



Invited reply

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[†]William I. Woods, our colleague and co-author, died on 11 September 2015, age 68, as we were preparing this Response. Bill, a geographer, soil scientist and archaeologist, was a leading authority on Amazonian Dark Earths (ADEs), and Professor of Geography Emeritus at the University of Kansas.

The accompanying comment can be viewed at <http://dx.doi.org/10.1098/rspb.2015.1837>.

Response to comment by McMichael, Piperno and Bush

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We thank McMichael *et al.* for commenting on our recent review [1]. They focus on: our misinterpretation of their published data; use of data that is not pre-Conquest; and the extrapolative nature of our review. As they point out, we agree with them about heterogeneous landscape domestication across Amazonia, but we disagree with their conclusions about the extent to which forests were altered in western Amazonia and elsewhere [2,3]. As western Amazonia covers approximately 2 000 000 km², they are making a major statement. We consider their claim to be of an excessively ‘extrapolative nature’ given their data.

The empirical data they mention (300 soil cores from 109 sites in western and central Amazonia [3,4]) are clustered in five small areas, with only one long transect. In western Amazonia, they worked in three localities [3, fig. 2] with 24 sites and 124 cores. Each core was 10 cm in diameter and up to 120 cm in depth ([3], supplementary material), representing 0.0094 m³ to extract phytoliths and charcoal; in total, they have 1.17 m³ to represent the 2 000 000 km² of western Amazonia. There is no abundance diagram in which phytoliths are attributed to species, genera or families. Nor is there a charcoal abundance diagram and, as pointed out by Stahl [5], they reported trace amounts of charcoal (less than 0.25 mm³ cm⁻³) as absent ([3], supplementary material, p. 4). Based on these three localities, they claim that the western region was sparsely inhabited and forests little modified, because they did not find abundant charcoal and early successional herbaceous (ESH) taxa phytoliths—where few should be expected. The absence of charcoal and ESH phytoliths is not necessarily indicative of the absence of forest management. Forest management generally does not involve burning, and phytoliths are not diagnostic of many useful plants. Hence, their results cannot be used to affirm that there was no forest management. In fact, they admit that their methods are inappropriate for the task: ‘Consequently, detecting an enrichment of native forest with fruit trees and shade cultivation of some crops are beyond the methodological possibilities of this study.’ [6, p. 138].

Bush & Silman [7] point out that the degree of landscape domestication diminishes as one moves from a settlement through cultivated areas into managed areas and finally into areas used for hunting and collecting, which they consider to be unmanaged and we consider to have been less intensively managed. Curiously, this expectation did not guide their sampling strategy [3]. Hence, not surprisingly, they did not find evidence for significant use of fire [3] and conclude that there was no significant deforestation for agriculture. In their new review [8], they model these expectations based on data in McMichael *et al.* [3] and suggest that charcoal can be found up to 15 km from rivers, thus providing a good sampling strategy for future work—if they start from known archaeological sites.

They emphasize [2] that none of the 1791 Radar na Amazônia (RADAM) profiles nor the 100 Rainfor project profiles used in their modelling exercise

[9] are in archaeological sites. The lack of RADAM profiles in archaeological sites was intentional, since this was an exploratory survey (1970–1975) of Brazilian Amazonian soils. For a soil type to be included in a map with a scale of 1:1 000 000, it must occupy at least 3000 ha, an order of magnitude larger than any single archaeological site yet found in Amazonia. It follows that archaeological sites were purposefully avoided, because they do not represent a typical soil anywhere. The Rainfor project (2000–present) placed their sites away from villages in the expectation of reduced impact by villagers on the local forest. Because many modern villages are located on archaeological sites, the lack of mention of these sites by the Rainfor team is expected. As McClenachan *et al.* [10] point out, it is important to understand the limits of one's data.

As to our use of data that is not pre-Conquest, they point out that modern vegetation may be influenced by many factors besides pre-Conquest management, as emphasized by Levis *et al.* [11, p. 5]. Why do we think that pre-Conquest management is an important factor? As an example, Thomas *et al.* [12] modelled the relationship between archaeological sites and Brazil nut stands, and concluded that 'in central and eastern Amazonia, anthropogenic disturbance has been more important (*sic* for the dispersal and local abundance of the species) since pre-Columbian times' [12, p. 1]. A meta-analysis of Brazil nut demography [13] found trees with more than 150 cm diameter at breast height (DBH) in all their sites. A dendrochronological study [14] shows that Brazil nut trees with this DBH can be at least 350 years old. It is therefore likely that large numbers of the trees in the meta-analysis [13] were dispersed by humans or planted before colonization started (1616 with the founding of Belém). The same is logically true for other large-statured useful tree species.

McMichael *et al.* [2] then affirm 'But to map a native species of the Amazon and claim that humans have altered its distribution across the Basin is unsubstantiated'. A new study about the geographical distribution of the Brazil nut's genetic diversity [15] supports previous studies that show low genetic diversity across much of the Brazil nut's distribution. Thomas *et al.* [12] suggest that this represents recent dispersal out of hypothesized Pleistocene refuges, so it is a 'claim that humans have altered its distribution across the Basin'. (McMichael is a co-author of [12].)

McMichael *et al.* [2] also criticize Levis *et al.* [11] because they do not present a 'baseline for comparisons of enrichment versus natural distribution patterns'. This is quite true, because Levis *et al.* were not making statistical comparisons, but were describing a trend that agrees with Bush & Silman [7]. Their comment raises an interesting question: how does one determine 'natural distribution patterns' in forests that have been managed intentionally and unintentionally for 13 000 years, during which time the climate changed considerably?

Our use of ethnobotanical data was designed to highlight indigenous and traditional forest management along trails and near camps and settlements ([1], citations 31–38). There is an abundance of such studies in Amazonia, so if modern Native Amazonians practise this kind of forest management it is reasonable to assume that pre-Conquest Native Amazonians did also. As pointed out by Bush *et al.* [16, p. 305] in a study about prehistoric maize cultivation and landscape management in Ecuador, 'Another implication of these data is that historical terra firma Amazonian forests were in part accommodated to several thousand years of human exploitation'. The same locality was restudied by McMichael *et al.* [6] and they affirm that their methods are not appropriate for identifying forest management (see quotation above), although they once expected such management.

As to the 'extrapolative nature of our review', it was designed to synthesize numerous sources of information about Amazonia, rather than only charcoal and phytoliths. McClenachan *et al.* [10] suggest that 'identification of a full suite of sources relevant to the research question' [10, p. 935] and 'use of multiple lines of evidence with understanding of their limitations' [10, p. 937] are best practices in historical ecology. Where there is no modern research, as in large parts of Amazonia, there is often information from ethnohistory, and inferences about landscape domestication from ethnography complement this, as does the biogeography of Amazonian languages, crop origins and concentrations of crop diversity, and modern forest composition (see [1] for references). All of these are modern data, but each has a history that allows inferences about the past. Use of as many sources of information as are available strengthens extrapolations, not the opposite.

Finally, scientists can be both independent scientists and social activists regarding indigenous peoples, just as scientists are social activists regarding climate change today.

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