Oxygen Isotope Dendrochronology of the Newport Medieval Ship

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Abstract

Since the discovery of the Newport Medieval Ship in 2002, many studies have tried to establish a chronology for its construction and subsequent abandonment. Whilst conventional ring-width dendrochronology has been able to identify the provenance and provide a *terminus post quem* for the ship, until now a felling date for timbers associated with the original construction of the vessel has proved elusive. This study reports results from the application of stable isotope dendrochronology to date timbers from the ship. Using a combination of dendrochronologically-dated timbers and stable oxygen isotopic data from dated and undated samples, we can provide an independent verification of the ring-width dendrochronology and to return the first felling dates for an assemblage of the ship's framing timbers. Our results indicate that the ship was likely constructed shortly after the winter of AD 1457/8 with an operational lifetime of less than a decade. The study highlights the potential for the use of stable isotope dendrochronology for the precise, absolute dating of archaeological ship remains where ring-width dendrochronology alone has not proved effective.

Keywords

Oak, *Quercus*, Newport Medieval Ship, stable isotope dendrochronology, tree ring.

Introduction and state of the question

While it has become largely true that 'dendrochronology is the default method used for dating wooden shipwrecks' (Krąpiec & Krąpiec, 2014, p. 143) the effective application of tree-ring dating in nautical archaeology, let alone a deeper dendroarchaeological approach, can prove a significant undertaking (Domínguez-Delmás, Rich, Daly, Nayling, & Haneca, 2019). This has certainly been true in the extended case study of the Newport Medieval Ship, and more broadly for shipwrecks of Iberian or Mediterranean origin (Domínguez Delmás, Rich, & Nayling, 2022). Since the discovery in 2002 of this clinker-built merchant vessel preserved within the sediments of the river Usk in Newport, South Wales, significant effort has been invested to determine its origin and history.

Initial attempts to absolutely date tree-ring samples taken from the ship's hull within days of its discovery proved unsuccessful. Precise dating of the ship was imperative to demonstrate the ship's significance in the face of its threatened destruction by construction works. As excavations continued under extreme time pressures, recovered artefacts (coinage and ceramics) pointed to Iberian connections but could not initially be closely dated with confidence. Continued sampling of dislocated timbers recovered from within the ship, including a timber rough-out and a large knee, soon provided absolute dates from the mid-fifteenth century matched against British chronologies (Nayling, 2013; Nayling & Susperregi, 2014). This proof of medieval date was pivotal, alongside the vociferous community-led "Save Our Ship" campaign, in securing the ship's future through a funded program of excavation, documentation and recovery. The controlled removal of the ship exposed an underlying structure comprised of oak and elm trunks with limited woodworking which appeared to have been placed in advance of the ship's arrival. Precise dating of these against British ringwidth chronologies, with felling dates including one in the spring of AD 1468 provided a precise *terminus post quem* for the ship's deposition (Nayling & Jones, 2014, p. 246).

During and following post-excavation documentation of the thousands of recovered timbers, hundreds of timbers were sampled for tree-ring analysis. Absolute dating of timbers against British chronologies, including repair patches (tingles) (5_Tingles, felling date range AD 1459-1483), two knees (knee_1614, winter AD 1461/2; knee_1629, winter AD 1465/6,), a rider (R4_2973, felling date range AD 1461-90) and an inserted block (block_734, winter AD1465/6), pointed to British contact and alterations during the ship's working life. Despite success in developing several mean sequences from structural groups such as clinker hull planks (NewportT37, 173-year mean) and framing timbers (NewportT7, 105-year mean), none of these timbers associated with the ship's original construction could be securely dated when compared against either the British or European reference chronologies available at the time (Nayling, 2013). During construction of the Newport T37 mean, five groups of two or more timbers had such similar ring-width sequences that they could be interpreted as having been derived from the same parent trees, and 'single tree' mean series for each of these was calculated and then combined with ring-width series from a further 32 timbers (hence the descriptor T37).While some of the additional timbers could come from common parent trees, there is insufficient statistical correlation (normally Baillie-Pilcher *t* value >10) and visual similarity of their ring-width sequences to infer this. During construction of the Newport T37 mean, two subgroups of timbers with higher correlations (one of 29 sequences derived from 36 individual hull planks and two filler pieces, and of second of only five individual planks sequences) were noted. The construction of this mean series is relevant here as the two hull plank samples selected for oxygen isotope analysis came from these two subgroups included within the NewportT37 mean. The Newport T7 mean was made up of seven correlated ring-width sequences from framing timbers. None of these individual sequences showed sufficiently high statistical correlation and visual similarity to infer same tree derivation.

