in the Antarctic Peninsula is noted by McConnell et al.[1], but not explained other than through an indirect reference to the challenges of inferring atmospheric emissions of biomass burning from local palaeofire records. Presumably, the same challenges also apply to the local palaeofire records from Patagonia, indicating burning during the early European era there, but not to the Lago Cipreses and Lake Vera records they used as representative of Patagonia and Tasmania, respectively. A wider purview of the reported palaeoecological and historical observations would suggest that anthropogenic burning across the inhabited regions of the Southern Hemisphere collectively—not just the short-lived early Māori burning episode—is likely to be responsible for the peak black carbon levels recorded in Antarctic Peninsula ice during the past millennium.

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Attributing this apparent hemispheric-wide environmental impact to a single cultural phase is not consistent with the evidence, including that presented by McConnell et al.[1].

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Acknowledgements I acknowledge informative discussions with G. Dunbar and R. McKay, and thank D. Lowe, P. Pliscoff, W. Henriquez and I. Jara for their comments on the manuscript.

Competing interests The author declares no competing interests.

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Reply to: Black carbon attribution

https://doi.org/10.1038/s41586-022-05519-x

Published online: 21 December 2022

Check for updates

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REPLYING TO R. M. Newnham *Nature* https://doi.org/10.1038/s41586-022-05518-y (2022)

We appreciate the remarks in the accompanying Comment[1] regarding our interpretation of the fallout of biomass burning over Antarctica during the past two millennia. Our previous study[2] was based on precise measurements of an unambiguous combustion indicator—refractory black carbon[3]—in a broad array of Antarctic ice cores, as well as extensive atmospheric modelling. For many reasons, however, we do not find Newnham's evidence or arguments[1] sufficient to alter our conclusions. In our previous study[2], we proposed that (1) large increases in biomass-burning emissions poleward of 40° S, which were documented in the Antarctic ice cores starting around AD 1300, largely resulted from the introduction of fire to New Zealand by early Polynesian settlers; (2) climate-modulated emissions from Patagonia and Tasmania generally declined after about AD 1400 as a result of overall wetter conditions, which were caused by widely recognized changes in the Southern Annual Mode[4]; and (3) anthropogenic burning emissions from New Zealand dwarfed earlier emissions from these three regions (not from the mid-latitudes of the Southern Hemisphere as a whole, as incorrectly summarized by Newnham[1]).

First, implicit in Newnham's suggestions[1] is that lake-sediment and peat-bog charcoal records can be interpreted as proxies of atmospheric emissions. In fact, charcoal records indicate only the presence of fire activity in the nearby landscape and provide little or no quantitative information regarding the magnitude of those emissions. Conversely, records of black-carbon deposition from ice cores are directly proportional to atmospheric concentrations and therefore to emissions—although these are potentially modulated by atmospheric-transport and deposition processes[2].

Second, the evidence presented by Newnham[1] to challenge our previous attribution[2] of the emissions in New Zealand to the black-carbon deposition in the Antarctic Peninsula is highly misleading. The local fire-proxy records that Newnham[1] identifies include only those that ostensibly support his hypothesis, while ignoring the majority that do not. For example, Newnham[1] cites the charcoal record of Lago Teo, which shows an increase in recent fire activity. However, not included in his synthesis are two nearby, equally valid lake-sediment records that are included in the same publication[5] and that indicate very different fire histories. Although primarily focusing on Patagonia, Newnham[1] similarly argues that biomass-burning emissions in Tasmania were greater during the past 500 years on the basis of a composite charcoal record from southwestern Tasmania[6]. However, even cursory examination of that record shows that the trends are not statistically significant (supplementary figures 4 and 5 of ref. [6]). Therefore, the composite record provides little information on past regional fire activity. Rather than focusing on highly variable, often contradictory individual proxy records of local fire activities, we instead based our previous interpretation[2] on expected regional emissions that were underpinned by the consensus understanding of widespread, climate-modulated burning driven by changes in the Southern Annular Mode[4–8]. We previously illustrated the effects of these large-scale circulation changes on climate and burning using the charcoal records of Lago Cipreses in Patagonia[8] and Lake Vera in Tasmania[7] (figure 1 of ref. [2]). We did not assume, as Newnham[1] suggests, that these two records represent local fire-proxy records for these regions in general.

Third, our findings are based on black-carbon deposition records from a broad array of six well-dated and synchronized Antarctic ice cores extending over 18 degrees of latitude; any hypothesized changes in biomass-burning emissions must be consistent with deposition observed throughout the array, not simply with the records from the northern Antarctic Peninsula. The decline in black-carbon deposition from the fourteenth to eighteenth century over continental Antarctica, and particularly over Dronning Maud Land—which is especially sensitive to emissions from Patagonia—is in agreement with circulation-driven reductions in burning in Patagonia and Tasmania[7,8] and at odds with the anthropogenic increases suggested by Newnham[1]. In addition, Newnham[1] uses simply the proximity of Patagonia to the northern Antarctic Peninsula to underpin his attribution of emissions in Patagonia to the black-carbon deposition; however, westerly winds dominate the large-scale atmospheric circulation in these regions, resulting in strongly eastward transport of black carbon (figures 2 and 3 of ref. [2]). Atmospheric modelling based on physics such as the analysis used in our previous study[2] is required to understand and quantify atmospheric aerosol transport and deposition.

Finally, and most importantly, the black-carbon deposition records of our Antarctic ice-core array spanned more than 2,000 years, thereby enabling the quantification of emissions from Tasmania, New Zealand and Patagonia, both before and after the pronounced change in around AD 1300. Low variability in the north–south deposition ratios before the fourteenth century (figure 1 of ref. [2]) indicates that emissions from these three regions were always less than 8–16% of those during the sixteenth century (depending on whether the emissions were from southern Patagonia or Tasmania)[2]. This means that only areas in which the combined large-scale emissions after around AD 1300 were consistently an order of magnitude higher than before AD 1300 can be considered as potential source regions for the increased emissions. Nearly all of the Patagonian records identified by Newnham[1] indicate much more modest increases in recent fire activity, with levels often similar to or less than those during the first millennium and are therefore clearly inconsistent with the observed 2,000-year deposition pattern over Antarctica.

We acknowledge that some local fire-proxy records from Patagonia (for example, for Rio Rubens bog[9,10]) suggest large, short-lived increases in fire activity during the past 500 years that may have contributed to spikes in the north–south deposition ratios. However, most do not, reflecting different biomass-burning regimes that depend on the local climate, vegetation and human activities[9]. Objective and comprehensive evaluation of local fire-proxy records from all three potential source regions for biomass burning clearly shows that only those from New Zealand consistently indicate the order-of-magnitude increases in fire activity after about AD 1300 required to explain the spatial and temporal

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patterns archived in the Antarctic ice cores. We also emphasize that Newnham's comments[1] mostly refer to the sixteenth to eighteenth centuries, and that there is little disagreement with our primary finding that the introduction of fire to New Zealand by early Polynesian settlers about AD 1300 resulted in a centuries-long increase in biomass-burning aerosols of up to threefold over the northern Antarctic Peninsula, 7,000 km away.

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Author contributions J.R.M. led the writing of the paper, with contributions from N.J.C. and A.S. To expedite this Reply, the research and writing were performed by a subset of the original authors who had particularly relevant expertise, and therefore many of the original authors have been not been included in this paper.

Competing interests The authors declare no competing interests.

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