

# *Widespread reforestation before European influence on Amazonia*

Article

Supplemental Material

Bush, M. B., Nascimento, M. N., Akesson, C. M., Cardenes-Sandi, G. M., Maezumi, S. Y., Behling, H., Correa-Metrio, A., Church, W., Huisman, S. N., Kelly, T., Mayle, F. E. ORCID: <https://orcid.org/0000-0001-9208-0519> and McMichael, C. N. H. (2021) Widespread reforestation before European influence on Amazonia. *Science*, 372 (6541). pp. 484-487. ISSN 1095-9203 doi: 10.1126/science.abf3870 Available at <https://centaur.reading.ac.uk/97776/>

It is advisable to refer to the publisher's version if you intend to cite from the work. See [Guidance on citing](#).

To link to this article DOI: <http://dx.doi.org/10.1126/science.abf3870>

Publisher: American Association for the Advancement of Science

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the [End User Agreement](#).

[www.reading.ac.uk/centaur](http://www.reading.ac.uk/centaur)

**CentAUR**

Central Archive at the University of Reading

Reading's research outputs online



## Supplementary Materials for

### **Widespread reforestation preceded European influence on Amazonia**

M.B. Bush<sup>1\*</sup>, M.N. Nascimento<sup>1,3</sup>, C.M. Åkesson<sup>1†</sup>, G.M. Cárdenes-Sandí<sup>2</sup>, S.Y. Maezumi<sup>3</sup>, H. Behling<sup>4</sup>, A. Correa-Metrio<sup>5</sup>, W. Church<sup>6</sup>, S.N. Huisman<sup>3</sup>, T. Kelly<sup>7</sup>, F.E. Mayle<sup>8</sup>, C.N.H. McMichael<sup>3\*</sup>

correspondence to: [mbush@fit.edu](mailto:mbush@fit.edu) [c.n.h.mcmichael@uva.nl](mailto:c.n.h.mcmichael@uva.nl)

#### **This PDF file includes:**

Materials and Methods  
Supplementary Text  
Figs. S1 to S3  
Captions for databases S1

#### **Other Supplementary Materials for this manuscript includes the following:**

Database S1:

Table 1: Metadata for all sites used in the analysis

Table 2: Percentage of change in forest pollen in comparison with previous time slice, highlighting increases or decreases  $\geq 5\%$ .

Table 3: Percentage of change in forest pollen in comparison with previous time slice, highlighting increases or decreases  $\geq 10\%$ .

Tables 4,6,8,10,12,14,16,18,20: Total pollen abundance of forest, *Cecropia*, *Mauritia*, and maize presence against age (cal yr BP and CE) for the 9 high-resolution study sites used in this study.

Tables 5,7,9,11,13,15,17,19,21. Charcoal abundances against age (cal yr BP and CE) for the 9 high-resolution study sites used in this study.

## Materials and Methods

### Analysis of lake sediments

We compiled fossil pollen and charcoal data from 39 lake-sediment records (database S1) in Amazonia *sensu stricto* (42). We did not include pollen or charcoal reconstructions from peatland or palm swamp settings. To be included, all sites had to have a minimum of six fossil pollen samples within the last 2000 years and appear to be continuous records. The categorization of ‘occupied sites’ for the 39 lake sediments was based on the presence of cultigen pollen (predominantly *Zea mays*), increases in the pollen of grasses and weeds, or the presence of charcoal.

For each site (N = 39), we calculated the total forest percentage of all tree and shrub taxa contained in the pollen record (including *Cecropia*) (database S1). *Cecropia* pollen percentages are also shown separately, as this tree is an indicator of site abandonment and early successional forest regrowth (43). Raw pollen counts were not available for all lakes, but for those reported, pollen counts are generally > 300 grains per sample (database S1). At Lake Caranã, *Mauritia* pollen was so abundant that it represented > 84% of the total pollen sum (22). As *Mauritia* is an obligate wetland palm, this local pollen representation could mask changes in forest cover in the adjacent uplands. Consequently, *Mauritia* was excluded from the pollen sum for Lake Caranã, and forest pollen percentages were recalculated. Prior work in modern Amazonian settings has shown that forest disturbance by humans (15, 16) is revealed by a reduction in the proportion of forest pollen by 5-10%. Based on prior assays of the sensitivity of forest pollen representation to human disturbance we tabulated the proportion of sites that in contiguous samples lost or gained at least 5% or 10% of total forest pollen for each 200-year time window from -50 to 1950 (databases S1, Fig. S1).

