Bouldnor Cliff, Isle Of Wight

Tree-ring analysis and radiocarbon wiggle-matching of subfossil oaks

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Discovery, Innovation and Science in the Historic Environment

Research Report Series no. 73/2015

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NGR: SK 605 101

ISSN 2059-4453 (Online)

SUMMARY
Analysis of all samples taken from Bouldnor Cliff between 2000–5 has led to the construction of two site means, Bouldnor_T11 and Bouldnor_T3. These site means have been compared with each other without cross-matching. The sequences have also been compared with undated prehistoric sequences from the British Isles without producing any significant correlations with the exception of those from the Severn Estuary. Hence these tree-ring sequences, at present, are not absolutely dated. Wiggle-match radiocarbon dating of a timber BC_C14_1, part of Bouldnor_T11 estimates this site mean dates from *6275-6245 cal BC* (*95% probability*) to *6000–5960 cal BC* (*95% probability*).

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ACKNOWLEDGEMENTS
The sampling and analysis programme was partly funded by English Heritage. The sampling programme would not have been possible without the support and enthusiasm of HWTMA staff and volunteers. The front cover photo is ©The Maritime Archaeology Trust.

ARCHIVE LOCATION
Isle of Wight County Archaeology and Historic Environment Service
Westridge Centre
Brading Road
Ryde
Isle of Wight PO33 1QS

DATE OF RESEARCH
2006–2018

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INTRODUCTION

This report summarises the results of dendrochronological survey at the submerged Mesolithic site of Bouldnor Cliff (Momber *et al* 2011) off the northern shore of the Isle of Wight, integrating the results of fieldwork and analysis carried out between 2000 and 2006. Fieldwork from 2003 onwards has been project funded by English Heritage. This study focuses on material recovered from the lower peat shelf at Bouldnor Cliff at three main locations now defined as Area II, Area IV and Area V.

Throughout the period of the study, objectives at the site-specific level sought to improve understanding of the chronology of the exposed deposits through relational dating of oak tree-ring series including the temporal relationships between the different site areas. Broader objectives included the development of practical methods for the *in situ* dendrochronological assessment of subfossil trees in submerged environments and effective sampling techniques taking into account the constraints of different diving configurations and underwater conditions. The construction of well-replicated tree-ring chronologies of Mesolithic date, predating the absolutely-dated oak chronologies of Britain and Ireland formed a wider research goal with work at Bouldnor running in parallel with similar studies undertaken by the first author as part of a NERC-funded project in the Severn Estuary.

Dendrochronological analysis at Bouldnor Cliff is complemented and informed by a substantial programme of radiocarbon dating of deposits and wood from the various site areas (Momber *et al* 2011). The wiggle-match dating of sequential decadal blocks from one of the building blocks of the Bouldnor Cliff chronology provides scientific dating for the chronology.

DENDROCHRONOLOGY METHODOLOGY

Methods employed at the Lampeter Dendrochronology Laboratory in general follow those described in English Heritage (1998). The dendrochronological assessment and sampling of the wood at the Bouldnor Cliff exposure has involved a range of techniques utilised in terrestrial and intertidal contexts, adapted for the underwater environment.

The sampling strategy was focused on the recovery of samples from stratified oak trees with sufficient rings to make them suitable for tree-ring analysis. It should be stressed that the samples collected should not be considered representative of the full tree assemblage presented in the lower peat exposure at Bouldnor Cliff. A small number of samples were taken to identify non-oak elements within the peat exposure, but the samples reported on here were selected solely for their dendrochronological potential.

The identification of oak underwater is less straightforward than in air. Examination of a clean transverse face of the wood can usually be achieved although anatomical features characteristic of this genus, such as ring-porous structure and the presence of wide, multiseriate medullary rays, are more difficult to discern in a water saturated environment. In the case of substantial oak trees, with large areas of heartwood exposed on the peat surface, the black colour of the heartwood, and a characteristic, finely pitted surface (the result of degradation by gribble, *Limnoria lignorum*) can assist identification. Assessment of ring count is, perversely, made more difficult by a 'gribbled' surface to the wood. Freshly broken sections, especially at the eroding peat edge, can provide clear cross-section views, although the larger oaks, with their inner core of robust heartwood, rarely sheer in this way, unlike fully waterlogged smaller oaks or species such as alder. In some instances, relatively small wedge samples were taken to allow examination of a part of the ring sequence of trees with apparent potential prior to extraction of a full cross-section slice. Razor blades, to clean transverse sections, along with a magnifier and a strong light source, help offset some of the complications of carrying out *in situ* assessment.

