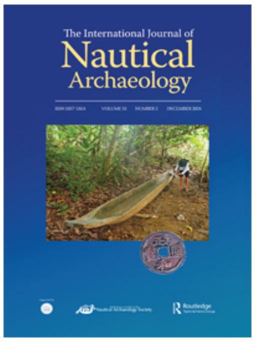

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NOTE

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Inter-Genus Oxygen Isotope Dendrochronology of the Newport Medieval Ship Keel

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Introduction

The evolving history and interpretation of the Newport Medieval Ship, a clinker-built vessel preserved within the sediments of the River Usk (Wales, United Kingdom) is underpinned by tree-ring analysis. Following discovery of the ship in 2002, dendrochronology has determined felling dates and a UK origin for the structure upon which the ship came to rest and for dislocated timbers recovered from within the ship, which include timber rough-outs and a large knee. These provided absolute dates from the mid-15th century when matched against British chronologies (Nayling, 2013; Nayling & Jones, 2014). This proof of medieval date was pivotal for the future preservation of the ship.

At the time of the initial analyses, it was not possible to determine a felling date for the original structure by comparing ring-width measurements from the ship against available UK or continental European chronologies. Recovered artefacts (coinage and ceramics) pointed to Iberian connections (Besly, 2006; Redknap, 2017) but it was not until 2014 that a number of sampled timbers were dated using a new reference chronology developed from the Basque Country / Euskal Herria, northern Spain (Nayling & Susperregi, 2014). This breakthrough confirmed an Iberian origin and served to provide the first dendrochronological dates for the main structure of the ship. As none of the dated timbers preserved bark edge and local sapwood estimates were unavailable, only a minimum age (*terminus post quem*) for these timbers could be assigned.

Subsequent dendrochronology of several hundred samples resulted in the development of several floating chronologies comprising multiple cross-matched timbers. Some of these preserved bark edge, but unfortunately, they could not be securely dated against existing dendrochronologically-dated series. This inability to cross-date the different timber assemblages may indicate regional differences in timber origin or the impact of woodland management specific to the needs of shipbuilding (Aragón Ruano, 2001, 2010; Domínguez Delmás et al., 2022).

Using a combination of securely dated samples from two of the assemblages and regional reference chronologies from the UK and France, Nayling et al. (2023) reported the first precise felling dates for the Newport Medieval Ship based upon the isotopic dating of an assemblage comprising a chock and framing timbers. The resulting bark-edge dates indicate that at least two these timbers were felled during the winter of AD 1457/58. As the framing timbers represent some of the later elements to be added during construction the ship could not have been completed before winter AD 1457/58. This date served to reduce further the relatively short working lifetime of the ship to less than a decade prior to its final arrival in Newport after spring AD 1468. It is therefore clear that the key to a more complete understanding of timber sourcing and ship construction in the past is the determination of a secure chronology of felling dates developed from multiple component timbers.

Wood was often worked in the green, or shortly after felling, so in cases where felling dates cluster in time, this may indicate a more selective or bespoke approach to timber sourcing and a more rapid construction. If individual elements differ significantly in felling date or the chronology of the timbers runs contrary to the accepted order of ship construction, then this may indicate an approach where timbers have been sourced over several years with construction from stockpiled materials or rough-outs.

The keel is the fundamental structural timber of a ship and represents the starting point for its construction. The framing timbers, in clinker construction, are secondary elements and are added after at least partial

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construction of the clinker hull. Isotopic dating of each of these structural elements, may therefore help to clarify aspects relating to the timber sourcing and the construction sequence and timetable of this vessel.

Unlike most of the ship's construction which was made from oak, the 19.8 m keel was fashioned from a single beech timber. A sample for dendrochronology was sourced relatively high in the tree, at least 14 m above ground level (Nayling, 2013). The initial ring-width sequence from this sample comprised 97 rings and retained bark edge, but it could not be dated using ring-width dendrochronology as there is very limited historical data for beech and no suitable beech reference chronologies for Iberia or the UK covering this period.