A major breakthrough occurred in 2014 when the ring-width from cross-matched samples from the hull planks (NewportT37), which comprised timbers with mostly no or less-commonly only partial sapwood, were successfully dated against a new oak (*Quercus* subg. *Quercus*) ring-width chronology developed in Euskal Herria/Basque Country, northern Spain (Nayling and Susperregi 2014). This discovery transformed the narrative relating to this vessel, enabling not only the broad provenancing of the hull planks used to construct the ship, but also providing a *terminus post quem* sometime after AD 1449 for its construction. It was not possible to refine this date or to estimate a felling date range due to the absence of region- and species-specific sapwood estimates. Notwithstanding these limitations however, the successful dating of the ship against Iberian chronologies, together with the dating of the cradle and repairs offered a better understanding of the working lifetime of the vessel.

A further outcome of the dendrochronological analyses was the cross-matching of the ring-width sequences from seven of the framing timbers from which a 105-year ring-width mean (NewportT7) was calculated. Whilst this series and its components could not be dated against either regional reference chronologies, or the absolutely dated hull plank mean (NewportT37), it was noted that five of the samples all ended at the same relative position (ring 105) and these preserved possible or definite bark edge. The term bark edge is used to indicate that, on the measured sample, the last ring of the parent tree immediately inside the bark was present and hence can precisely date when the tree was felled to the year or even the season (Nayling, 2016, Table 1). The NewportT7 assemblage also correlated with BRP_1752 a chock with possible bark edge preserved, at the same relative end date (Nayling & Susperregi, 2014, fig 5). Although some filler pieces from within the ship did cross-match against the hull plank mean, the framing timbers appear to have been derived from oaks which were both younger than the parent trees from which the planks derived, and contained natural curvature suited to their use as framing elements – a pattern seen in the more limited evidence from other Iberian clinker-built medieval vessels such as Barreiros and Barceloneta I (Domínguez Delmás et al., 2022, fig 1.5). It is suggested that the parent trees from which the framing timbers of the Newport Medieval Ship were hewn may have grown in a location closer to the coastal construction site than those exploited for hull planks, under rather different ecological conditions. These trees may also have been subjected to woodland management and disturbance known to have taken place in Biscayan lowland coastal woodlands (Aragón Ruano, 2001, 2010). This hypothesis could explain the lack of ring-width correlation between the two ring-width means. It also points to a way forward in seeking the elusive precise absolute dating of the construction of the Newport Medieval Ship through the analysis of oxygen stable isotopes.

Material and methods

Recent developments in the analysis of tree-ring stable isotopes for absolute dating provide opportunities for precise dating of wooden artefacts (Loader et al., 2019; Sakamoto, Hakozaki, Nakao, & Nakatsuka, 2017; Sano et al., 2022). Stable isotope dendrochronology shares many of the underlying principles of ring-width dendrochronology, but with some important distinctions that enable stable isotopes to date fast-grown, invariant samples from across a wider geographic range and a wider range of species than is normally possible using ring-widths alone. This is because the isotopic signal preserved within the water and the carbon dioxide assimilated by trees during photosynthesis and growth is expressed strongly over a large geographic region and sampled almost passively by the trees (Loader et al., 2021; Loader et al., 2022; McCarroll et al., 2019; Nakatsuka et al., 2020; Treydte et al., 2007).

