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Martin C. Bridge, Anthony M. Fowler

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A NEW WAY OF LOOKING AT DENDROPROVENANCING: SPATIAL FIELD CORRELATIONS OF RESIDUALS

Martin C. Bridge[1,2] * **martin.bridge@ucl.ac.uk**, Anthony M. Fowler[3]

1. University College London, Institute of Archaeology, 31-34 Gordon Square, London, WC1H 0PY UK.
2. Oxford Dendrochronology Laboratory, Oxford, UK.
3. School of the Environment, University of Auckland, Auckland, New Zealand.

* Corresponding author.

Abstract

A graphical method is used to demonstrate the results of new analytical steps introduced as an aid to provenancing oak within the British Isles. The current method for determining the likely area of origin of a tree-ring series is to map the distribution of *t*-values obtained when the subject chronology is compared with each of the available reference chronologies. Although useful, this falls into the trap that the *t*-value itself is subject to variation in length of the series being compared. The first step to overcome this is to instead use the R-value, a common way of characterising inter-site tree-ring relationships. It can be seen however that with dated sites, the geographical spread of well-matching sites is often quite large (the very reason why one can have confidence in the dating). This new method introduces two new steps. The first is to subtract the regional growth signal before comparing the sites. It is then possible to focus on the often more minor local scale variations in growth, the weak relationships previously overwhelmed by the regional signal sometimes becoming apparent using the paired inter-site correlations (residuals). The second step is then introduced, exploiting the information available in these maps. Objectively quantifying the agreement between the spatial correlation fields for a single site is achieved by scoring and mapping the agreement between the inter-site correlation maps for each other site, here termed the 'field correlation'. It is shown that this sometimes gives an improved indication of the likely area of growth, and can be used in conjunction with any other information available to suggest likely geographical origins with more confidence.

Keywords Dendroprovenancing; oak dendrochronology; British Isles

Introduction

Background

The area of dendroprovenancing is becoming more important in studies of the origin of commercial timbers, and also in historical studies, particularly with regard to portable items such as ships, chests and works of art. This interest is evidenced by recent papers on the topic such as Gut (2018) and Akhmetzyanov et al (2019), the latter concentrating on anatomical features. There is a long history of importing oak to Britain from the Baltic area and much later from North America, and traditional methods of dendro-provenancing, often involving mapping *t*-values with the subject in question, can distinguish these quite easily (see for example Daly 2007; Haneca *et al* 2005; Čufar 2007). What is of interest here is the ability to distinguish the area of tree growth of timbers within the British Isles used in buildings, furniture, ships and other artefacts, which at present can often be poorly defined.

The British Isles data set for both living and historical oak continues to expand in both the numbers of sites and their geographical spread. It was hoped that this process would of itself lead to a refinement of provenancing questions, with more comparisons becoming available perhaps clarifying the likely geographical origin as the network expanded. However, the greater number and spread of sites has not seemingly provided sufficient new information to resolve these questions, although it does allow more confidence in any results obtained because of the greater coverage.

The traditional graphical means of illustrating and interpreting dendroprovenancing data is to map the cross-matching values with the site under examination using increasingly sized circles to represent increasing classes of *t*-values. In some cases (Fig 1; an updated version of Fig 1 in Bridge 2012) non-significant matches have also been shown as adding additional geographical information in the consideration of possible areas of origin for archaeological timbers, by effectively ruling out the areas with very weak matching. Whilst this has proved very useful in many cases, particularly in cases where the growth area of the trees is very distant from the object being investigated, as is often the case with portable items such as chests, or panel paintings utilizing imported boards, it is sometimes not possible to distinguish a geographical region that is the most likely growth area for the trees. This appears to be particularly true in maritime climates such as in much of Britain (Bridge 2012), whereas in more continental areas, it does seem possible to get a more defined likely geographical origin (see for example Daly 2007). This particular example (Fig 1) does show a strong regional affiliation, although one high *t*-value in central southern England (highlighted) is the result of a matching against a very long chronology, giving potentially misleading spatial information.

Critique of current methods

There is one major problem with the *t*-statistic approach. Once dating is assured, there is a difference between the statistical significance of the measure, and the relationship strength between sites, the latter being the one most important in provenancing questions. High values of *t* may be generated by long records (as in the example in Fig 1), and may also be associated with high sample depth, but these do not truly reflect the relationship strength between sites. Sites with many more samples should have a better climate signal contained within them, and so both *t* and R are likely to have higher values, but these do not directly reflect provenancing issues.

There is often a problem of high R values being derived across the network of sites because of the pervasive climate signal, and alternatives are needed to explore the spatial patterns that lie within the data. The study of living trees in the British Isles, where the growth origin is known, has highlighted some anomalies (Bridge 2000; 2012), reinforcing the idea that the closest high matching correlation values are not always with the geographically closest chronologies, but may be related to ecological or micro-climatic differences. If one first plots the outcomes of correlations (R) using the ring width series (w) or the more useful indices (R-ind) with these already dated sites, the level of significance from a *t*-value is less relevant, as a high *t*-value can result from a very long sequence from a relatively low R-value, and for provenancing we are interested in the similarity between the sites.

These findings have resulted here to the development of additional forms of matching, exploiting additional spatial information available in the matching of the data sets, in an attempt to better classify the area of origin of the timbers investigated. After analysing the results from living tree sites, attention is then turned to historical sites, with examples highlighting potentially useful developments.

The data set

Fowler and Bridge (2015) introduced the use of a British Isles dataset based on a collection of both living and historical sites, which has continued to grow in recent years. About half of the data is available in the public domain, but other sites are from private laboratories. In the analyses presented below, the proposed new techniques were applied first to the living tree sites, and then to historical sites.

Living tree sites have been derived by several workers and cover a wide spread in the British Isles. They mostly go back to the early nineteenth century with their modern end going from the early 1980s to 2011, with sample depths varying, but all containing more than 10 trees. Most (over 90%) are available in the public domain.

The available archaeological site chronologies have sample depths ranging from one to more than 30 timbers. This potential data set was reduced by excluding all inner-London sites and chronologies – because London has a long history of importing timber from a wide hinterland, making site location unhelpful in the mapping context of this research. The database was further reduced by excluding sites with fewer than three timbers, although it should be noted that many of the 2073 retained archaeological chronologies (from a total dataset of 2178) will have component parts with reduced sample depth, primarily at the beginning and/or end of the series. The database is dominated by sites containing 5–10 series. In addition, some historical Continental sites have also been added which give another perspective on matching within Britain, but this is not discussed further here. Currently the dataset used has 70 sites at 1000 CE, peaking at 960 sites at 1443 CE and dropping quickly through the seventeenth century to just 44 sites at 2000 CE, with sample depth being very similar to that shown in Fowler and Bridge (2015) Fig 1.

One historical site where there is good documentary evidence for the source of the timber used coming from a near-by site a few kilometres to the north is the Warden's Hall at Merton College, Oxford (Miles and Bridge 2016), the earliest two-tier queen-post roof yet dated. Next, individual timbers from the *Mary Rose*, a Tudor warship previously explored by Bridge (2011) were re-assessed. Previous work on individual timbers from the *Mary Rose* (Bridge 2011; 2012), a Tudor warship built in Portsmouth (central southern England coast), with later refit timbers thought likely by traditional dendroprovenancing to have come from East Anglia, a region to the north-east of London, showed that while many gave good indications of their likely geographic origin, some seemed to match really well over much of the southern British Isles, and so it was thought appropriate to see if this new concept and visual tool could assist in these cases. Two Orlop Deck rising knees, ORK50 and ORK100 were two such timbers.

Another interesting case, that of a church chest in St Peter's Church, Laneham, Nottinghamshire, was then looked at, followed by a re-appraisal of thirteenth-century material found in England, but long considered to be of possible Irish origin. Miles (2002) clearly established the use of Irish oak in the construction of Salisbury Cathedral, backed up by documentary evidence, but previously, Hillam had found timber at Canynges House, Bristol (Hillam 1988), re-used boat timbers at Bristol Bridge (Hillam 1984), timber at Dundas Wharf, Bristol (Nicholson and Hillam 1987), and radially split planks at Trichay Streeet, Exeter (Hillam 1984), all of which gave good matches at the time to existing Irish chronologies and were suspected of being of possible Irish origin. These were therefore investigated further, along with more modern sites that showed potentially anomalous results.

Methods

The analysis that follows has been carried out using a development of the software introduced in Fowler and Bridge (2015). That software (*OakMapper*) plotted the R values for the indexed site chronologies (hereafter referred to as R-ind) between sites along the lines of the traditional *t-value* methodology, and noted a number of occasions where the strongest matches were not always with the closest geographical site. Using R-ind values does not overcome the issues associated with greater sample depth in individual chronologies, but it does allow the spatial pattern, including weak and negative R values to be more readily appreciated. The *OakMapper* software has been incrementally improved over time. As other species and parts of the world are also now being investigated, the evolving software has been renamed *TreeRingMapper*. This however is only one vehicle by which the method can be carried out, most standard statistical packages could readily derive the values obtained. Similarly the maps used in this paper have been derived from the open source GIS program QGIS, since the focus here is on the method, not the means of delivery.

TreeRingMapper has the flexibility to change the geographical area of the map shown and is currently being used for investigations in New Zealand (Boswijk and Fowler, accepted 2019), to plot positive and negative relationships using red (positive) and blue (negative) circles of differing size and colour intensity as a visual tool (with the five strongest matches being further highlighted in the figures in this paper using a yellow H within the red circle), and to alter the size of the correlation window to suit the length of the series being used. This allows the ends of site chronologies that are not well replicated to be excluded if it is thought that they are unduly influencing the outcome. In the first instance plots of the outcomes of correlations (R) using the ring width series (w) or the more useful indices (R-ind) are made. Here we are looking at already dated sites, so the level of significance from a *t*-value is less relevant, as a high *t*-value can result from a very long sequence from a relatively low R-value, and for provenancing we are interested in the similarity between the sites.

These findings have led to the development here of additional forms of matching, exploiting additional spatial information available in the matching of the data sets, in an attempt to better classify the area of origin of the timbers investigated. Firstly the regional common signal, a mean made from all the sites in the database at a given period, is removed from the sites, and the R values are calculated from these residuals (hereafter referred to as R-resid). When looking at the maximum R-resid values in trying to determine the area of origin, a rich spatial pattern represented in the lesser values is largely ignored, but each value calculated has a small, but potentially useful separate piece of information that might be of interest. The findings led to the development of an additional form of matching, exploiting additional spatial information available in the matching of the data sets, in an attempt to better classify the area of origin of the timbers investigated. This is addressed in the second stage below, but is best illustrated using an example of matches between modern tree sites.

Field-R Correlations (spatial field correlations of residuals)

The common signal may be expressed as the mean chronology formed from all the sites. If one then removes that common signal from each individual site chronology, one is left with that part of the dataset (residuals) reflecting more local conditions.

The R-resid plots show that these have interesting provenancing information, but as mentioned above, the smaller values may themselves harbour further information that can be exploited. The second stage of analysis uses pair-wise matching of sites that of course also contain geographical differences. Each R-resid result is matched against each other R-resid result generated, and the result is mapped, giving an overview of the matching, rather than just looking at the strongest matches.

Results and Discussion

Application to Living Tree Sites

Figures 2 a, c and e show the geographical distribution of R-ind values for each of three sites, STOM17 a site in central England (Howard *et al* 2000), Glen of the Downs (GOTD) near the east coast of Ireland (Pilcher and Baillie 1980), and Hockley near the south-east coast of England (Bridge 1983). The R-ind values for STOM17 are plotted against those for Glen of the Downs and Hockley in Fig 3a, where nearly all R-inds are shown to be positive, showing the pervasive common signal in British Isles oak index chronologies. It is clear however that the STOM17 – Hockley relationship is much stronger than the STOM17 – GOTD one. This indicates that STOM17's R-ind pattern (Fig 2a) is much more similar to Hockley's (Fig 2e) than to that for GOTD (Fig 2c). By then carrying out pair-wise inter-site matching, the resulting R-resids are centred on zero (Fig 3b), but give a similar spread to those in Fig 3a. STOM17 and Hockley still have a positive relationship, but the relationships for STOM17 and GOTD for the Rs between these residuals are now generally unrelated (Figs 2 b, d and f).