Once trees had been assessed and selected, a variety of sampling techniques were used. Increment coring was employed with only very limited success in early trials. A range of problems were encountered. Of particular importance is the extent to which piddock (*Pholas dactylus*) have degraded the wood, leaving numerous 'burrows': Wood heavily damaged in this way is unlikely to provide continuous cores with complete tree-ring sequences, whereas slices normally allow extraction of the tree-ring sequence even if areas of the cross-section have been lost through such marine boring. Both handsaws and chainsaws (hydraulically powered) were used to take cross-sectional slices. Deployment of a hydraulic chainsaw requires excavation of sufficient sediment from around the sample site to avoid contact between this and the chain and an appropriately trained chainsaw operator diving on surface supply (with associated logistics). Cutting samples in this manner is relatively quick and considerably less strenuous work for the diver than hand sawing, especially on larger trees. Offset against these advantages, are the more limited range of the surface supplied diver, and the attendant costs of such diving practices. Handsaws have been employed to take both full cross-sectional samples and less substantial 'wedge' samples. This approach has been undertaken whilst diving on SCUBA. This does allow for a greater range for sampling on any one dive, and is particularly suited to exploratory surveys, and assessment. Hand sawing a full cross-sectional sample from a large tree bole on SCUBA can be very hard work. Air consumption is the limiting factor on dive duration on SCUBA at Bouldnor when samples are being taken. The stratigraphic context of each sample taken was recorded using sketches and notes during sampling dives. Where samples were taken in the vicinity of excavations in advance of extraction of monolith samples, scale drawings of these may also have been produced.

Prior to measurement, the samples were cleaned with razor blades to expose the fullest ring sequence. In the case of slice samples which comprised half or more of the complete cross-section of the parent tree, two radii were usually measured. The complete sequences of growth rings in the samples that were selected for dating purposes were measured to an accuracy of 0.01mm using a micro-computer based travelling stage (Tyers 1999). Cross-correlation algorithms (Baillie and Pilcher 1973; Munro 1984) were employed to search for positions where the ring sequences were highly correlated. The ring sequences were plotted electronically and exported to a computer graphics software package (Coreldraw™ v.12) to enable visual comparisons to be made between sequences at the positions indicated and, where these were satisfactory, new mean sequences were constructed from the synchronised sequences. The *t*-values reported below are derived from the original CROS algorithm (Baillie and Pilcher 1973). A *t*-value of 3.5 or over is usually indicative of a good match, although this is with the proviso that high *t*-values at the same relative or absolute position must be obtained from a range of independent sequences, and that satisfactory visual matching supports these positions.

In a few cases, more than one sample has been taken from the same tree. Where this became apparent during analysis, new raw 'tree' sequences were constructed using the cross-matched sequences from each sample prior to construction of a site master. All the measured sequences from this assemblage were then compared with each other and any found to cross-match were combined to form a site master curve.

At this stage, in a dendrochronological study focused on tree-ring dating, measured sequences and calculated site masters would be tested against a range of reference chronologies to attempt to provide calendar dates for the ring-sequences. The samples from Bouldnor Cliff derive from contexts dating to the seventh millennium cal BC or the very earliest sixth millennium cal BC (Momber *et al* 2011). Replicated, dated oak chronologies in Britain and Ireland presently extend back to *c*. 5000 BC. With no absolutely dated oak chronologies from this region, useful comparison is restricted to undated prehistoric sequences, Mesolithic sequences being developed from the Severn Estuary, and continental sequences.

DENDROCHRONOLOGY RESULTS

Details of those samples subjected to dendrochronological analysis are given in Table 1.