This study applied stable oxygen isotope dendrochronology to three timbers from the Newport Medieval Ship. The three timbers comprise two dated series; P5.5_2343 and P16.1_2360, both planks from the outer hull dated by ring-width dendrochronology to AD 1351-1446 and AD 1335-1423 respectively and forming series within the plank mean NewportT37, and one undated series with bark edge; F14.2_2912 a framing timber from the undated NewportT7 mean (Nayling, 2013; Nayling & Susperregi, 2014). The dated plank samples were selected for three main reasons. Firstly, their average ring widths were relatively high compared with other plank samples, facilitating confident cutting of the latewood from each annual ring for cellulose extraction. Secondly, although the ring-width series from these two samples form part of the ring-width mean Newport T37, they belong to two separate sub-groups of ring-width series within this mean and exhibited only a low correlation of Baillie- Pilcher *t* value = 2.88 (Baillie & Pilcher, 1973). If stable oxygen isotope series from the two samples could be securely cross-matched with each other, at the indicated relative position, this would support their relative dating based on ring-widths alone. Thirdly, successful cross-matching would confirm that these samples, derived from timbers buried for over 500 years in a waterlogged environment and conserved through a combination of polyethylene glycol (PEG) impregnation and freeze drying, still retained a viable and coherent oxygen isotopic signal.

The framing timber sample F14.2_2912 was selected for stable isotope dating against the two dated hull planks. If cross-matching was established, this would in turn provide absolute dating for the six other framing timbers cross-matched within the floating framing timber mean Newport T7 and the cross-matching chock BRP_1752. Given that six of these timbers exhibited possible or definite bark edge in the same relative year, such absolute dating could deliver precise dating for the ship's original construction.

Following selection of the samples, laths were cut from the conserved timber samples using a fine-toothed handsaw (Figure 1). To minimise visual impact, as the samples will in due course be reassembled with the rest of the ship for museum display, the laths were cut from the inboard face of the radial plank samples. These laths were cleaned, and their ring-widths measured to the nearest 1/100 mm. The resultant ring-width series were compared with the original measurements of the samples undertaken in 2007/8 to ensure correct measurement and absolute or relative dating.

The individual rings were manually divided using a scalpel under magnification and the latewood processed to alpha-cellulose as described by Loader et al. (1997), using a modified setup (Wieloch et al., 2011), prior to homogenisation using an ultrasonic probe (Laumer et al., 2009) and freeze drying (48h at -48°C 0.001 Pa). Several of the dried cellulose samples exhibited an orange hue, which we believe to be iron oxide entering the outer rings of the sample from the depositional environment. As iron oxide could adversely affect isotopic analyses, the samples were treated with 10% hydrochloric acid at room temperature. Samples were left in solution for at least 18 hours, until no further change in sample colour was identified. The resulting white cellulose was then washed (minimum 5 times) to neutrality using de-ionised water. In cases where impurities could not be chemically removed, discoloured cellulose fragments were removed manually from the sample using forceps. The treated samples were again freeze dried. The dry alpha-cellulose was pyrolised to carbon monoxide over glassy carbon at 1400ºC using a Flash HT elemental analyser interfaced with a Delta V isotope ratio mass spectrometer. Results are expressed using the delta (δ) notation as per mille (‰) deviations relative to the VSMOW standard (Coplen, 1995). Analytical precision is typically better than 0.3 per mille (σ_{n-1} n=10). Oxygen isotope ratios are then converted to indices using a 9-year rectangular filter by subtraction and the series compared individually using the method outlined in Loader *et al.* (2019). It was not always possible or appropriate to prepare cellulose from the latewood of all rings due to poor preservation or diagenesis and any rings not analysed were considered when reporting dates. Equally, even when isotope ratios were determined, some outermost rings e.g. sapwood, were excluded from subsequent statistical analysis due to perceived drop off in isotope ratios associated with degradation or contamination.