Whilst this seems to work well with sites of known origin (the living trees and the historical Merton site discussed below) there are some anomalies (Hockley) and this highlighted the need not only for further development of the tool itself, but perhaps also some independent means of provenancing, such as chemical signatures in the wood. Another problem is that some historical sites show good matching over very wide geographical areas (the very basis of their dating) and attempting to suggest growth-origin areas within the database has proved very difficult. This is true also of some individual ships timbers from the *Mary Rose*, discussed elsewhere (Bridge 2011). Living tree sites have shown that some have strong matches with sites at distances of hundreds of kilometres, whilst showing lower values with many closer sites, which may be due for example to similarities in ecological conditions or soil types, or may have a cluster of well-matching sites well removed from their known area of growth. Coastal sites cannot have centring clusters, any cluster must inevitably have the wrong weighting (i.e. appear to be inland). Some sites show no particular clustering with any area.

From the above, it is apparent that the correlation of the inter-site correlations is a useful objective metric of how well sites agree in terms of their spatial patterns. This ‘field correlation score’ (Field-R correlation) has two positive features: it reflects R-resids across all sites (rather than just focussing on the highest Rs), and because each pair of sites is represented by a single value, it can be readily mapped (Figs 4 a-c), but does represent an additional level of conceptual complexity that can be difficult to grasp. To reiterate, the field-R correlations exploit that small degree of spatial information to be found amongst the paired R-resid results that is often overlooked, and if provenancing is achievable, then one might expect that local sites should not only match each other, but should also have similar spatial correlation patterns.

It is assumed that calculating and then mapping these Field-R correlations (Figs 4 a-c), thus taking account of the spatial correlation patterns, may give a clearer idea of provenance. The ideal result would be that a tighter cluster of high scores centred on the selected site. The actual results are as follows:

a) STOM17 (Figs 2b and 4a) – the Field-R correlations have a greater spread in values than the corresponding R-resid values – as shown by the bar graphs on the right hand side. In this case the Field-R correlations essentially exclude Ireland, north and west England, Wales, and the north-east English coast. There is however no tightening of the clustering and the weight of evidence is centred to the south-east of the actual location.

b) Glen of the Downs (Figs 2c and 4b) – the Field-R correlations give a more realistic provenancing result than the R-inds. There are still high values found in northern England, but the south of England becomes excluded. Interestingly different sites in Ireland give the strongest matches between the R-inds and the Field-R correlations.

c) Hockley (Figs 2c and 4c) – The R-inds suggest an incorrect central-England provenance, and this site was used by Bridge (2000) to illustrate the problems with simple provenancing based on ring-widths alone, as it shows a strong correlation with a site some 300km distant, whilst giving much weaker correlations with several much closer sites. Here the Field-R correlations show many more negative correlations in the north and west.

Overall, Field-R correlations have a much wider spread of values and highlight differences, which give better visual representations, even though no significant new information has been generated. Contrary to expectations, the removal of the common climate signal (R-resid) has not resulted in tighter clustering of the high site scores. The results for these living tree sites are nevertheless encouraging: in the case of STOM17 where the provenancing is well represented by the R-inds, the additional steps taken to produce and map the Field R correlations confirmed the original provenancing whilst eliminating peripheral areas. With the Glen of the Downs site where provenancing was essentially non-existent with correlations of the index site masters, these new steps tentatively suggest a more realistic outcome, and for Hockley, where traditional methods suggested provenancing well to the west of the actual site, the Field R correlations partially compensated for this, and again led to the elimination of peripheral sites.

Whilst far from perfect, these new steps provide complementary additional perspectives, and seem worth pursuing in the case of historical sites where the actual provenance cannot be known with any certainty, but there are often many more geographically spread sites with which to make comparisons than with the living tree sites.

Application to historical sites

Using Merton College Warden’s Hall in the traditional way (Fig 5a) shows a site with very strong matches over a wide geographical area. This plot only shows results for values of *t* over 3.5 within England and Wales, so there are fewer sites plotted than in the subsequent figures for this site.

The R-ind values (Fig 5b) show strong matches over much of southern England, not much different to the traditional form of *t*-value mapping, but the use of Field-R Correlations (Fig 5d) considerably reduces the geographical spread and shows strongest matches in what is assumed, from the documentary evidence, to be the correct origin for the timber. This result suggests that this new approach may well have benefit in reducing the area of likely origin of timbers from historic timbers.

Note however that in Fig 5c, the R-resid plot shows a more confined, and perhaps more readily useful spread than the Field R correlations (Fig 5d), which shows that what is presented here is by no means a definitive new way of exploring datasets for provenancing. However, the two possible new steps each show their own merits and drawbacks.

In the case of the Mary Rose timbers, the use of the Field-R Correlation plots (Figs 6 and 7) suggest likely central southern England origins for these timbers, which would fit with the likely origins of many other timbers original to the ship.

The Laneham chest results are also of interest. Chests are of course very portable, and studies of chests elsewhere suggested that this chest was of a type more commonly manufactured and found in southern England (Pickvance, pers comm.). The distribution of R-ind values with this site (Fig 8) suggests a southern area of origin, but the matches are generally widespread. The distribution of Field-R correlations (Fig 9) indicates a more narrowly defined focus on sites to the western side of central southern England, and there now seems to be some documentary evidence supporting this (Simpson pers comm.). Interestingly, one of the five highest matches shown in Fig 8 is in the extreme south-east, with a chronology from Dover Castle. This royal property probably brought in timber from elsewhere, so the geographical information may well be misleading for this site – reinforcing the notion that for historical sites, one should be looking for patterns of distribution for the site chronology, rather than focussing on the strongest individual matches, or even looking at individual timbers where it is suspected that there may be multiple sources of timber.

The Irish question

The mapping of the results from sites in England thought to contain timbers of potentially Irish origin now leave little doubt as to that attribution, although these are not shown here as they would take up too much space. Using the methodology proposed in this paper throws up other possible sites that may need to be reappraised. The small fishing port of Mousehole in the far south-west coastal area of England has produced a site chronology for the period 1374–1614 which dates against other south-west England sites (Arnold and Howard 2008). Traditional-type plots of the strongest inter-site R values for the indexed site chronology (Fig 10a) show a widescale agreement with sites, Fig10b for the R-resid correlations shows a similar pattern for the strongest matches in Ireland and North Wales, but helps eliminate much of England as the source area, much the same as the Field-R correlations (Fig 10c).

Conclusions

Both the maps of the R-resid and Field R correlations are thought likely to prove useful tools in many cases, and they each deserve consideration in future provenancing questions in the British Isles. They may also prove useful in other geographical areas where traditional methods do not highlight likely areas of growth origin.

It has been shown that one needs first to look at the R-ind values to see if the site in question is matching strongly with the dataset. If it is, and those sites are widely distributed, the use of R-resid and then Field-R Correlations may be highlighting a narrower area of possible origin. Whilst this seems to work well with sites of known origin (the living trees and Merton) there are some anomalies (Hockley) and this highlights the need not only for further development of the tool itself, but perhaps also some independent means of provenancing, such as chemical signatures in the wood itself.

The new approaches presented here increase the confidence one can have in attributing historical oak found in southern England to an Irish origin. Many Cornish sites covering a similar time period to the Mousehole example presented here do not show this Irish connection, although yet more may have origins outside the county and are still being investigated. Whilst it cannot be proved by looking at these plots, there is a strong indication that this remote coastal site may have imported timber from elsewhere, and perhaps documentary or dendro-chemical methods will find supporting evidence for this hypothesis in the future.

It is important to highlight some important aspects of this new tool. Firstly, one cannot just jump straight to the end point (Field-R Correlations) to get information about the likely origin of timbers. One needs to look first at the R-values between the ring indices of the site in question and the reference chronologies (R-ind) values to see if the site is matching strongly with the dataset. If it is, and those sites are widely distributed, the next step is to remove the common signal and look at the correlations between the residuals (R-resid). The use of R-resid may highlight a narrower area of possible origin. Both R-resid and Field-R correlations may be useful in their own right for a given site, and both seem to be useful in eliminating areas, where R-ind plots show widespread matching.

An interesting observation that has been made of looking at many of the individual historic site chronologies is that quite often a distribution is found where there is an apparent boundary between positively and negatively matching sites running from the Bristol Channel to just north of the Wash (see for example Fig 10c), suggesting perhaps two regions within England and Wales. It is felt more likely that this represents some climatological difference than timber trading, or straightforward topographical differences, but this needs to be investigated further.

A possible future development of this approach may lie in the use of oxygen isotope chronologies as a means of dating when conventional dendrochronology has proved inadequate – such as in cases of relatively ‘complacent’ ring width series (i.e. where the year-to-year ring width variation is low) and with short ring-width sequences of around 50 years (Loader *et al* 2019). The oxygen isotope signal is mostly influenced by summer rainfall, and that signal has been shown to be relatively consistent throughout southern Britain (Young *et al* 2015). The situation is therefore, at least at first sight, a little like the case where the overwhelming climate signal results in good *t* and R values for a single ring width chronology against very many widespread sites, which the operations outlined in this paper have sought to differentiate.

The *TreeRingMapper* software is available on application to the authors, although it is not necessary to use it to generate the results produced in this paper.

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FIGURE CAPTIONS

Figure 1. Traditional *t*-value mapping for a ring-width series from Rider 6 of the *Mary Rose*. The green circle with a yellow grid in it represents a potentially geographically anomalous high *t*-value from a match with a long series.

