LETTER

REPLY TO ELIAS ET AL.:

Multiproxy evidence of widespread landscape disturbance in multiple Azorean lakes before the Portuguese arrival

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Despite the multidisciplinary and comprehensive approach taken in ref. 1, we acknowledge that there are still open questions that require further research. We emphasize that our study relies on multiple records that show the synchronous arrival of humans on multiple islands before *ca.* 1400 CE. Elias et al. (2) raise specific concerns about the record from Peixinho Lake, one of the five lakes included in the study, while ignoring the other multiproxy lake sediment records. The arguments presented by Elias et al. (2) do not undermine in any way the main conclusions of our paper, but still we would like to explicitly address the main criticisms with regard to the only record in question.

Elias et al. (2) question the age model developed for Peixinho due to possible "old" volcanic carbon contamination. Previous work in the Azores has shown that dating aquatic macrophytes can result in "old" carbon contamination (3); however, our pollen concentrates are almost entirely composed of terrestrial pollen grains, not aquatic macrophytes. Terrestrial pollen grains are not affected by volcanic carbon emissions (4). The age model from Peixinho (figure S6C of ref. 1) included two tephra layers at 650 and 700 CE, which correspond to the dates of the tephra layers found in the record of Pico Bog (see figure 2 of ref. 5). For this reason, we are puzzled by the figure presented by Elias et al. (figure 1 of ref. 2), where the authors seem to artificially wiggle-match the two pollen curves without taking into account two key stratigraphic layers and ignoring the two tephra layers (Pico-4 and Pico-5) published in ref. 5.

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Common key indicators of human impacts on islands reflect multiple and synchronous changes in the landscape, e.g., fire, deforestation, the presence of cereal grains, and fecal biomarkers (6, 7). In the record from Peixinho and the lake records from the other islands, we observed an increase in macrocharcoal and polycyclic aromatic hydrocarbons, the presence of *Secale cereale*, 5β-stigmastanol, coprostanol, and coprophilous spores, as well as a decrease in arboreal pollen. These signals are followed by increases in lake trophic states. The grains of *Secale* were counted in subsequent pollen slides indicating a local source and not erratic long-distance dispersal. *Plantago* spp. were identified to *Plantago lanceolata* and *Plantago coronopus*, of which *P. lanceolata* is an introduced species (5) and is an indicator of pastures (8). This evidence clearly demonstrates changes in the Azorean landscape resulting from human arrival before the 15th century. The early decrease in arboreal pollen is also observed in figure 5 of ref. 5, although this was not highlighted in the original paper.

As stated in ref. 1, we acknowledge the point raised by Elias et al. (2) that the Portuguese arrival led to more extensive changes in the landscape. Our multiproxy, multisite datasets strongly suggest that people had already occupied the Azores Archipelago and altered the pristine landscape before the official arrival of the Portuguese.

1 P. M. Raposeiro *et al.*, Climate change facilitated the early colonization of the Azores Archipelago during medieval times. *Proc. Natl. Acad. Sci. U.S.A.* **118**, e2108236118 (2021).

2 R. B. Elias *et al.*, Is there solid evidence of widespread landscape disturbance in the Azores before the arrival of the Portuguese? *Proc. Natl. Acad. Sci. U.S.A.*, 10.1073/pnas.2119218119 (2022).

3 S. Björck *et al.*, A Holocene lacustrine record in the central North Atlantic: Proxies for volcanic activity, short-term NAO mode variability, and long-term precipitation changes. *Quat. Sci. Rev.* **25**, 9–32 (2006).

4 N. Piotrowska, A. Bluszcz, D. Demske, W. Granoszewski, G. Heumann, Extraction and AMS radiocarbon dating of pollen from Lake Baikal sediments. *Radiocarbon* **46**, 181–187 (2004).

5 S. E. Connor *et al.*, The ecological impact of oceanic island colonization—A palaeoecological perspective from the Azores. *J. Biogeogr.* **39**, 1007–1023 (2012).

6 N. Dubois *et al.*, First human impacts and responses of aquatic systems: A review of palaeolimnological records from around the world. *Anthr. Rev.* **5**, 28–68 (2017).

7 D. A. Sear *et al.*, Human settlement of East Polynesia earlier, incremental, and coincident with prolonged South Pacific drought. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 8813–8819 (2020).

8 K. Behre, The interpretation of anthropogenic indicators in pollen diagrams. *Pollen Spores* **23**, 225–245 (1981).