Seven samples recovered in 2000 were subjected to dendrochronological analysis. Many of these samples were recovered using a hydraulic chainsaw employed by divers using surface supplied equipment. This approach allowed the recovery of full cross-section samples from substantial trees with long tree-ring sequences. A large section of the same tree as sample BCS06 was later sub-sampled for wiggle-match dating (sample BC_C14_1), and a combined, 242-year raw tree-ring sequence has been produced for cross-matching against other tree-ring series (BC06_C14, Table 2a, Figure 1). It is notable that nearly all the tree-ring sequences from the 2000 season (sometimes in combination with sequences from further samples from the same trees taken in later seasons) have cross-matched to form part of an eleven tree, 285-year site mean Bouldnor_T11 (Figure 1, Table 3a, Appendix 1). The only exception is the undated sequence (BCS10) which is relatively short at only 55 rings (Table 1).

Six samples recovered during 2001 using SCUBA equipment were measured, only two of which have cross-matched with the main group of samples forming the main site mean Bouldnor_T11. Three samples BC01S04, BC01S11 and BC01UNL1 cross-matched against each other and against BC2DS14 taken in 2003 (see below). The latter sequences did not match against the main site mean.

A total of sixteen samples were taken during the 2003 fieldwork programme. Not all of these samples have been analysed either due to insufficient rings or the presence of very narrow bands of rings making reliable measurement impossible. Those subjected to analysis are shown in Table 1. Sample BC202 came from a tree exposed during excavations at Area II, the same tree as that sampled in 2000 (BCS08). A combined 120-year raw sequence, (BC08_202) was constructed from the correlated ring-widths of these samples (see Table 2c). Similarly, the ring-widths from a small wedge sample (BC203) taken from the same tree as BCS02 taken in 2000 were combined in a 145-year raw sequence BC02_203 (Table 2b). Four sequences resulting from analysis of samples taken in 2003 have cross-matched to form part of the 11-timber site mean Bouldnor_T11 including the two combined sequences, BC02_203 and BC08_202 from Area II, and two further samples taken from trees in Area IV, BC416 and BC415 (Figure 1, Table 3, Appendix 1). One sample from a tree found on a drift dive to the west of Area II proved to be from the same tree as sample BC01S11 (Table 2d) and a combined 164-year raw sequence (BC111_214) crossmatched against two other sequences from samples taken in 2001 to form the 265-year 3-tree site mean Bouldnor_T3 (Figure 2, Appendix 2).

An oak tree in Area V (from the peat platform close to the pit features BC-V/CF01; Momber *et al* 2011, 74–5), was sampled by a dive team during initial field investigations in 2004 (BC518) and subsequently re-sampled by the first author in 2005 (BC520). Correlation between the two samples (Table 2e) confirms they came from the same tree, and a combined 138-year sequence forms part of the main site mean Bouldnor_T11, indicating broad contemporaneity between Area V and the previously investigated Areas II and IV.

DISCUSSION

Completion of analysis of all samples taken from Bouldnor Cliff between 2000 and 2005 has led to the construction of two site means, Bouldnor_T11 and Bouldnor_T3. These site means have been compared with each other without cross-matching. The sequences have also been compared with undated prehistoric sequences from the British Isles without producing any significant correlations with the exception of those from the Severn Estuary. Sequences have been passed to colleagues on the European continent but no correlations have been identified. Hence these tree-ring sequences, at present, are not absolutely dated.

RADIOCARBON SAMPLING AND ANALYSIS

The lack of dating evidence for samples from Bouldnor Cliff hampered its usefulness for dendrochronological research in Britain. Thus further dating was required. To this end, six sequential decadal blocks of sample BC_C14_1 (Table 5) were submitted to the ^{14}CHRONO, Queen's University Belfast for radiocarbon dating. The samples were processed and measured as described in Reimer *et al* (2015). The laboratory maintains a continual programme of quality assurance procedures, in addition to participation in international inter-comparisons (Scott 2003; Scott *et al* 2007). These tests indicate no laboratory offsets and demonstrate the reproducibility and accuracy of these measurements.

The results are conventional radiocarbon ages (Stuiver and Polach 1977; Table 5), and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986).