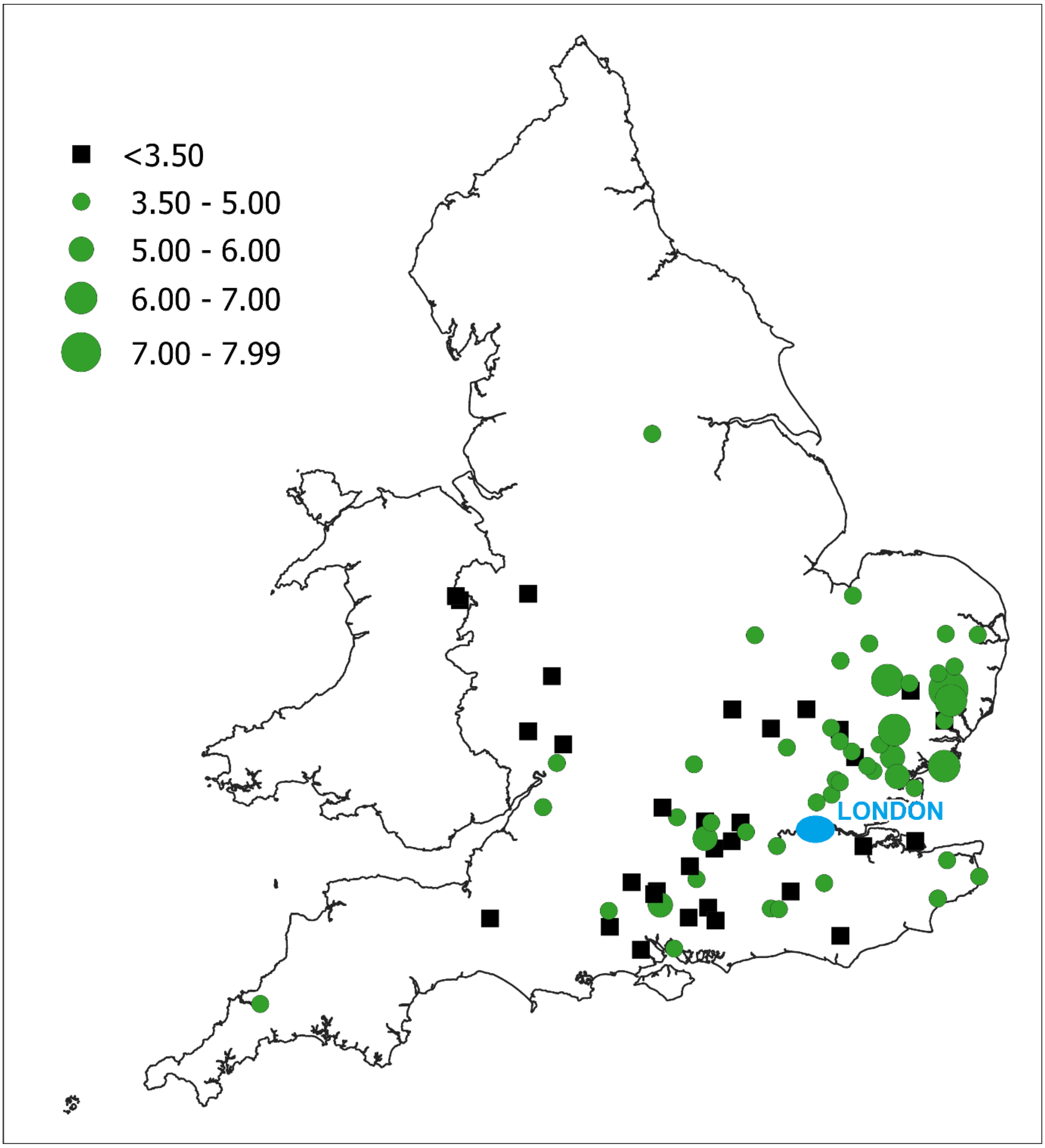


Figure 2a. Inter-site R values for the high-pass filtered indexed chronology (R-ind) for the living tree site STOM17 (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.

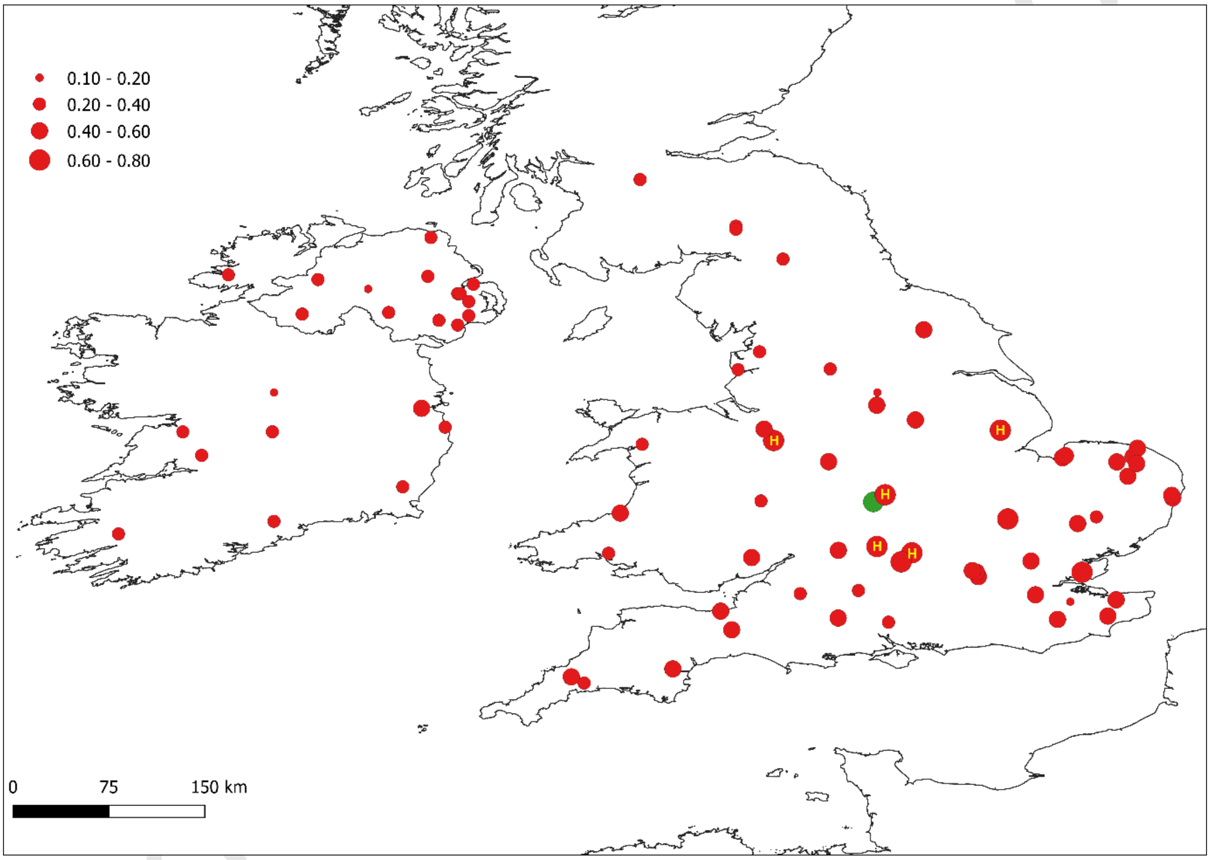
Figure 2b Inter-site R values for the residual chronologies (R-resid) for the living tree site STOM17 (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.

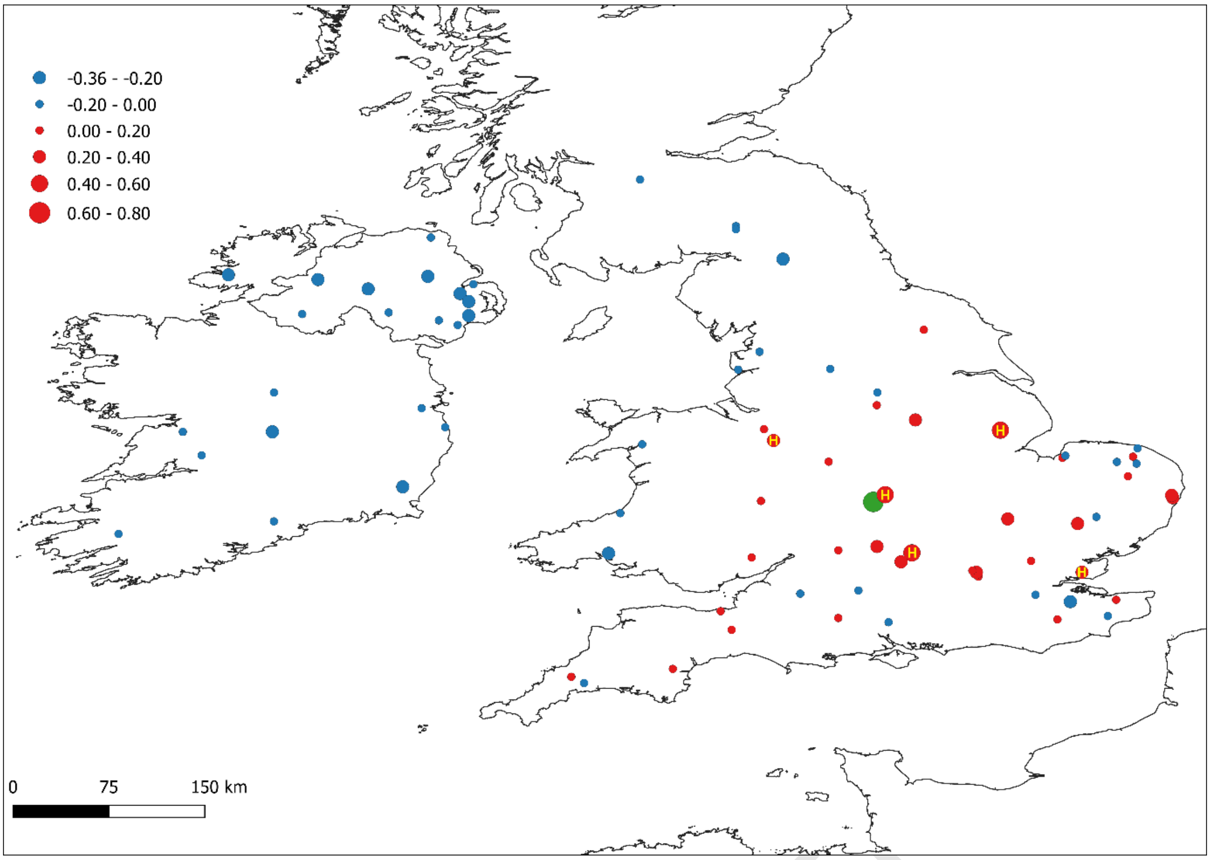
Figure 2c. Inter-site R values for the high-pass filtered indexed chronology (R-ind) for the living tree site GOTD (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.

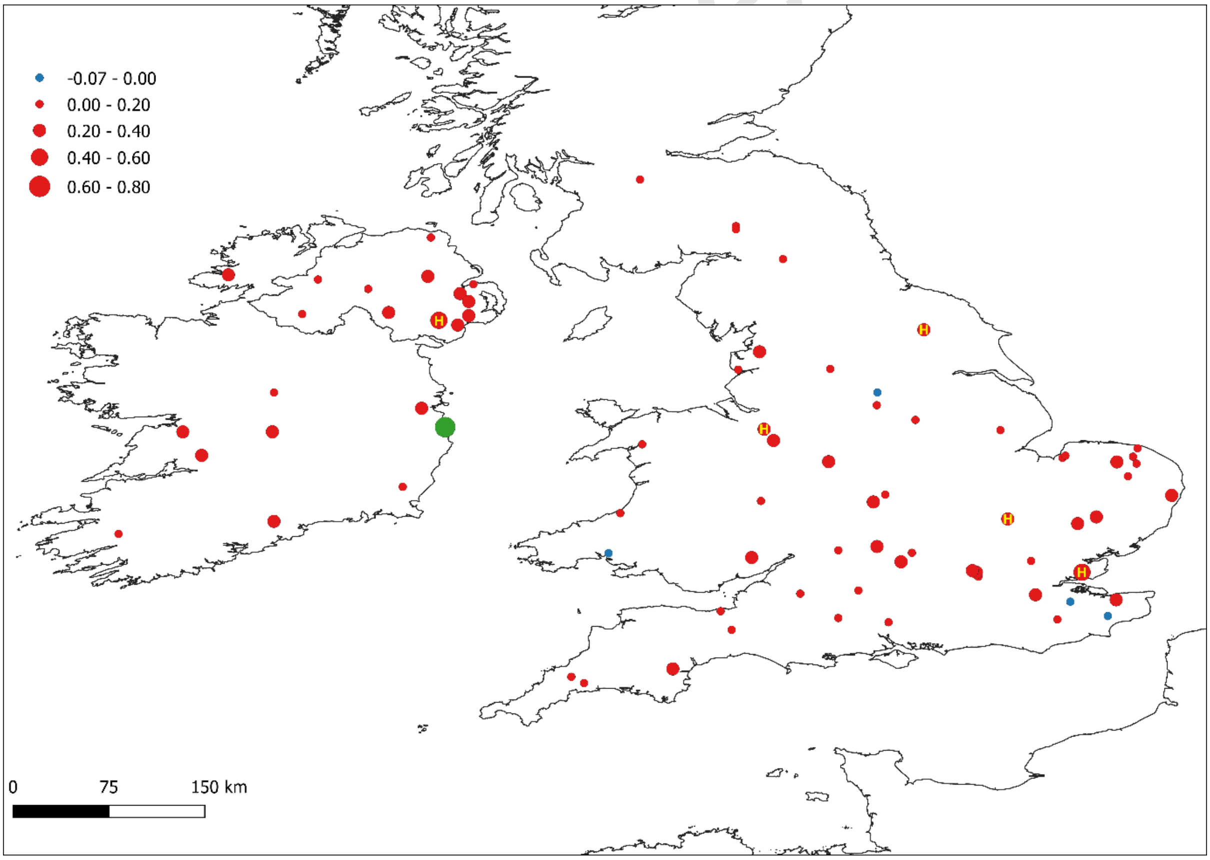
Figure 2d. Inter-site R values for the residual chronologies (R-resid) for the living tree site GOTD (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.