The two isotope series P5.5_2343 and P16.1_2360 were then compared pairwise. Following a standard dendrochronological approach, where a significant match was identified, the indices could then be combined by averaging to develop a 2-sample mean sequence for comparison with the undated series F14.2_2912. Where this was found to cross-match with the 2-sample mean sequence then this third sample could also be combined with isotopic data from the other two timbers prior to comparison with regional reference chronologies. When comparing the dendrochronologically-dated series, the following criteria were assigned: the series had to return the strongest date at a point consistent with the dendrochronological dating and to pass the thresholds identified by Loader et al. (2019) for consideration (i.e. the probability of error 1/p >100, and the ratio of the probabilities for first and second strongest matches (IF) >10). For the undated series F14.2_2912, as the date is not known, the statistics for the position of the best match had to pass these thresholds (1/p >100 IF >10) only. All comparisons made were subjected to an additional visual check. There are currently no well-replicated oxygen isotope chronologies for the Basque region so, until such a chronology is constructed composite isotope series were compared with regional chronologies from England and France following the dating protocol of Loader et al. (2019) which reports Bonferroni-corrected probabilities (1/p>100 IF>10).

Results and discussion

The isotopic data from the dendrochronologically-dated samples P5.5_2343 and P16.1_2360 comprise 87 and 89 rings respectively. Relative to the ring-width dating, these would represent the years AD 1354-1440 and AD 1335-1423. Isotopic data for sample F14.2_2912 comprises 84 rings, beginning 2 rings in from the innermost measured ring and ending 12 rings from the end of the measured ring-width series (bark edge).

Comparison of the isotope series from the previously dated plank samples returns the strongest match at a position consistent with the ring-width dendrochronology (Table 1, Figure 2). This confirms the relative dating of the two series and also the veracity of the isotope signal from samples obtained from a waterlogged burial environment which had also undergone conservation treatment. It is interesting to note that although the two ring-width series did not crossmatch against each other with a significant correlation (Baillie-Pilcher *t* value = 2.88), a reasonable match (Student's *t* value = 5.47) was obtained using the stable isotopes.

The two plank isotope series were combined (NS2343_2360AVG) and compared with the undated isotope series from F14.2_2912. A secure match was returned (Table 1, Figures 2 and 3), placing the date of the last ring measured isotopically at AD 1445, which equates to a date of AD 1457 for the last ring-width measurement. As possible bark edge was noted on this sample when first measured for ring widths (Nayling, 2013; Nayling & Susperregi, 2014), this represents a possible felling date of AD 1457B? and securely dates the other six framing timbers (NewportT7) and a single chock BRP2_1752 against which its ring-width were previously cross-matched (Figure 4). The correlation between the previously dated ring-width mean NewportT37 (AD 1277 to AD 1449) and the now isotopically dated ring-width mean from framing timbers NewportT7 (AD 1353 to AD 1457) is not statistically significant (Baillie-Pilcher *t* value = 1.91). This demonstrates that the absolute dating of the framing timber mean could not have been anticipated through comparison of ring-widths alone.

Having successfully dated sample F14.2_2912, the three index series were combined into a single mean (NS2343_2360_2912AVG) and compared against the Loader et al. (2019) south central England reference chronology. No significant dates were obtained across the full chronology. This is perhaps to be expected given previous dendroprovenancing to the Basque region, but it serves to confirm that these timbers do not originate from the United Kingdom.

The absence of a well-replicated oxygen isotope reference chronology for northern Spain means that it is not possible to conduct a similar dating comparison. However, an oxygen isotope dataset is available for France (Labuhn et al., 2016) developed from *Q. robur* L. and *Q. petraea* (Matt.) Liebl., which was used here in an attempt to establish an independent isotopic dating of these findings.

When compared against the composite French dataset at the correct date, the mean series returns a significant match (Student's *t* value = 5.59, Table 1) which passes the thresholds for consideration as a date. Pairwise comparisons between the French Chronology and the individual series are also presented (Table 1). This result strengthens if the reference chronology is truncated to the period where there are at least four trees contributing to the chronology, indicating that the chronology signal strength could be enhanced through the addition of more trees. Importantly, this match with French isotopic data independently verifies the dating obtained by the ring-width dendrochronology and isotopic dendrochronology.