Radiocarbon dating

Radiocarbon dating is based on the radioactive decay of carbon-14 and can be used to date organic materials, including wood. A small proportion of the carbon atoms in the atmosphere are of a radioactive form, carbon-14. Living plants and animals take up carbon from the environment, and therefore contain a constant proportion of carbon-14. Once a plant or animal dies, however, its carbon-14 decays at a known rate. This makes it possible to calculate the date of formerly living material from the concentration of carbon-14 atoms remaining. Radiocarbon measurements, like those in Table 1 are expressed in radiocarbon years BP (before present, 'present' being a constant, conventional date of AD 1950).

Calibration

Radiocarbon ages are not the same as calendar ages because the concentration of carbon-14 in the atmosphere has fluctuated over time. A radiocarbon measurement has thus to be calibrated against an independent scale to arrive at the corresponding calendar date.

That independent scale is the IntCal13 calibration curve (Reimer *et al* 2013). This is constructed from radiocarbon measurements on samples dated absolutely by other, independent means: tree rings, plant macrofossils, speleothems, corals, and foraminifera. In this report the calibrations which relate the radiocarbon measurements directly to the calendrical time scale have been calculated using IntCal13 and the computer program OxCal v4.3 (https://c14.arch.ox. ac.uk/oxcal/; Bronk Ramsey 1995; 2001; 2009). The calibrated date ranges quoted for each sample in Table 5, expressed 'cal BC', were calculated by the maximum intercept method (Stuiver and Reimer 1986) and are rounded outwards to the nearest five years as recommended by Mook (1986). The graphical distributions of the calibrated dates, shown in outline in Figure 4 are derived from the probability method (Stuiver and Reimer 1993).

Bayesian wiggle-matching

Wiggle-matching uses information derived from tree-ring analysis in combination with radiocarbon dates to provide a revised understanding of the age of a timber; a review is presented by Galimberti *et al* (2004). In this technique, the shapes of multiple radiocarbon distributions can be 'matched' to the shape of the radiocarbon calibration curve. The exact interval between radiocarbon dates can be derived from tree-ring analysis, since one ring is laid down each year.

Although the technique can be done visually, Bayesian statistical analyses (including functions in the OxCal computer program) are now routinely employed. A general introduction to the Bayesian approach to interpreting archaeological data is provided by Buck *et al* (1996). The approach to wiggle-matching adopted here is described by Christen and Litton (1995).

Details of the algorithms employed in this analysis — a form of numerical integration undertaken using OxCal — are available from the on-line manual or from various publications by Christopher Bronk Ramsey (1998; 2001; 2009). Because it is possible to constrain a sequence of radiocarbon dates using this highly informative prior information (Bayliss *et al* 2007), model output will provide more precise posterior density estimates. These posterior density estimates are shown in black in the Figures and quoted in italic in the text.

The Acomb statistic shows how closely the dates as a whole agree with other information in the model; an acceptable threshold is reached when it is equal to or greater than An, a value based on the number of dates in the model. The A statistic shows how closely an individual date agrees with the other information in the model; an acceptable threshold is reached when it is equal to or greater than 60.

BC_C14_1

The chronological model for sample BC_C14_1 includes the radiocarbon dates for the six decadal blocks along with the information derived from the tree-ring analysis about the calendar age gap between them (Fig 4). The model has good overall agreement (Acomb=30.6 (An=28.9); n=6) and provides an estimate for the formation of the final ring of sample BC_C14_1, of *6025–5990 cal BC* (*95% probability*; *ring_220*; Fig4), probably *6015–6000 cal BC* (*68% probability*).

The last measured ring of sample BC_C14_1 equates to ring 258 of the 285-year site mean Bouldnor_T11. Hence this site mean is dated from *6275-6245 cal BC* (*95% probability*; *Bouldnor_T11_start*; Fig 5) probably *6270–6255 cal BC* (*68% probability*) to *6000–5960 cal BC* (95% probability; *Bouldnor_T11_end*; Fig 5). probably *5990–5970 cal BC* (*68% probability*).

High computer correlations have been identified between the mean Bouldnor_T11 and three cross-matching chronologies constructed independently by the primary author from intertidally exposed 'submerged forests' at Redwick and Goldcliff off the Welsh Gwent Levels, and Gravel Banks off Chittening Wharf, Avonmouth (Table 4, Figure 3; Nayling and Manning 2007; Bell *et al* 2009). A radiocarbon wiggle-match of one of the cross-matched tree-ring sequences forming part of the Redwick chronology (Nayling and Manning 2007, table 8.2) has poor overall agreement (Acomb=7.9 (An=28.9); n=6; Fig 6) with the radiocarbon dates and prior information provided by the tree-ring dating clearly being incompatible (although see Manning *et al* 2007, 99).