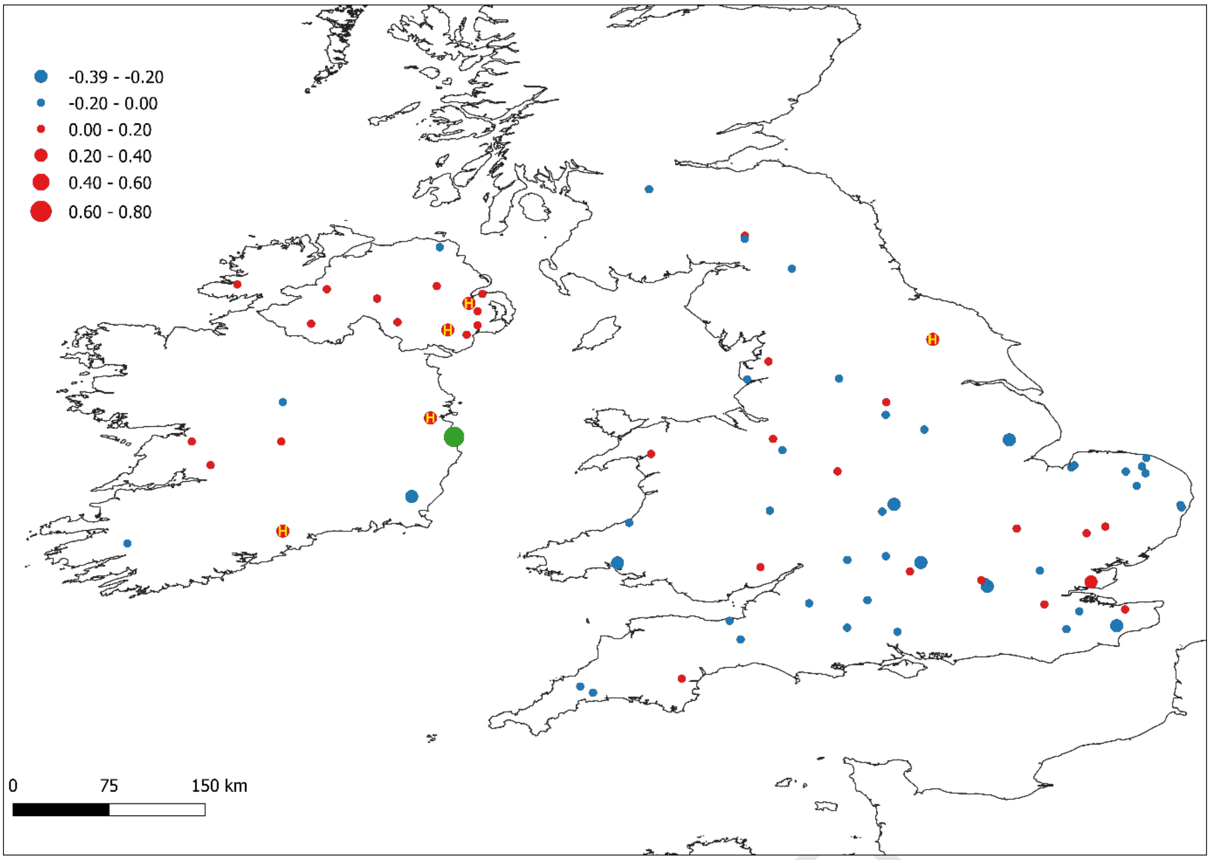
Figure 2e. Inter-site R values for the high-pass filtered indexed chronology (R-ind) for the living tree site HOCKLEY (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.

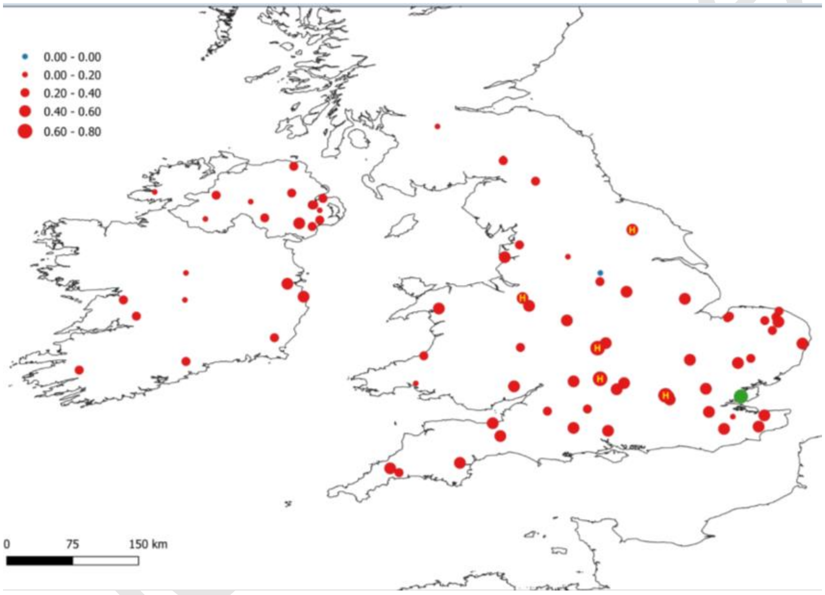
Figure 2f. Inter-site R values for the residual chronologies (R-resid) for the living tree site HOCKLEY (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.




-0.36 - -0.20
-0.20 - 0.00
0.00 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
H
0
75
150 km


-0.07 - 0.00
0.00 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
H
0
75
150 km


-0.39 - -0.20
-0.20 - 0.00
0.00 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
0
75
150 km
H


0.00 - 0.00
0.00 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
0
75
150 km
H

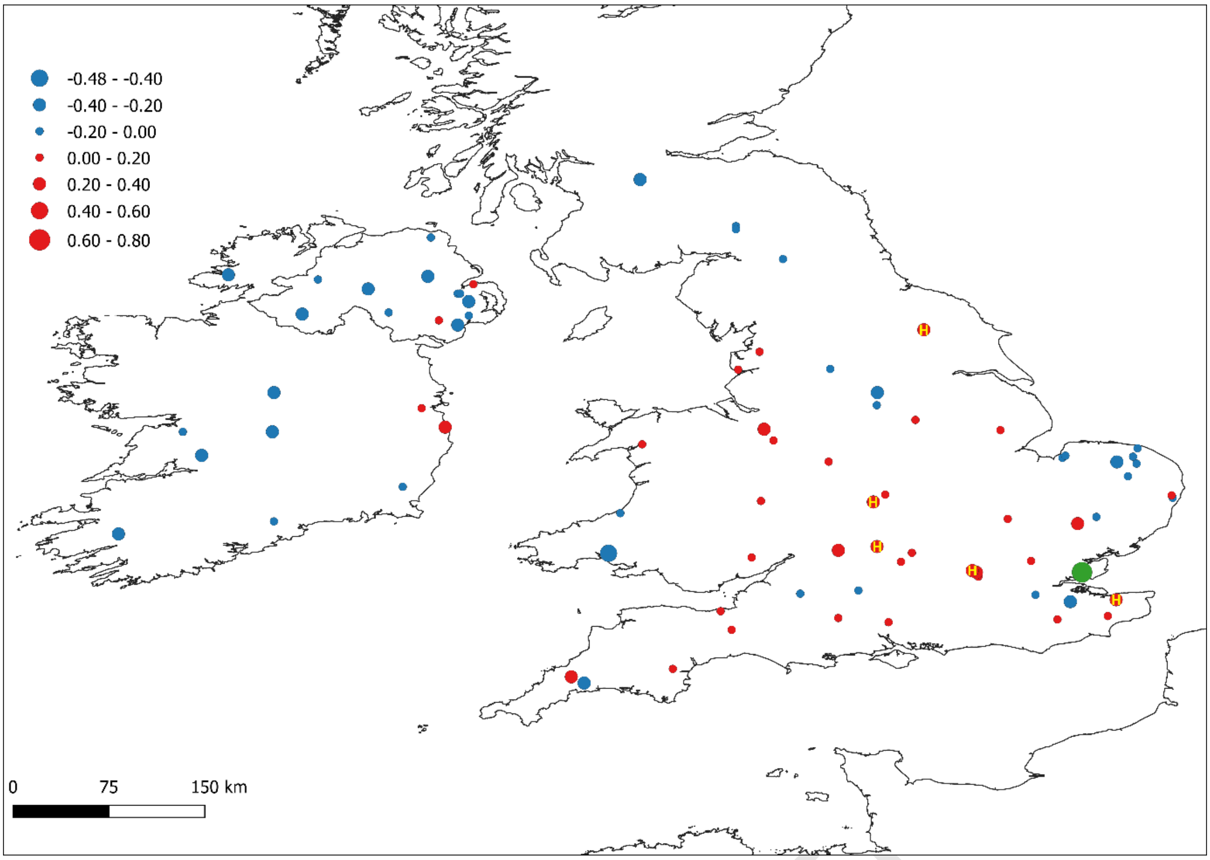


Figure 3. Inter-site correlations for each site against STOM17 indices (left) and residuals (right) plotted against equivalent results for Glen of the Downs (GOTD) and Hockley. The correlations against the four regression lines (0.24, 0.78 and -0.10, 0.67) are the Field R Correlation scores for GOTD and Hockley for the selected site STOM17 (see text for details).