It is now possible to assign an absolute felling date to timber F14.2_2912 and by association the rest of the NewportT7 group and chock BRP_1752 (Figure 4). This result delivers the first absolutely dated, precise felling dates for timbers used in the ship's original construction. Two of the dated framing timbers, first futtocks F40.2 and F35.3, had complete final rings indicating felling in the winter of AD1457/8. This implies that the ship could not have been completed before the winter of AD 1457/8. While construction of clinker-built ships would normally favour the use of green, unseasoned timber, delays in completion of the ship after the felling of the parent trees used for the framing timbers could occur for several reasons. These include the time taken to transport timbers from the source area to the shipyard and the stockpiling of timber. There are rare examples of dendrochronological evidence for differing felling dates for framing timbers used in the construction of comparable clinker-built vessels (Krąpiec & Krąpiec, 2014; Nayling, 1998; Tyers, 1998). In the case of the Newport Medieval Ship, the time required to complete construction, following insertion of the framing timbers, would have included insertion of the keelson, stringers, ceiling, knees and crossbeams; construction of the pump(s), decks and upper works; and setting of masts and spars. Rigging and provisioning of the ship would also need to be completed before the beginning of the ship's working life. Based on the dendrochronological dating, it would be reasonable to suggest that the ship was constructed 'soon after' the winter of AD 1457/8. The ship was found overlying a timber structure comprising oak and elm trunks with minimal working and felling dates in the winter of AD 1467/8 and the spring of AD 1468 (Nayling & Jones, 2014, p.245, fig. 7). If the timbers had been deposited soon after felling, and the ship positioned over this structure soon after, then it would appear that the ship had a working life of around a decade or less.

Conclusions

The independent verification of the relative and the absolute dating of the three samples using stable oxygen isotopes is significant and highlights the wider potential of the isotope dating technique to refine chronology in maritime applications, both independently or in concert with other dating methods. This ability to date the series independently using a record of oxygen isotopes from France is also significant as, even with relatively low sample replication, the secure match obtained confirms the broad spatial range of the isotope dating technique. When first establishing an Iberian origin for the ship, Nayling and Susperregi (2014) highlighted the presence of existing tree-ring samples from across the northern coastal region and the need to develop additional ring-width chronologies to refine provenancing and dating. Whilst the broad geographic range of the oxygen isotopic signal may make dendroprovenancing using isotopes alone somewhat challenging, the benefits this affords to chronology development and dating across regions should be explored further, especially in regions of variable geology and topography. There already exist established ring-width dendrochronology chronologies for this region and a logical and achievable next-step would be to develop a European network of isotopic reference chronologies to support similar applications for the dating and provenancing of our maritime heritage.

Author contributions

All authors contributed to the writing of the manuscript, NN and RJB conducted ring-width dendrochronology, excavation and sub-sampling. RJB prepared the rings samples. DD, NJL and DMcC conducted secondary sample preparation, isotopic analysis and isotopic dating. VD led development of the French isotope chronologies provided for this research. We are grateful to two anonymous reviewers for comments which helped us to improve this article.

Statement of Interests

The authors declare no conflict of interest.

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Table1: Results of crossdating between the oxygen isotope individual samples series, site mean and regional records. Inter-series comparisons and associated statistics are presented for the period of full overlap at the point of strongest match. Comparisons between the site mean and the regional chronologies adopt the dating protocols of Loader et al. (2019) and report Bonferroni-corrected probabilities.

