Climate inferences from oak archaeological samples

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1. Introduction

The widespread use of oak as a building material over many centuries, combined with the characteristics of oak tree rings (e.g. no missing rings and crossdating over long distances), has resulted in the ubiquitous use of oak for archaeological dating in the United Kingdom (UK). As a consequence, there is now a large and continually expanding data set of oak tree-rings. Although of immense importance for dating, this data set would not normally be considered suitable for dendro-climatology because of critical unknowns, such as the provenance of trees and forest management practice. On the other hand, the fact that new archaeological oak chronologies routinely crossdate with networks of sites across the UK clearly suggests that a common climate signal does in fact emerge, despite these limitations.

We hypothesize that the available archaeological network is now sufficiently extensive to allow investigation of millennial-scale climate variability for the UK. Specifically, we think that statistical analysis of the data set may be informative in terms of:

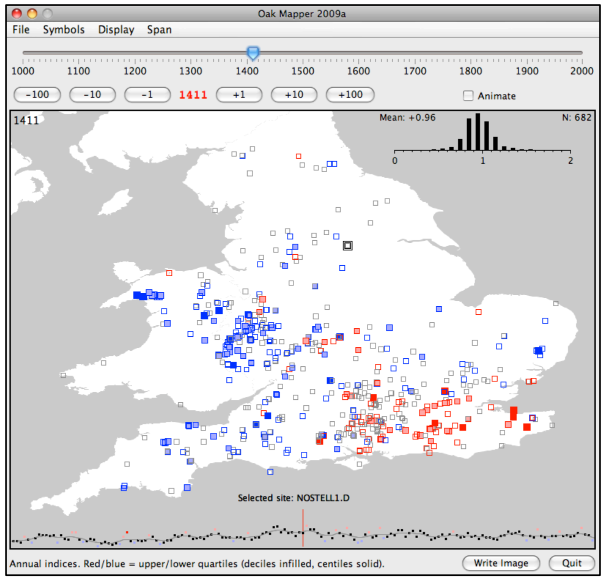
a) centennial-scale changes in the strength of large-scale climate forcing;

b) the evolving frequency and spatial pattern of extreme growth years, and;

c) the evolving strength and spatial character of regional climates.

2. Method & data

Method. A software visualization tool ("Oak Mapper") has been developed to explore spatial and temporal patterns in UK oak tree-ring chronologies through simple mapping of indices and inter-site correlations.



Data. 1719 UK oak chronologies have been assembled from multiple sources (see acknowledgements). Sample depth varies in space and time, reflecting the distribution of old timber-framed buildings, uneven funding of dating work, and access to data. The subset currently available is biased to southern England and to the middle on the 2nd millennium AD. The current database has fewer than 300 sites prior to 1311 and post 1590 AD.

3. Oak Mapper

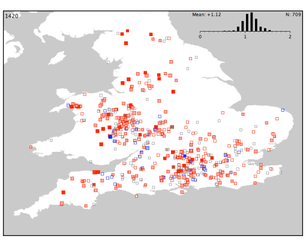
Overview. 'Oak Mapper' reads a text database of ring-widths and converts these to simple indices. These are interactively plotted for any year using symbol size to denote deviation from normal and colour for significant deviations. A histogram of values is displayed.

Example. The plot to the left shows a screen capture for 1411 AD. For the 682 available sites the mean index is near-normal (0.96), but with a clear spatial split (W narrow, SE wide).

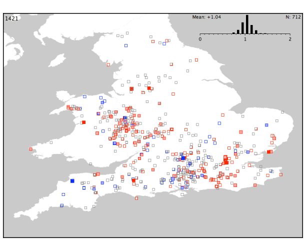
The black square is the 'selected' site. Raw values for the selected site are plotted along the bottom of the map, along with the smooth curve used to calculate ratio indices.

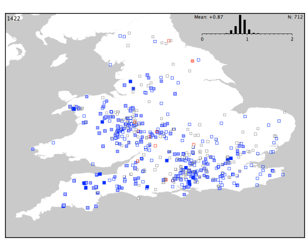
Correlations. Oak Mapper also plots inter-site correlations (R) for a variable window centered on the current year. Two R options are available: a) R of each site with the selected site – to identify spatial clusters, and; b) median R of each site with all others – to identifying evolving climate forcing.