Nine of the 39 lake sedimentary records (referred to as high-resolution sites) contain at least two dates over the last 2000 years, and over 10 pollen and charcoal samples in the last 1000 years (database S1, Fig. S3). The high-resolution sites are used to provide temporally detailed changes in the amount of forest pollen abundances before, during, and after the Great Dying period (1550-1750). We show the changes in forest pollen percentages for all the high-resolution sites, and also the deviation from the mean forest percentage for each site in 100-year time bins. We also present the mean of those deviations across sites for the last 2000 years. We show the same for *Cecropia* pollen.

The charcoal samples reported here were collected by many investigators, and thus sample preparation and measurement methods did not follow a standardized protocol (Database S1, Table 1). Without such a protocol a standardization method is necessary to account for differences in laboratory procedure, catchment size, and sediment properties when comparing charcoal amounts across sites (44). We performed proportional relative scaling to standardize the charcoal abundance data from each lake record (45), and report it as the Charcoal Index Value.

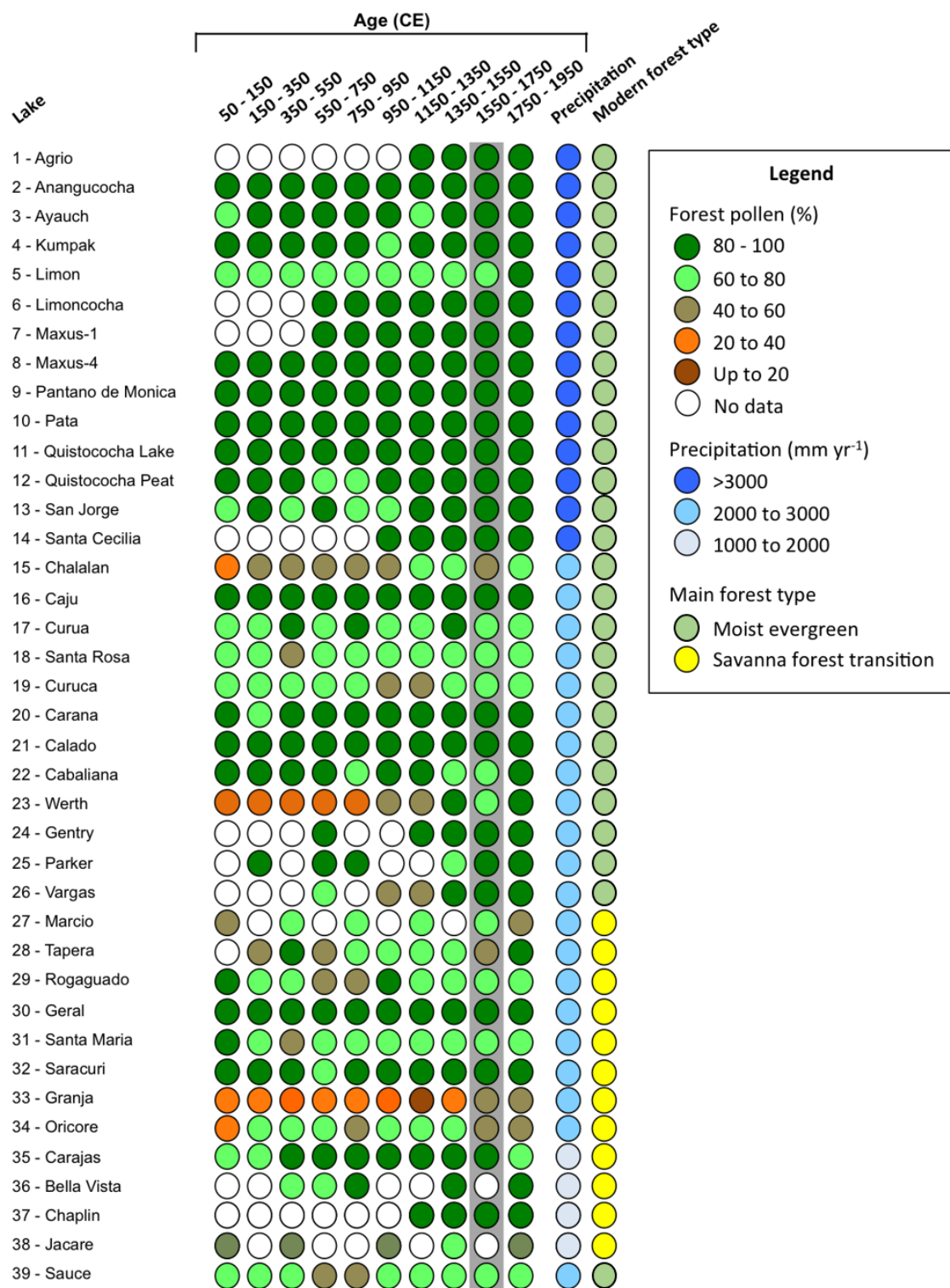
$$\text{Charcoal Index Value} = \left( \frac{c_i}{c_{\max}} * 100 \right) * f/N$$