Whilst the number of cross-matched samples forming the main site mean are limited, the bar diagram showing relative dating and proximity of the pith to the beginning of each tree-ring sequence do provide some indications of forest dynamics. It would appear that groups of trees probably germinated in the decades around *c 6250 cal BC* and in the decades before *c 6150 cal BC* (Fig 7) and that some long-lived trees died off at the beginning of the sixtieth century cal BC (*c 6000–5980 cal BC;* Fig 8).

The latter date range appears consistent with the estimate for marine inundation that was complete by *5990–5915 cal BC (95% probability; Marine Inundation;* Fig 9*)* probably *5985–5960 cal BC* (*68% probability*).

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Table 1: List of samples subjected to dendrochronological analysis

Sample Year	Sample Code	Description	Cross-section size (mm)	Total rings	Sapwood rings	ARW mm /year	Relative date of sequence
2000	BCS02	Chainsaw sample of substantial tree in Area II. Same tree as BC03 Area II DS03	500 x 260	145	+HS	1.59	5–149
2000	BCS03		285 x 150	111	+?HS	1.29	35–145
2000	BCS04		370 x 260	163+20h	+?HS	1.71	110-272
2000	BCS06	Chainsaw sample of substantial tree in Area II. Same tree as BC_C14	290 x 290	242	3+HS+26s	1.11	24–265
2000	BCS07		178 x 90	127	35+Bw	0.65	159–285
2000	BCS08	Same tree as BC03 Area II DS02	180 x 85	86	-	1.99	28–113
2000	BCS10		68 x 13	55	-	1.14	undated
(2000)	BC_C14_1	C14 wiggle-match sample. Same tree as BCS06	610 x 260	220	+?HS	1.14	39–258
2001	BC01S03	Wedge sample	0 x 0	82	+?HS	3.49	15–96
2001	BC01S04	Forms part of Bouldnor_T3	0 x 0	162	+	0.58	(1–162)
2001	BC01S05	Wedge sample	0 x 0	101	-	1.34	96–196
2001	BC01S06	Difficult to measure – many narrow rings	185 x 110	178	+?HS	0.56	undated
2001	BC01S11	Same tree as BC2DS14. Forms part of Bouldnor_T3	0 x 0	164	+	1.00	(32–195)
2001	BC01UNL1	Wedge sample (late dive?). Forms part of Bouldnor_T3	0 x 0	212	-	1.12	(54–265)
2003	BC202	Area II. Exposed during excavations in 2003. Within peat Correlation indicates same tree as sample BCS08 (see Table 2)	300 x 270	120	+?HS	1.24	1–120
2003	BC203	Area II. Substantial oak tree within peat. Tree previously sampled by chainsaw. Wedge sample taken for checking purposes. Correlation with BCS02 indicates same tree	110 x 52	38	-	2.73	43–80
2003	BC2DS14	Large oak found on drift dive of peat shelf west of Area II. Same tree as BC01S11. Forms part of Bouldnor_T3	0 x 0	110	-	1.55	(41–150)
2003	BC4DS04	Area IV. Small stem or branch in peat located 15.5m along baseline from DP3 to DP4 Half of stem survived, with possible HS boundary. Short sequence (46 rings) recorded	110 x 70	46	+?HS	1.48	1–46
2003	BC4DS06	Area IV DS06 Half stem with complete sapwood and bark	120 x 115	85	56+B	0.69	10–94