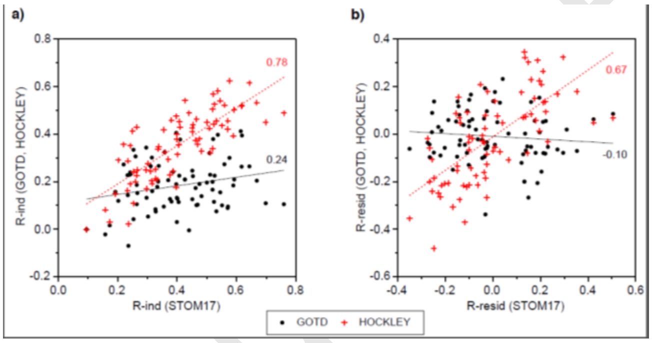
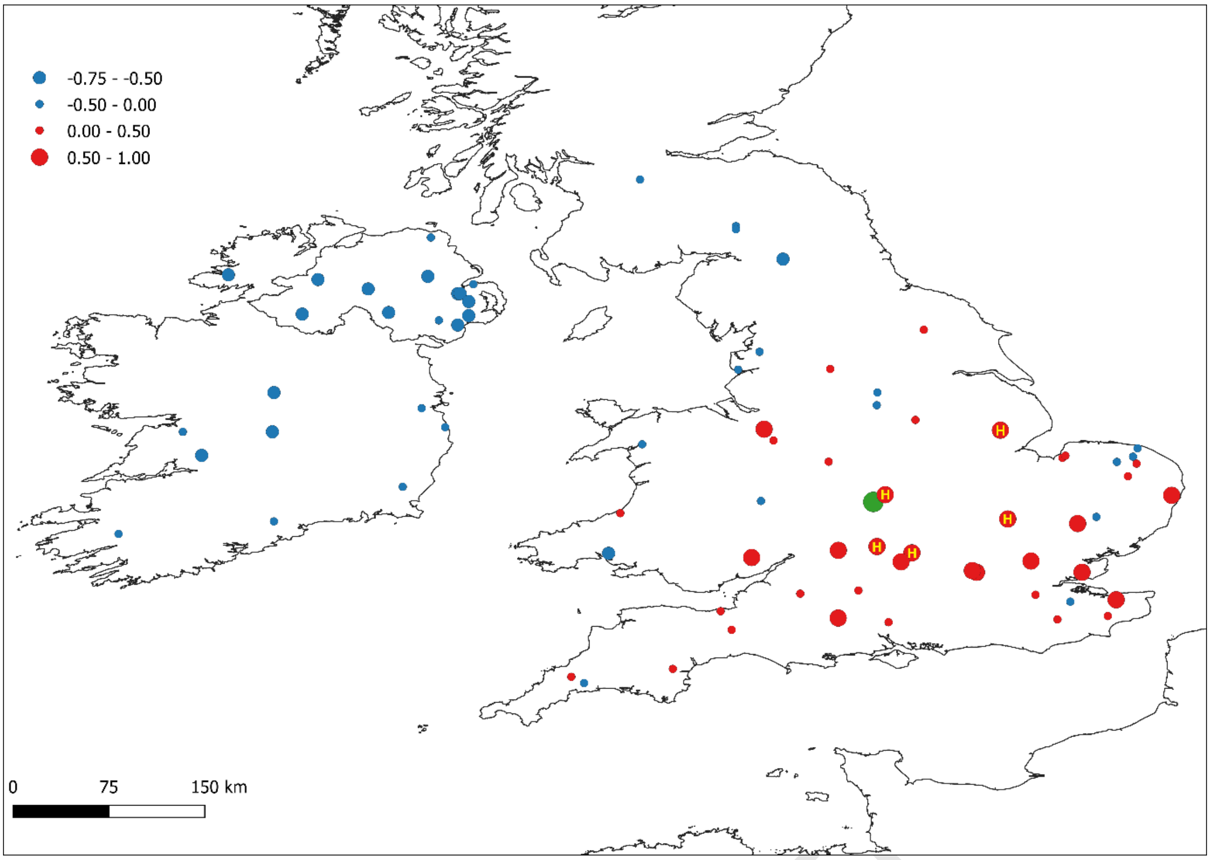
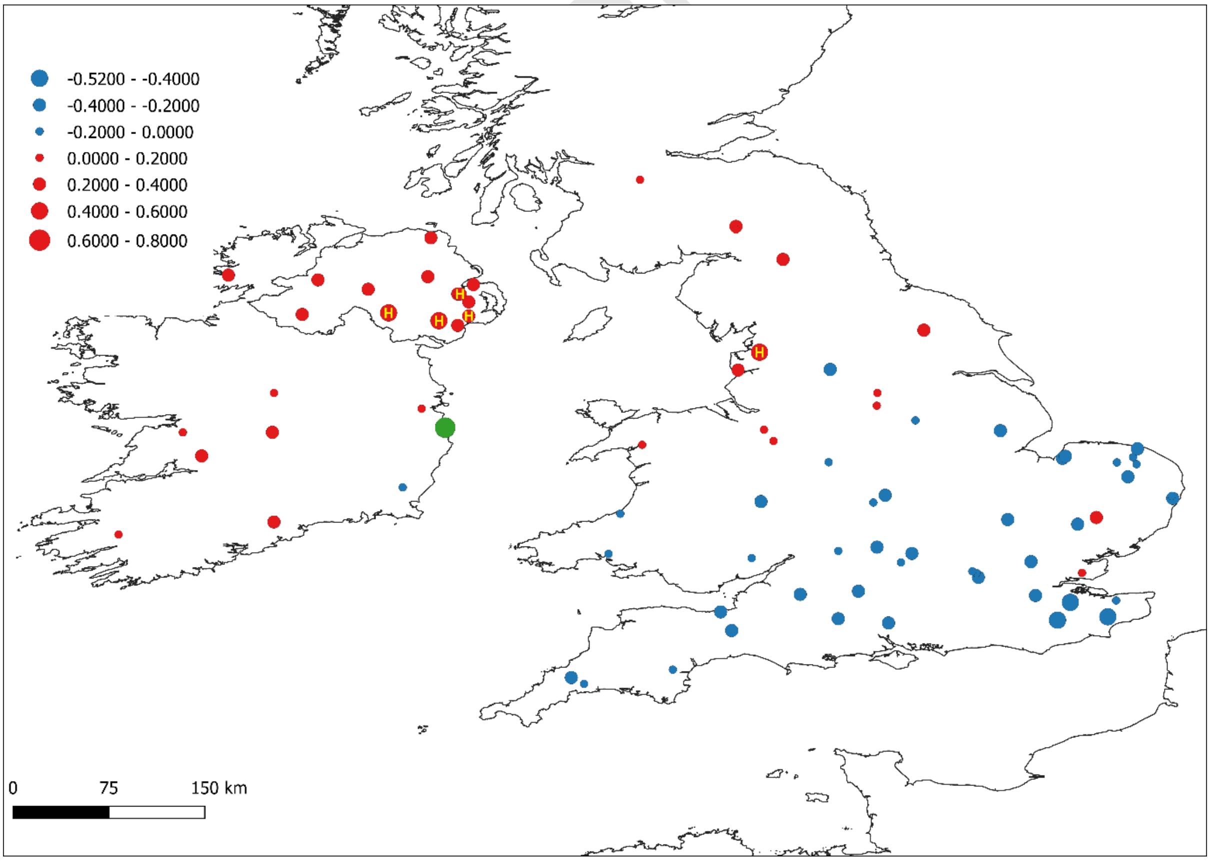


Figure 4a. Field R correlations for the living tree site STOM17 (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.

Figure 4b Field R correlations for the living tree site GOTD (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.

Figure 4c Field R correlations for the living tree site HOCKLEY (green dot) for the 101-year period (1851-1951). A yellow H highlights the five highest value sites.


-0.75 - -0.50
-0.50 - 0.00
0.00 - 0.50
0.50 - 1.00
H
0
75
150 km


-0.5200 - -0.4000
-0.4000 - -0.2000
-0.2000 - 0.0000
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
H
0
75
150 km

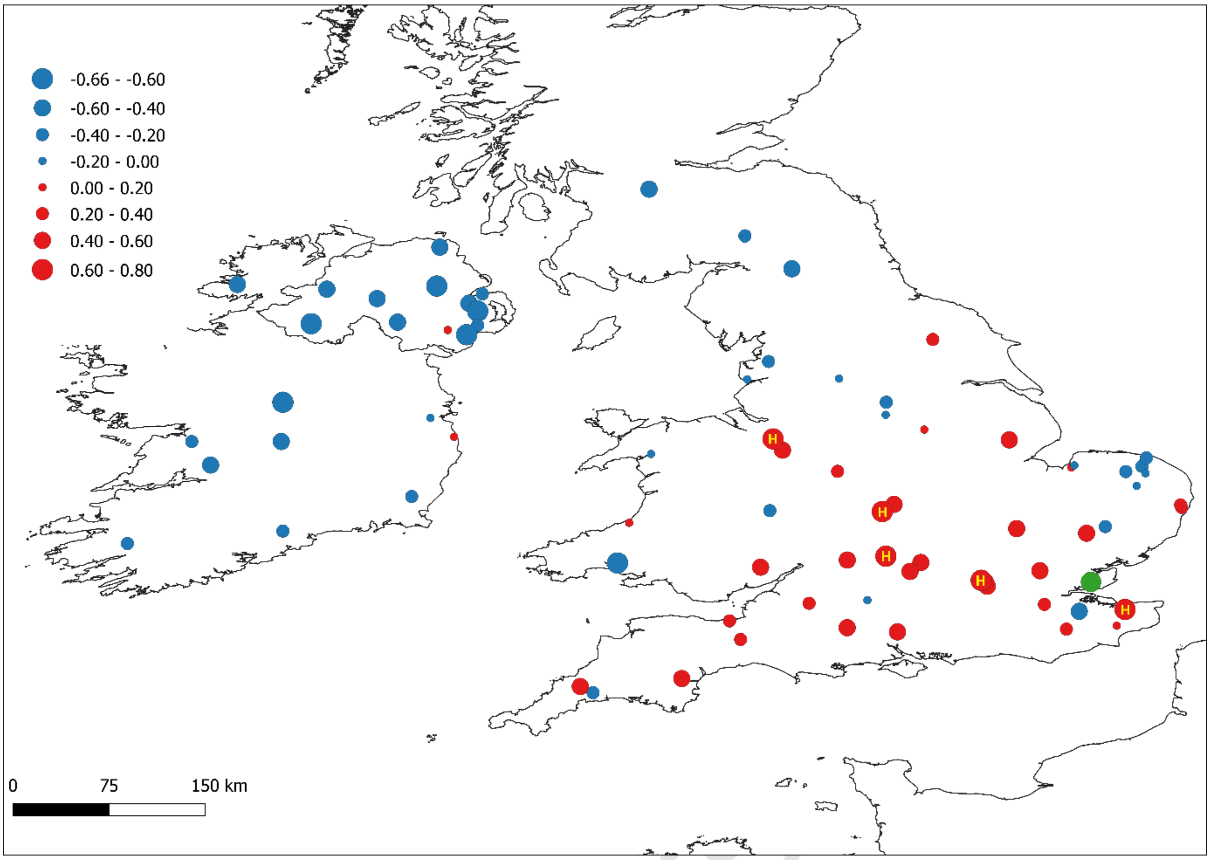
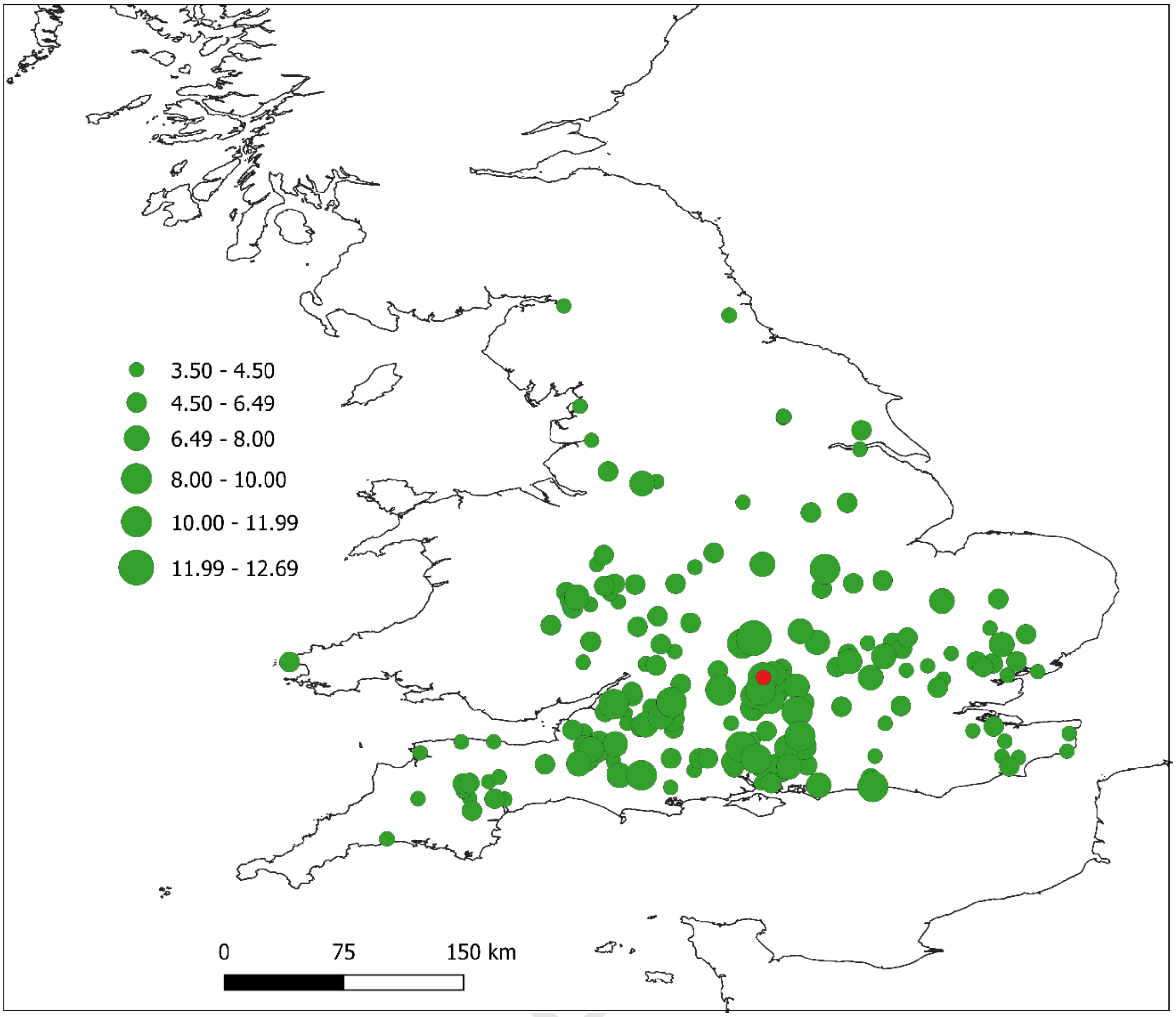