Sample Reference	Compared with	Correlation (r)	Student's *t*	No. Rings overlap	Degrees of freedom	1/p	Isolation Factor	Isotope series start	Isotope series end	Sample series start	Sample series end
NS_2343	NS_2360	0.577	**5.47**	70	60	>1 million	> 1000	1354	1440	1351	1446 (6)
NS_2912	NS_2343,2360	0.593	**6.51**	79	68	>1 million	> 1000	1362	1445	1359	1457 (B?)
NS_2343,2360,2912	S. England	0.216	2.16	111	95	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
NS_2343,2360,2912	France	0.496	**5.59**	111	96	16173	> 1000	1335	1445	1335	1457 (B?)
NS_2343	France	0.450	**4.37**	87	75	16682	> 1000	1354	1440	1351	1446 (6)
NS_2360	France	0.440	**4.27**	89	76	35571	> 1000	1335	1423	1335	1423
NS_2912	France	0.585	**6.13**	84	72	>1 million	> 1000	1362	1445	1359	1457 (B?)

IF = Isolation Factor, 1/p = probability of error (calculated for full overlap best match position), (B?) = Possible bark edge preserved, (6) = Six sapwood rings preserved on sample not analysed. Samples NS_2912 and NS_2343 include evidence of juvenile rings and diagenesis/contamination (outer rings). Three (juvenile) rings from both samples and nine and four outer rings respectively were excluded from the final dating calculation, their exclusion does not change the date obtained.

Figure Captions

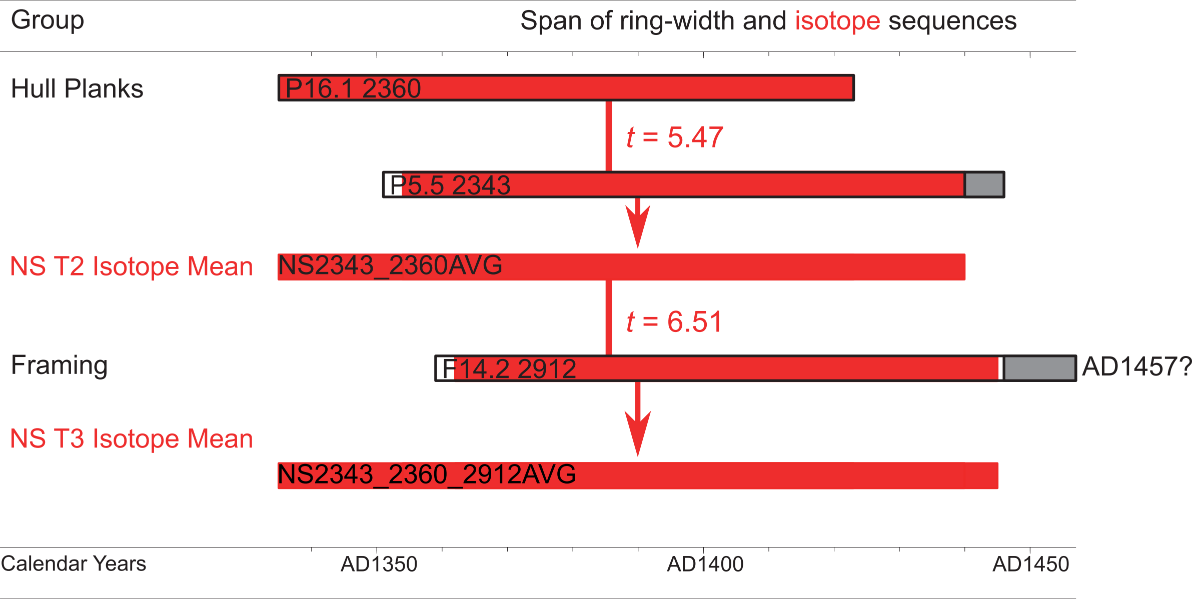
Figure 1: Subsampling of the conserved dendrochronology framing timber sample F14.2_2912. The extracted lath was then cut using a scalpel under magnification to collect the latewood from each annual ring (Photograph: R.J. Bale).

Figure 2: Bar diagram of original ring-width series (black outline with sapwood shaded grey) and isotope series (red) for the two hull plank samples, correlation between these two isotope series (Student's t = 5.47), construction of two-timber isotope mean, and correlation of isotope series from framing samples against it (Student's t = 6.51), and construction of three-timber isotope mean. Framing ring-width series absolutely dated with a possible bark edge date of AD 1457B? (Image: N. Nayling).