An advantage of isotopic dendrochronology is that it is possible 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 near-passively by the trees (Loader et al., 2021, 2022; McCarroll et al., 2019; Nakatsuka et al., 2020; Treydte et al., 2007). Given that the signal is regionally expressed, trees growing in the same region, irrespective of species, should record a similar oxygen isotope signal in their growth rings. Differences in microclimate, physiology, rooting depth, wood anatomy and leaf morphology can all modify this signal, but where a sufficiently similar signal is preserved then this can be used for dating. Loader et al. (2021) demonstrated the potential for stable oxygen isotope dendrochronology of non-oak genera in the UK and was able to demonstrate secure dating was possible from a range of genera including beech and elm. Previous studies from continental Europe have also shown significant correlation between the oxygen isotope signals from oak and beech (Daux et al., 2018; Hartl-Meier et al., 2015). It was therefore decided to attempt to date the beech keel against the isotopic data developed from oak planks and framing timbers reported previously by Nayling et al. (2023) with a view to dating the keel and refining the chronology of the vessel further.

Materials and Methods

The keel of the Newport Ship comprised a single beech timber. At the time of excavation, the wood was found to have degraded, and it was necessary to recover it in six sections. A sample was collected for ring-width dendrochronology from the after end of the second section from the bow. Sample NS1756 comprised 94 rings with bark edge. The beech keel required conservation treatment in polyethylene glycol (PEG) followed by freeze-drying to stabilise the sample and prevent further degradation. This process was started after completion of documentation and ring width measurement of sample NS1756 and has now been completed. All the ship's timbers (including dendrochronology samples) are now fully conserved and are stored in a controlled environment at the Newport Medieval Ship Centre.

For stable isotope dating a subsample was collected from the conserved dendrochronology sample. This sample (NS1756) comprises 94 rings and also retains the bark edge. A lath was cut from the conserved timber sample using a fine-toothed handsaw, cleaned, and ring-widths remeasured to the nearest 1/100 mm. The resultant ring-width series was compared with the original measurements of the samples undertaken in 2006 to ensure correct measurement and absolute or relative dating.

The individual rings were manually divided using a scalpel under magnification. Beech is a diffuse porous species and so the whole ring was cut for isotopic analysis (Loader et al., 2021). Each ring was processed to alpha-cellulose for dating as described by Loader et al. (1997), using a modified setup (Wieloch et al., 2011). Samples exhibiting iron staining were treated with two 10% hydrochloric acid washes at 80°C for one hour each. The resulting white cellulose was then washed (minimum five times) to neutrality using deionised water. Any discolouration remaining after this treatment was removed manually from the sample using forceps. Samples were homogenised using an ultrasonic probe (Laumer et al., 2009) and freeze dried (48 h at -48°C 0.001 Pa). The dry alpha-cellulose was pyrolised to carbon monoxide over glassy carbon at 1400°C 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 from the keel sample were then converted to indices using the method outlined in Loader et al. (2019). As there is currently no reference chronology for beech or oak from the Basque region, the isotope series from the keel (comprising of 94 isotope measurements representing rings 1-94) was compared against the three individual sample series and a composite three-sample mean (NS T3 mean), developed using the three precisely-dated series P5.5_2343, P16.1_2360 and F14.2_2912 reported by Nayling et al. (2023).

Results

Table 1 and Figure 1 show the cross-dating results obtained between the beech (keel) and oak (planks

Table 1. Results of cross dating between the oxygen isotope keel sample (beech) against the individual plank and framing timber series and the 3-sample site mean (oak). Inter-series comparisons and associated statistics are presented for the period of full overlap at the point of strongest match. Comparisons between the keel samples and the 3-sample site mean 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	Sample series end
NS1756	NS2343	0.58	**5.85**	77	66	>100k	> 1000	1457 (B)
NS1756	NS2360	0.57	**4.96**	60	50	>1000	> 100	1457 (B)
NS1756	NS2912	0.58	**5.89**	82	70	>1 million	>1000	1457 (B)
NS1756	NS2343,2360,2912	0.68	**7.83**	82	70	>1million	>1000	1457 (B)

1/p = probability of error (calculated for full overlap best match position), (B) = Bark edge preserved. Samples NS2912 and NS2343 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.