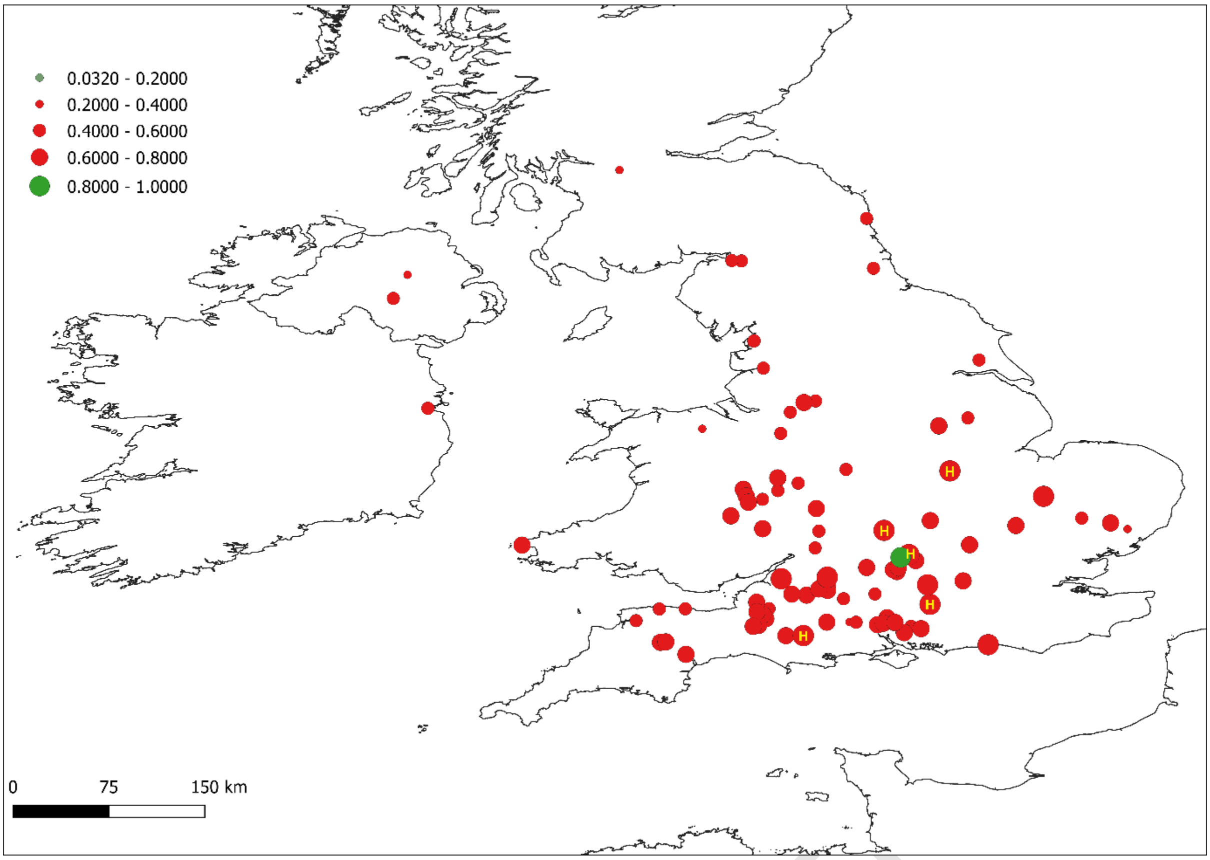
Figure 5a Traditional *t*-value distribution map for the historical site Merton (red dot)

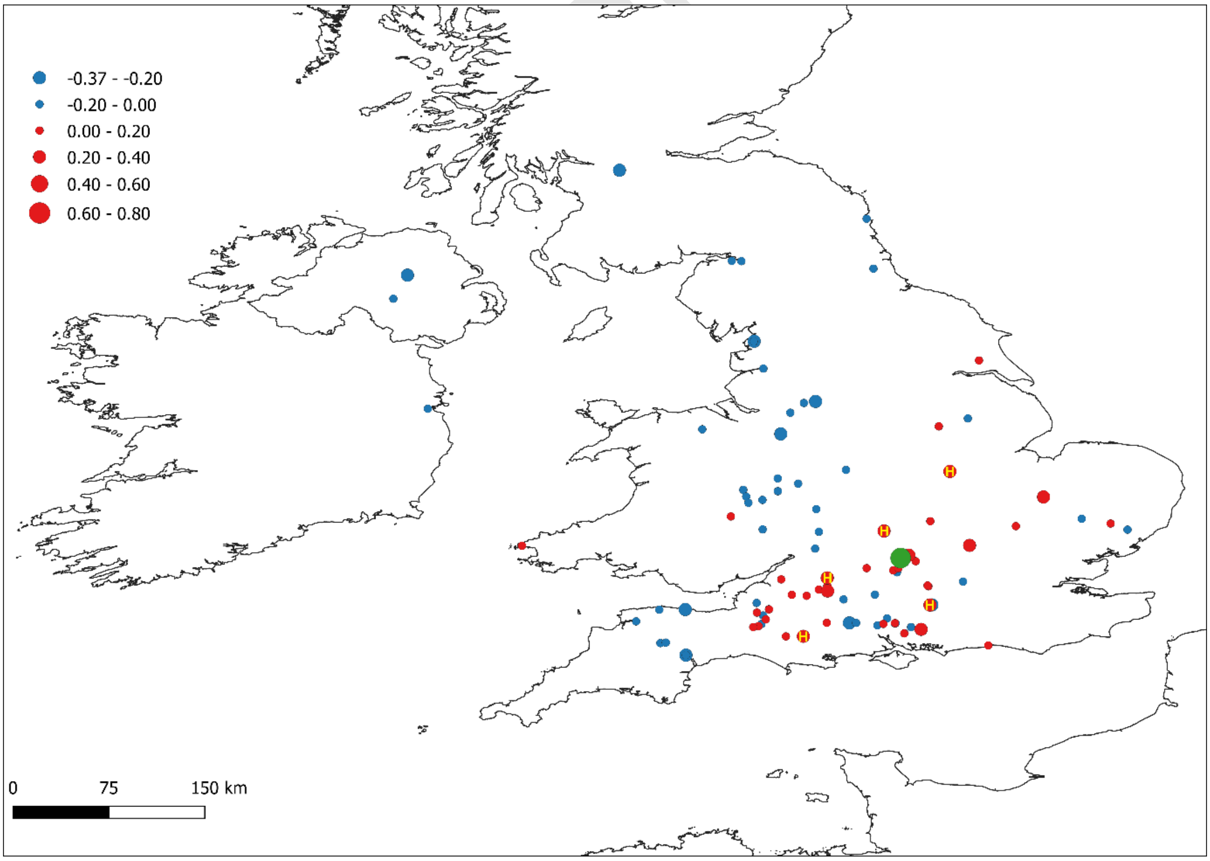
Figure 5b Inter-site R values for the high-pass filtered indexed chronology (R-ind) for the 109-year window centred on 1236 for the historical site Merton (green dot).

Figure 5c Inter-site R values for the residual chronologies (R-resid) for the 109-year window centred on 1236 for the historical site Merton (green dot).

Figure 5d. Field R correlations for 109-year window centred on 1236 for the historical site Merton (green dot)


3.50 - 4.50
4.50 - 6.49
6.49 - 8.00
8.00 - 10.00
10.00 - 11.99
11.99 - 12.69
0
75
150 km


0.0320 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
H
0
75
150 km


-0.37 - -0.20
-0.20 - 0.00
0.00 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
H
0
75
150 km

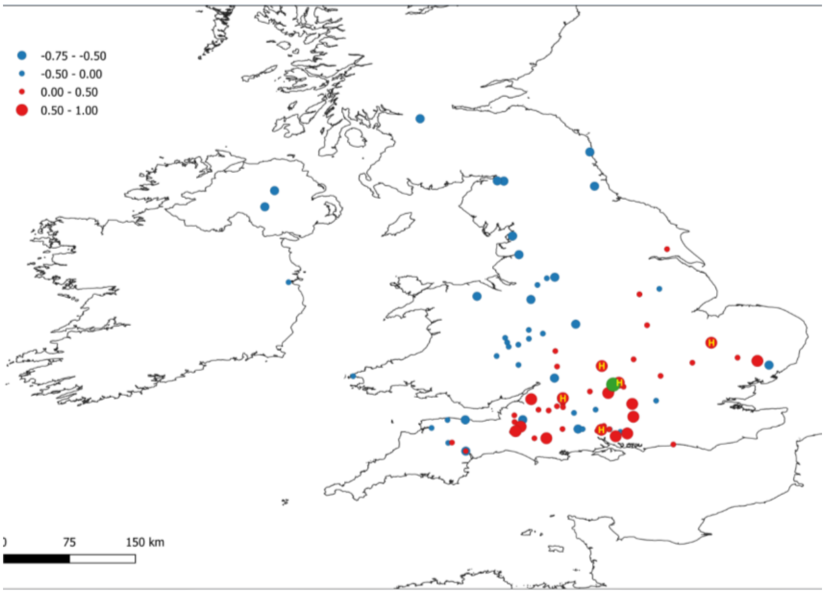


Figure 6. Field R correlations for the historic timber ORK50 from the *Mary Rose*, for the 87-year window centred on 1448