This approach scales each measurement ( $c_i$ ) within each lake sediment record to a value ranging between 0 and 100, where 0 is the absence of charcoal and 100 is the maximum abundance measurement for that record ( $c_{\max}$ ). The scaled measurements are

then multiplied by the proportion of samples within the record containing charcoal ( $f/N$ ). Proportional relative scaling is particularly robust in assessing fire in systems where fire is infrequent or rare, because 0 is used as the true absence value, and samples containing small or infrequent amounts of charcoal are down-weighted (45). The scaled data are reported as the Charcoal Index value. We show the Charcoal Index values for each site, and the mean of the Charcoal Index values across all sites ( $N = 9$ ) for 100-year time windows for the last 2000 years.

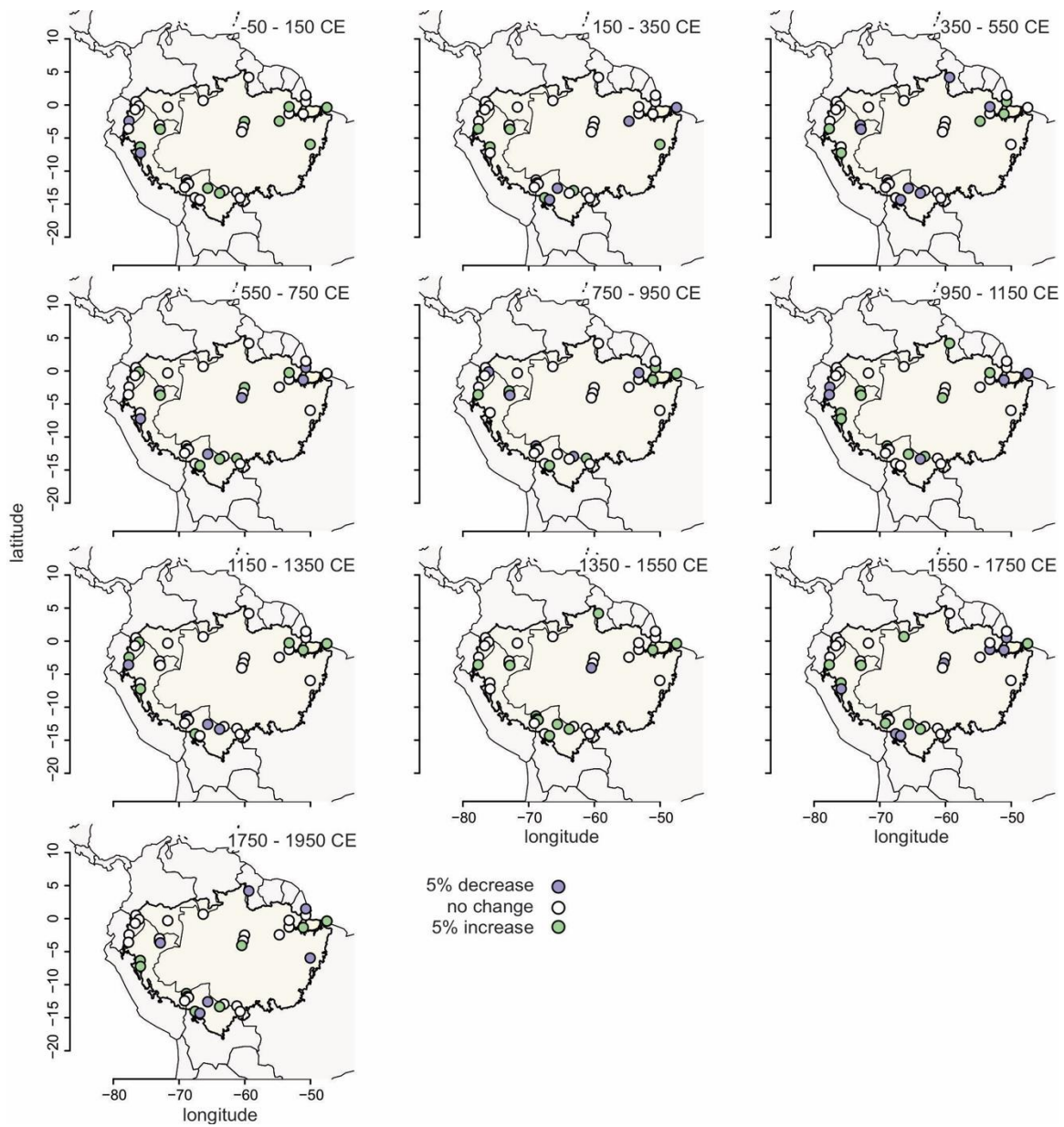
### **Supplementary Text**

References (see main text for full list of references)



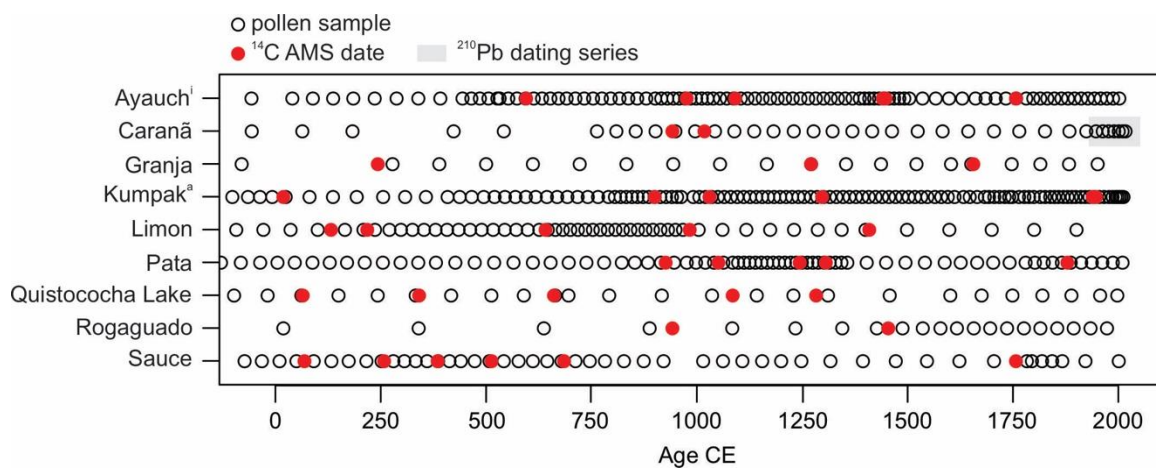
**Fig. S1.**

Summary of the change in forest per 200 years over the last 2000 years in the 39 study sites. The gray bar identifies the period of arrival of Europeans. See database S1, for references and site characteristics.



**Fig. S2**

Spatial and temporal pattern of sites showing increases or decreases in forest pollen of > 5%, using 200-year windows. Light yellow outline shows boundaries of Amazonia sensu stricto (38).



**Fig. S3**

Sampling resolution of the nine high-resolution sites used in the analyses. See database S1 for further site characteristics and data.



**Additional Data table S1 (separate file)**

Database S1 contains the data on the site characteristics, pollen, and charcoal data used in this analysis. Table 1 contains all of the metadata on the sites and references to original publications. Table 2-3 contains the percentages in forest pollen change compared with the previous samples (for 5% and 10%) thresholds. The remaining tables contain the charcoal and pollen data for the nine high-resolution sites used in the analysis.