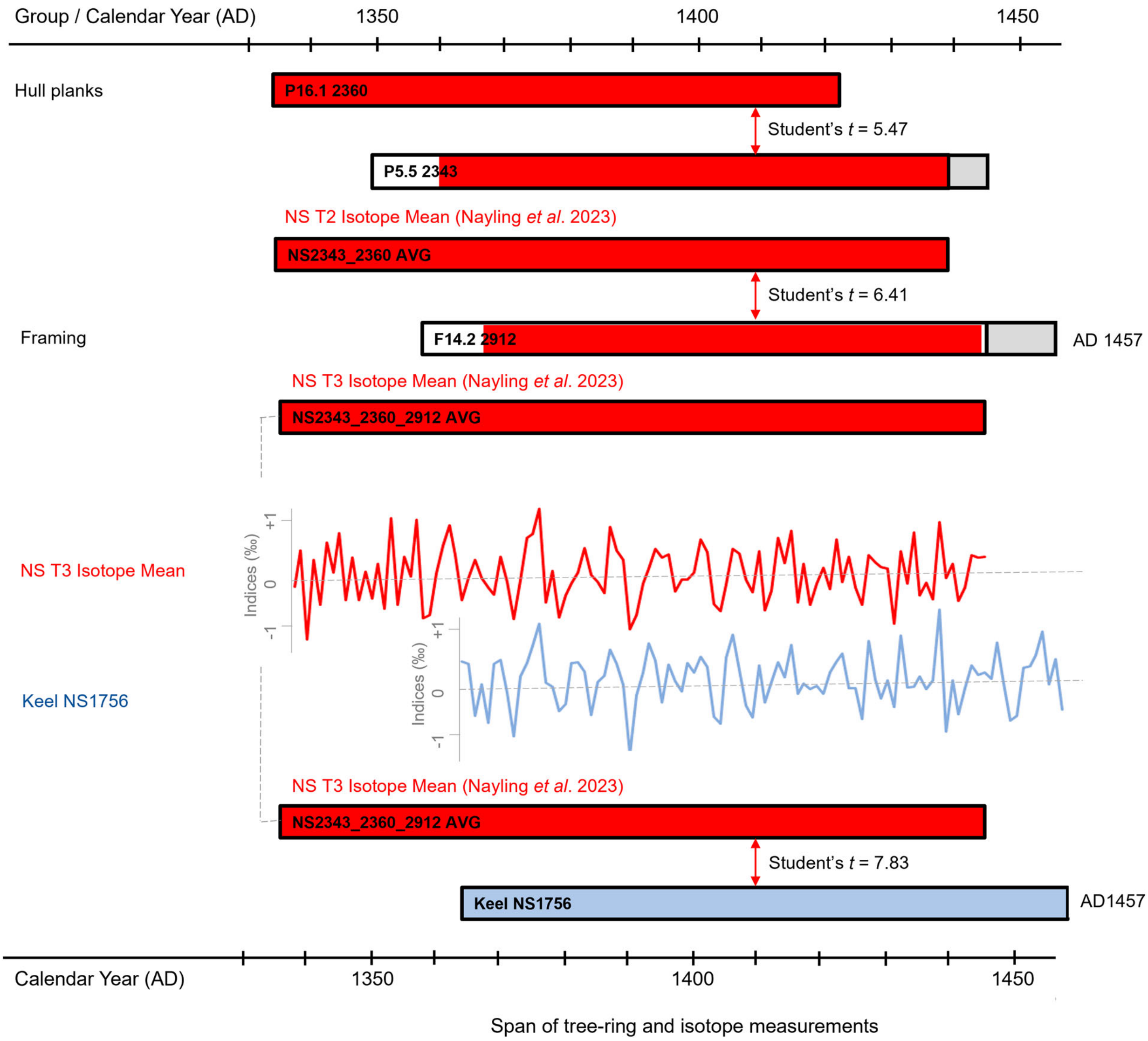

Figure 1. Bar diagram of original ring-width series (black outline with sapwood shaded grey) and isotope series for the three oak samples (red) and beech sample (blue). The isotopic cross-dating between the keel (NS1756) isotope series (Student's $t = 7.83$) and the three-timber isotope mean (NS T3 mean) yields a bark edge (felling) date of AD 1457/8 for the keel. The two line graphs present the indexed series aligned at the position of best match. (Image: N.J. Loader).