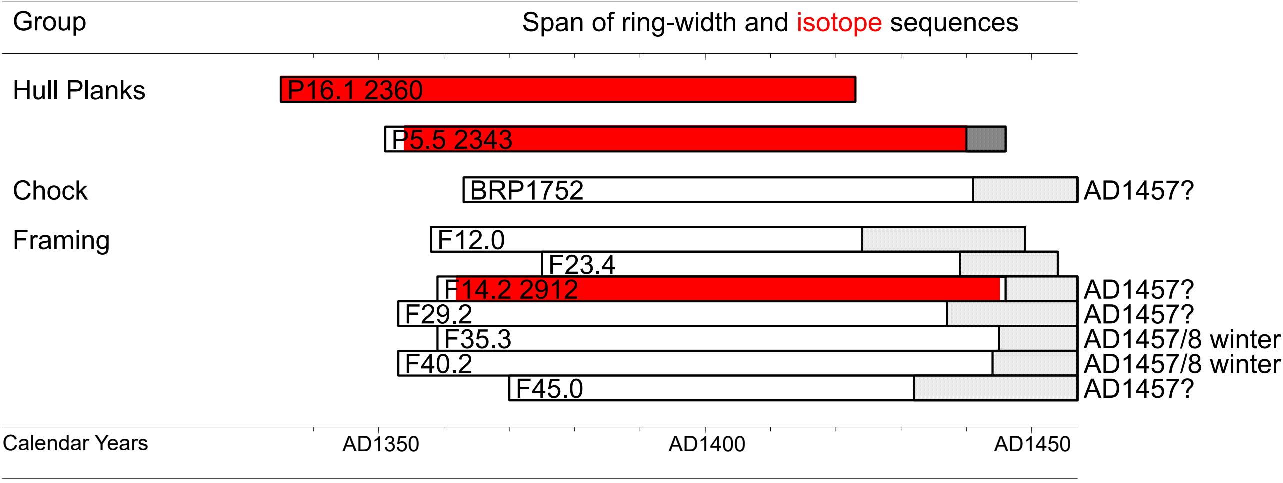
Figure 3: Visual comparison of the oxygen isotope series F114.2_NS2912 and the isotope mean of dated timbers P5.5_NS2343 and P16.1_NS2360, positioned at the date of best match AD 1335 to AD 1445 (Student's t = 6.51 1/p >1 Million, IF >1000). Twelve annual rings (not measured isotopically) at the end of NS2912 with possible bark edge imply a felling date of AD 1457B? (Image: N.J. Loader)

Figure 4. Bar diagram of the absolute dating of the original ring-width series (black outline with sapwood shaded grey) and isotope series (red) for the two hull plank samples, and framing timbers group NewportT7 and chock BRP_1752 indicating absolute felling dates (Image: N. Nayling).


8 9 10 11 12 13 14 15 16 20
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 51 52


Group
Span of ring-width and isotope sequences
Hull Planks
P16.1 2360
t = 5.47
P5.5 2343
NS T2 Isotope Mean
NS2343_2360AVG
t = 6.51
Framing
F14.2 2912
AD1457?
NS T3 Isotope Mean
NS2343_2360_2912AVG
Calendar Years
AD1350
AD1400
AD1450


Isotope indices
2
1.5
1
0.5
0
-0.5
-1
-1.5
1330 1340 1350 1360 1370 1380 1390 1400 1410 1420 1430 1440 1450
Year (AD)
NS2343,2360 AVG
NS2912



Group
Span of ring-width and isotope sequences
Hull Planks
P16.1 2360
P5.5 2343
Chock
BRP1752
AD1457?
Framing
F12.0
F23.4
F14.2 2912
AD1457?
F29.2
AD1457?
F35.3
AD1457/8 winter
F40.2
AD1457/8 winter
F45.0
AD1457?
Calendar Years
AD1350
AD1400
AD1450