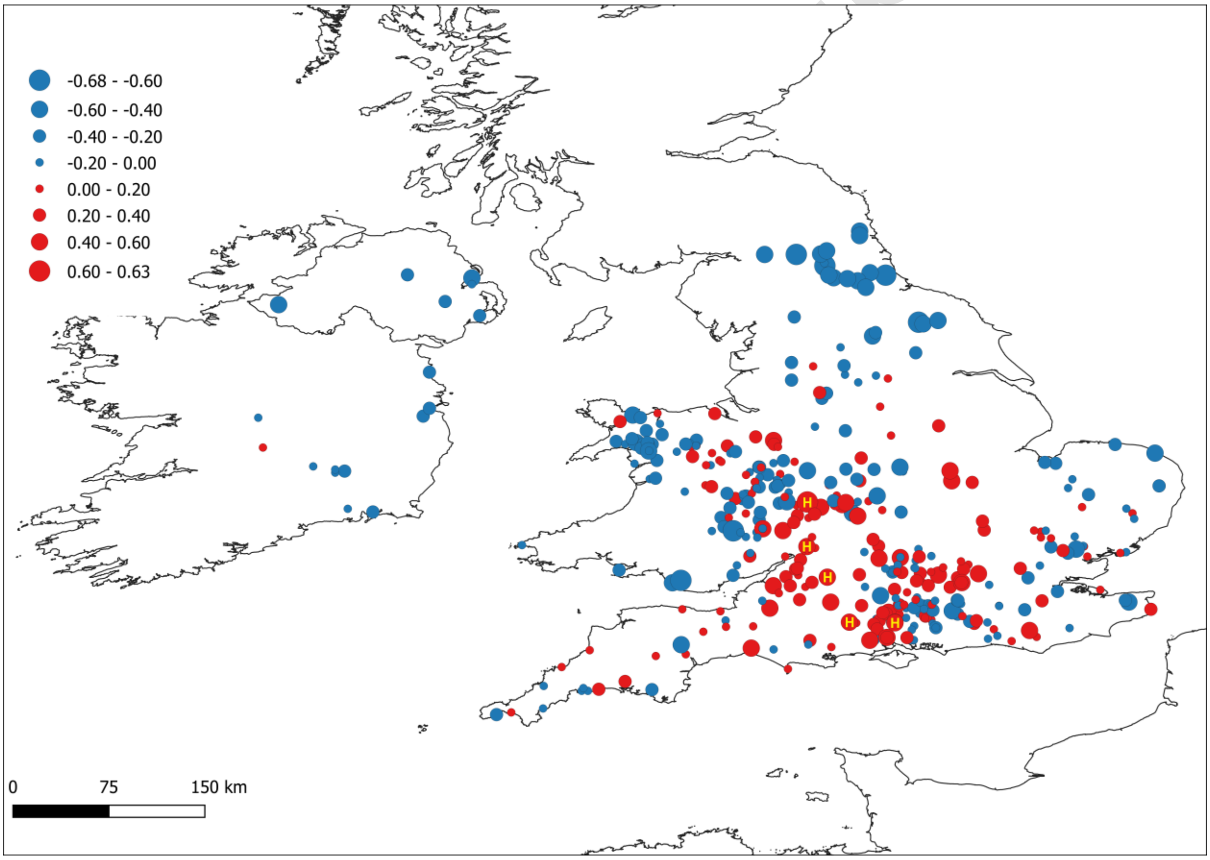


Figure 7. Field R correlations for the historic timber ORK100 from the *Mary Rose*, for the 95-year window centred on 1458

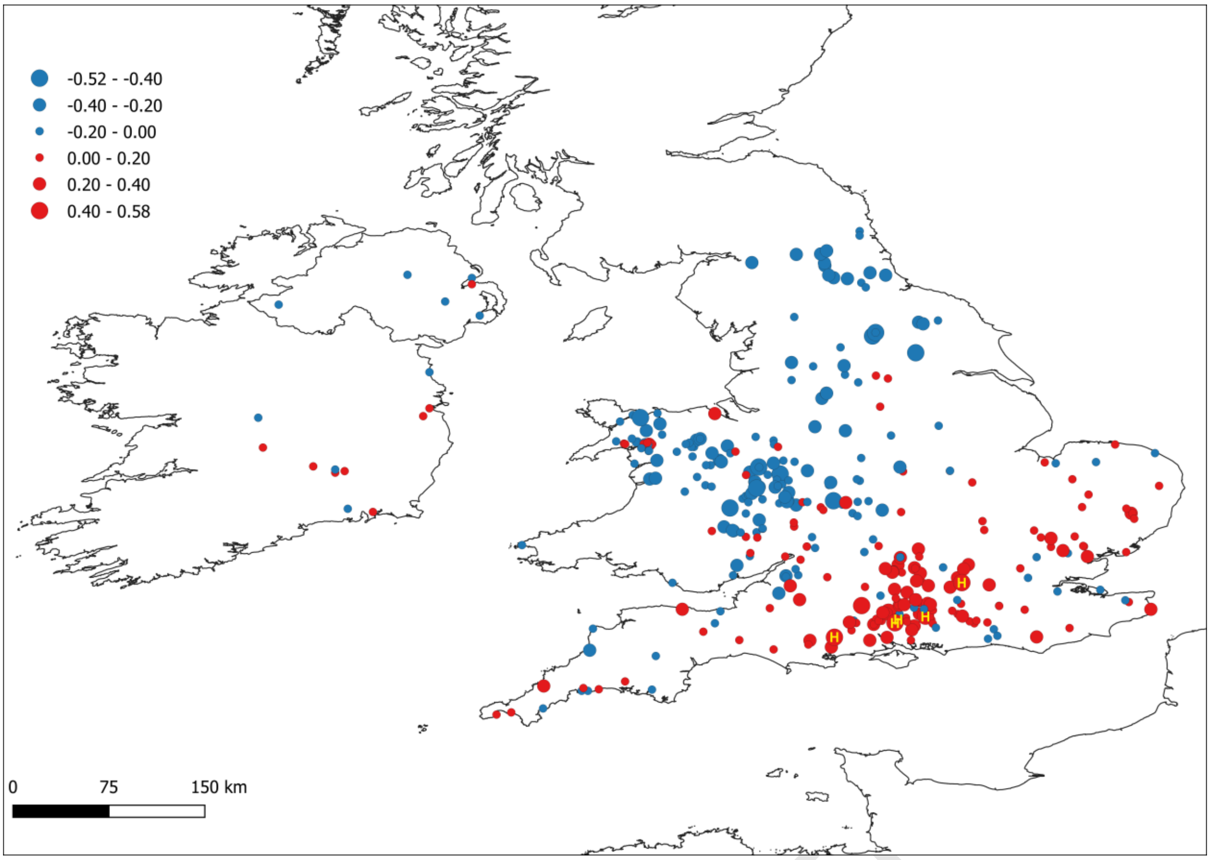


Figure 8. Inter-site R values for the high-pass filtered indexed chronology (R-ind) Laneham Chest for the 111-year window centred on 1168

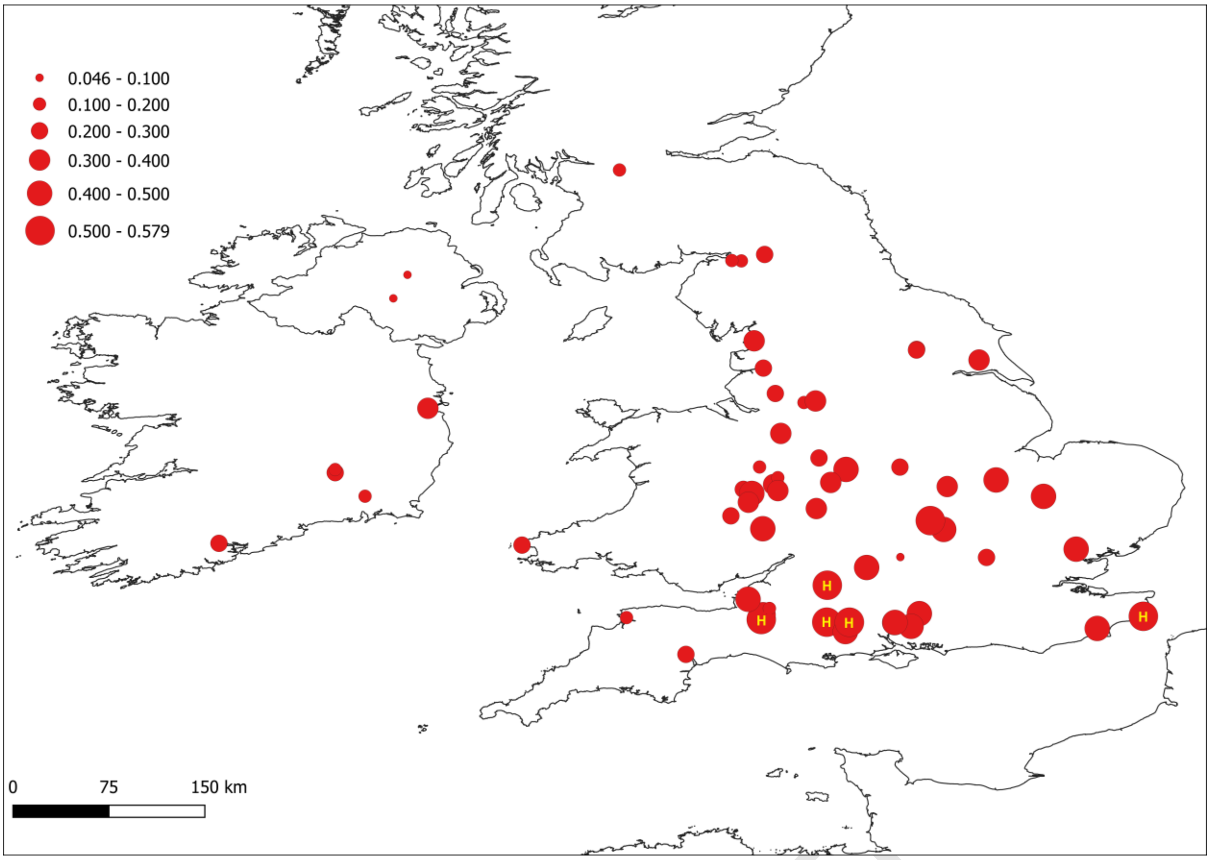


Figure 9. Field R correlations for Laneham chest for the 111-year window centred on 1168