and framing timber) samples and their relative positioning. Good correlations are obtained between the individual series which all pass the thresholds for dating proposed by Loader et al. (2019). The match strengthens when the keel sample is compared against the NS T3 mean isotope series, reporting a Student's $t = 7.83$, and both a probability of error (1/p) and isolation factor (IF) > 1 million. As the keel sample has bark edge preserved then it is possible to assign a felling date of AD 1457/58 for the beech tree used to produce the keel. As beech is a diffuse porous species, assigning a season of felling is more difficult than with oak or other ring porous tree species where the difference between earlywood and latewood is distinct (and has not been done in this case). Hence the keel could have been felled during the growth season of AD 1457 or the dormant period of the winter of AD 1457/8. Six of the group of cross-matched timbers recently dated through isotopic dendrochronology had definite (B) or possible bark edge (?) with felling dates in AD 1457 (one chock and three framing timbers) or the winter of AD 1457/8 (two framing timbers). Hence the felling of the trees used for production of the keel and this group of framing timbers and a single chock could have been contemporary. This is the same felling date assigned to the oak trees used for the framing timber assemblage dated isotopically by Nayling et al. (2023).

Discussion and Conclusions

Successful inter-genus dating reveals that the keel, normally the first timber in ship construction and the framing timbers, typically added later in the construction process after at least partial construction of the clinker-built hull, share a common felling date. This common felling date contributes to our understanding of the timescales for timber sourcing and construction of the Newport Medieval Ship. Dating would suggest that timbers were likely felled for its construction in the same year (between summer of AD 1457 and early spring AD 1458) and that primary construction was a relatively rapid process, assuming that the wood was used in a 'green' or unseasoned state. Rare examples exist for the use of timbers with differing felling dates in ship construction (Krąpiec & Krąpiec, 2014; Nayling, 1998; Tyers, 1998), usually interpreted as evidence of stockpiling or felling aligned with the timetable of construction. Given the demonstrated ability of isotopic dendrochronology to date timbers often rejected for ring-width dendrochronological analysis (on the basis of non-oak genera or relatively short ring sequences), a revised sampling strategy for the Newport Ship will now be developed to analyse timbers which were not originally sampled (or which did not date) and which comprise structural elements introduced later in the ship's construction. This approach will allow analysis of additional elements such as stringers, beam shelves, deck beams, knees, hatch covers, ceiling planks and repairs.

A key find reported during initial excavations was the discovery of a freshly minted (uncirculated) silver coin (MSG173) deposited purposefully into the inboard face of the keel at its junction with the stempost and dating the construction of the ship to after May 1447 (Besly, 2006). The AD 1457/58 felling date for the keel timber reveals an interval of about a decade between the date that the coin was minted and its deposition (the earliest date for the start of construction). This temporal offset informs future interpretations of similar deposits and was only identifiable through the paired application of stylistic and dendrochronological methods.

Successful precise dating of the keel of the Newport Medieval Ship has further refined the chronology of the ship's construction and working lifetime. The dating of the keel and framing elements indicate that timber sourcing and likely use in construction of at least the lower hull of the ship would have been a relatively rapid process that commenced during or shortly after AD 1458.

There are many challenges associated with the application of tree-ring dating techniques to waterlogged/preserved timber recovered from maritime context. In refining the chronology of the Newport Medieval Ship, this study has further demonstrated the value and potential for future application of isotope dendrochronology to date (conserved PEG pre-treated and freeze-dried) timbers of oak and non-oak genera recovered from maritime contexts.

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Author Contributions

All authors contributed to the writing of the manuscript. NN and RJB conducted initial ring-width measurement and sub-sampling. RJB subdivided the ring samples. DD, NJL and DMcC conducted cellulose preparation, isotopic analysis and isotopic dating. VD led development of the French isotope chronologies that provided independent dating of the NS T3 isotope mean used in this research.

Permissions Statement

Toby Jones, Curator of the Newport Medieval Ship, Newport Museums and Heritage Service, kindly provided access to the samples.

Disclosure Statement

The authors declare no conflict of interest.

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