4. Characteristic growth patterns



The 1411 AD split pattern is fairly unusual. For the last 1000 years, extreme rings have tended to be large-scale anomalies (e.g. 1420 & 1422) with co-occurring opposite extremes rare. However, a sub-regional *focus* is often apparent (e.g. towards the SW in 1422) and patchy spatial patterns are common in the absence of strong regional-scale signal (e.g. 1421). There are also some characteristic regional contrasts.



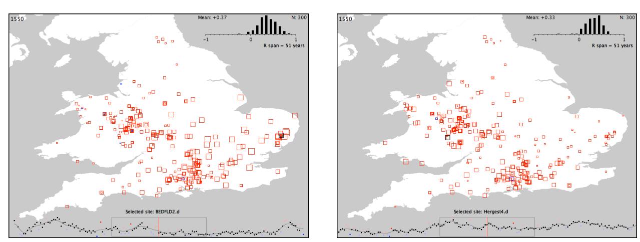


Tree-ring index plots for 1420, 1421, & 1422. Red/blue indicates upper/lower quartiles with deciles infilled (solid colour for centiles).

5. Inter-site correlations

The two plots below show the correlation of each site's tree-ring indices with the indices of two selected sites (black symbols) for a 51-year window centered on 1550 AD. Selected sites, the respective times series, and the correlation window are shown at the bottom of each plot. Symbol size scales with |R|, red (blue) indicates positive (negative) correlations, and the histogram (top-right) shows the R distribution.

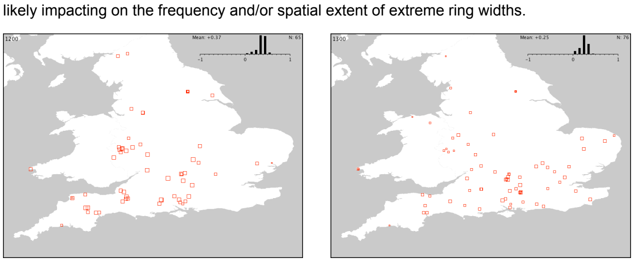
The key result here is that there is evident spatial structure to inter-site R. Although almost all sites are positively correlated, regional clustering is apparent, especially in the case of eastern sites, and eastern and western sites are only weakly correlated. Selecting other sites identifies other spatial groupings and repeating for different times reveals a variable correlation structure (not shown). This suggests that R-based cluster analysis is likely to tease out changing spatial relationships, and hence evolving climate forcing.



Correlation of site indices with two selected sites (black symbol) for a 51-year window centered on 1550 AD. See text for additional details.

6. Evolving climate forcing

If the strength of climate forcing evolves through time, we would expect to see corresponding waxing and waning of inter-site R. To investigate this an alternative way of mapping inter-site R is shown in the two plots below. In this case the window has been extended to 101 years centered on 1200 and 1300 and each plotted symbol is the median R of each site with all other sites. Larger symbols and a right-shift of the histogram in the case of 1200 AD, relative to 1300, indicates a stronger common signal. If the common signal is indeed related to climate forcing, then we are seeing evidence of climate change – most likely impacting on the frequency and/or spatial extent of extreme ring widths.



Median correlation of indices for each site with all other sites for 101-year windows centered on 1200 & 1300 AD. Symbol size scales with |R| (all positive).

7. Conclusions & future directions

Conclusions. Simply assembling and visualizing a subset of the available data has clearly demonstrated that oak archaeological tree-ring chronologies have value far beyond the dating purpose for which they were collected. In particular, the results suggest that there is potential to contribute to millennial-scale assessments of regional climate change. There may also be spinoff benefits of the approach for the archaeological dating community through the identification of evolving regional ring-width patterns, and perhaps for dating verification and/or quality control.

Future Directions: To fully exploit the potential of archaeological samples for climate reconstruction would be a multi-year and multi-disciplinary task. First steps are likely to include:

a) data infilling and expansion (hopefully well beyond the UK);

b) refinement of the visualization tool to cope with obscured sites in high sample density areas (perhaps using a gridded approach);

c) application of objective clustering methods to identify evolving patterns, and;

d) development of transfer functions linking atmospheric circulation to these clusters.

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Software availability. 'Oak Mapper' is written in the Java programming language, enabling cross-platform deployment. Anyone interesting in the program is welcome to contact Anthony Fowler for the application or the source code.