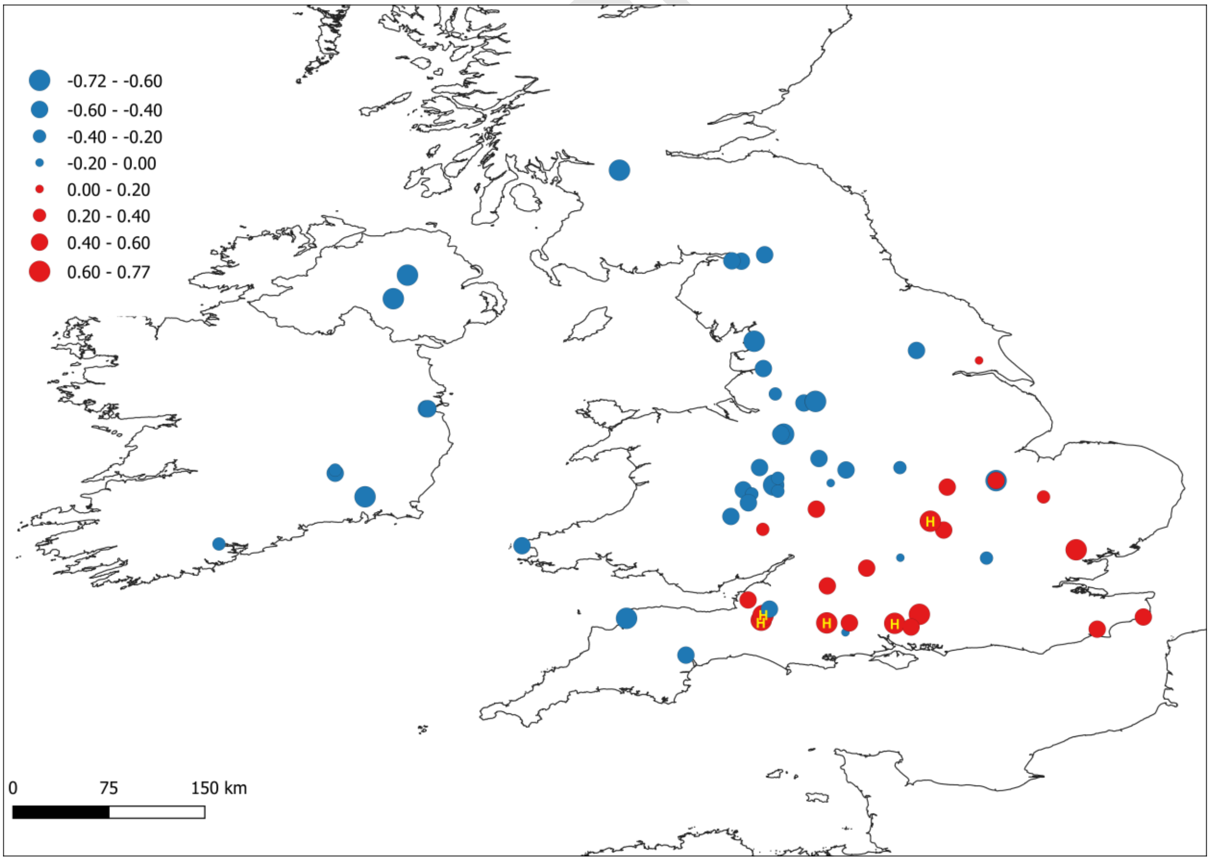
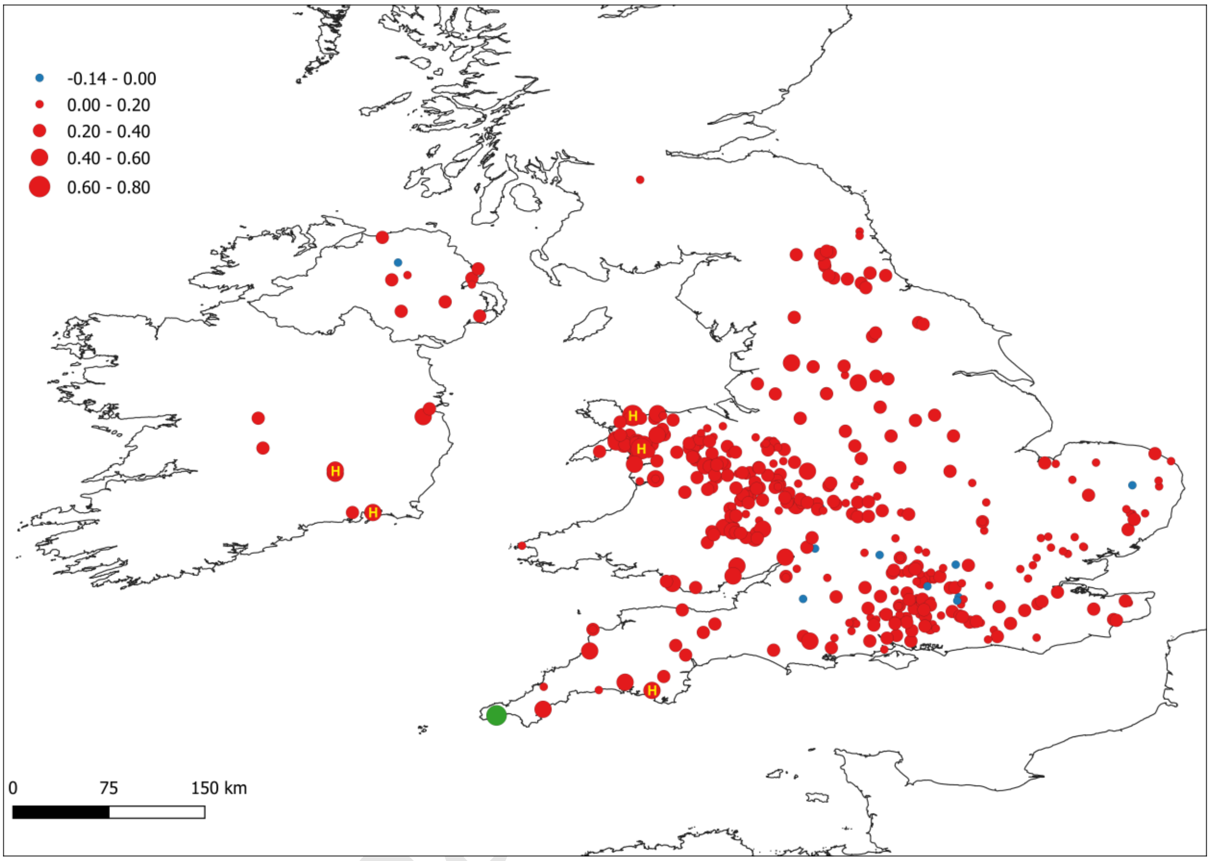
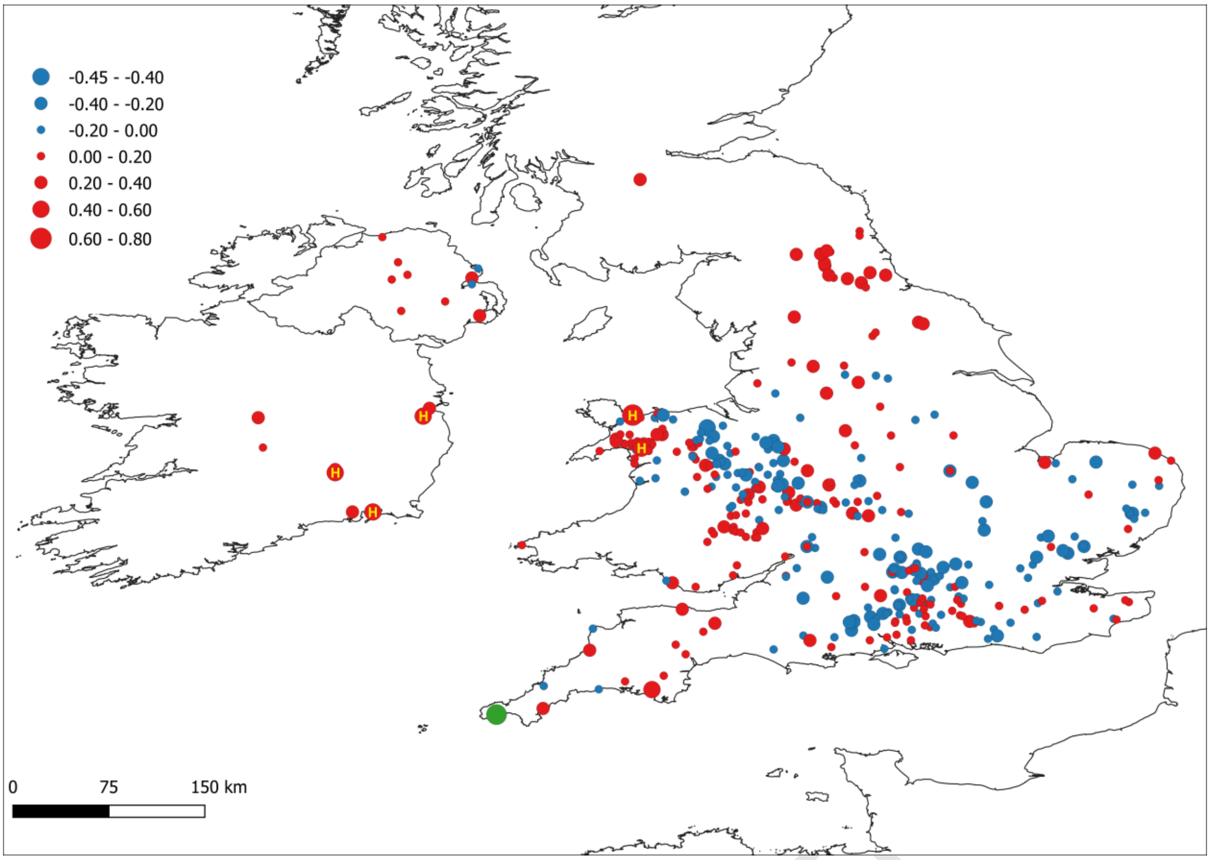


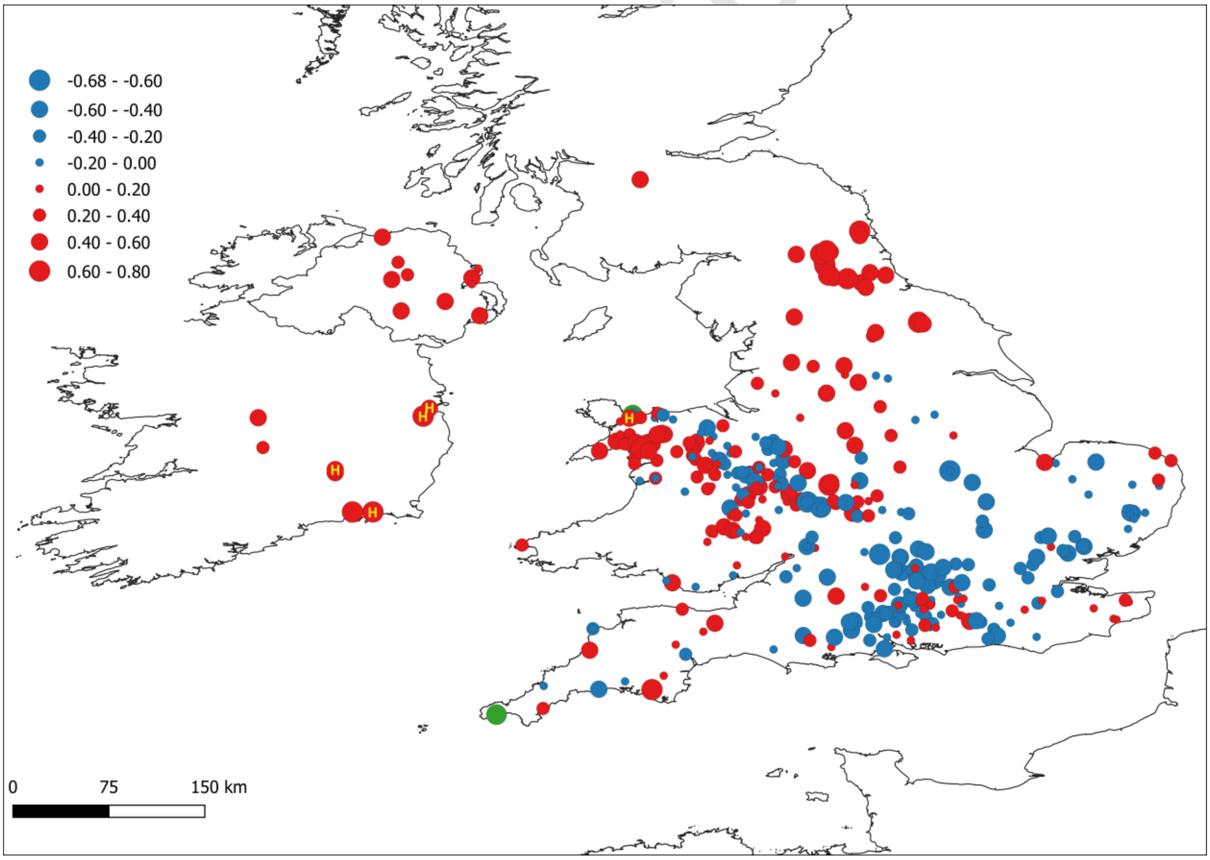
Figure 10a Inter-site R values for the high-pass filtered indexed chronology (R-ind) for the historic chronology Mousehole (green dot) for the 87-year window centred on 1489

Figure 10b Inter-site R values for the residual chronologies (R-resid) for the 87-year window centred on 1489 for the historic chronology Mousehole (green dot)

Figure 10c Field R correlations for the historic chronology Mousehole (green dot) for the 165-year window centred on 1499.




-0.45 - -0.40
-0.40 - -0.20
-0.20 - 0.00
0.00 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
H
0
75
150 km


-0.68 - -0.60
-0.60 - -0.40
-0.40 - -0.20
-0.20 - 0.00
0.00 - 0.20
0.20 - 0.40
0.40 - 0.60
0.60 - 0.80
H
0
75
150 km