Sample Year	Sample Code	Description	Cross-section size (mm)	Total rings	Sapwood rings	ARW mm /year	Relative date of sequence
		edge. Compressed with slow grown rings in sapwood. Cross-match against DS08					
2003	BC408	Area IV. Oak stem recovered next to DP2 Slow grown later rings especially last 16 rings of sapwood which were not measured Cross-matches with DS06	0 x 0	78	36+16s	1.13	1–78
2003	BC415	Large oak found on drift dive of peat shelf east of Area IV Wedge sample taken Included in 12 sample mean	0 x 0	175	-	1.10	107–281
2003	BC416	East of Area IV 2003 DS16 Medium/large oak found on drift dive of peat shelf. Half slice taken. Included in 12 sample mean	0 x 0	100	+?HS	1.53	98–197
2005	BC518	Area V.	170 x 155	92	-	1.41	42–133
2005	BC520	Area V dive log 20 probable repeat of 18	190 x 170	95	-	1.59	40–134
2006	BC5UNUM6	Area 5 unnumbered sample of upright	0 x 0	119	28+B	0.51	undated

Table 2: t*-value matrices for samples from same trees*

a) BC06 taken in 2000, and a sample of a recovered section of the same tree used for wiggle-match radiocarbon dating (C14_1)

Sample	BCS06
BC_C14_1	15.98

b) BCS02 taken in 2000, and a small wedge sample BC203 taken from same tree in Area II in 2003

Sample	BCS02
BC203	9.37

c) BC08 taken in 2000, and sample BC202 taken from the same tree in Area II in 2003

Sample	BCS08
BC202	12.79

d) BC01S11 taken in 2001, and BC2DS14 taken from the same tree in west of Area II in 2003

Sample	BC01S11
BC2DS14	15.14

e) BC518 taken in 2004, and BC520 taken from the same tree in Area V in 2005

Sample	BC520
BC518	13.95

Table 3a: t-*value matrix for samples forming the 285 year, 11-tree site mean* ***Bouldnor_T11***. \ = *overlap < 15 years* - = t-*values less than 3.00*

Filenames	BC06_C14	BC08_202	BCS07	BCS03	BCS04	BC01S05	BC01S03	BC416	BC4DS15A	BC51820
BC02_203	13.79	5.83	\	-	7.25	6.16	5.49	5.93	-	3.72
BC06_C14		7.40	8.98	3.70	13.80	7.68	5.97	8.48	4.73	5.28
BC08_202			\	6.73	\	-	-	-	\	3.25
BCS07				\	8.03	5.01	\	5.27	5.89	\
BCS03					-	-	-	-	-	3.40
BCS04						7.60	\	7.82	5.34	-
BC01S05							\	9.56	4.76	-
BC01S03								\	\	6.12
BC416									4.80	-
BC4DS15A										-

Table 3b: t-*value matrix for samples forming the 265 year, 3-tree site mean* ***Bouldnor_T3***

Filenames	BC01UN01	BC01S04
BC111_214	7.18	7.12
BC01UN01	*	7.55

Table 4: t*-values for the 285 year, 11-tree site mean* ***Bouldnor_T11****, against Mesolithic oak ring-width chronologies from the Severn Estuary*

Site Masters	*t*-value
Redwick, Gwent Levels, Wales (Nayling pers comm.)	7.90
Goldcliff, Gwent Levels, Wales (Nayling pers comm.)	7.46
Gravel Banks, nr Avonmouth, England (Nayling pers comm.)	7.91

Table 5: Radiocarbon results from timber BC_C14_1

Laboratory number	Sample reference and material	δ^{13}C (‰)	Radiocarbon Age (BP)	Calibrated date – cal BC (2σ)	*Highest Posterior Interval - cal BC (95% probability)*
UB-6858	Q10745A *Quercus* sp. heartwood, rings 161–170	−26.0±0.22	7168±42	6090–5980	*6080–6045*
UB-6859	Q10745B *Quercus* sp. heartwood rings 171–180	−27.0±0.22	7115±42	6070–5900	*6070–6035*
UB-6860	Q10745C *Quercus* sp. heartwood rings 181–190	−25.0±0.22	7127±40	6070–5910	*6060–6025*
UB-6861	Q10745D *Quercus* sp. heartwood rings 191–200	−25.0±0.22	7191±41	6200–5990	*6050–6015*
UB-6862	Q10745E *Quercus* sp. heartwood rings 201–210	−25.0±0.22	7259±41	6230–6020	*6040–6005*
UB-6863	Q10745F *Quercus* sp. heartwood rings 211–220	−27.0±0.22	7156±41	6080–5930	*6030–5995*

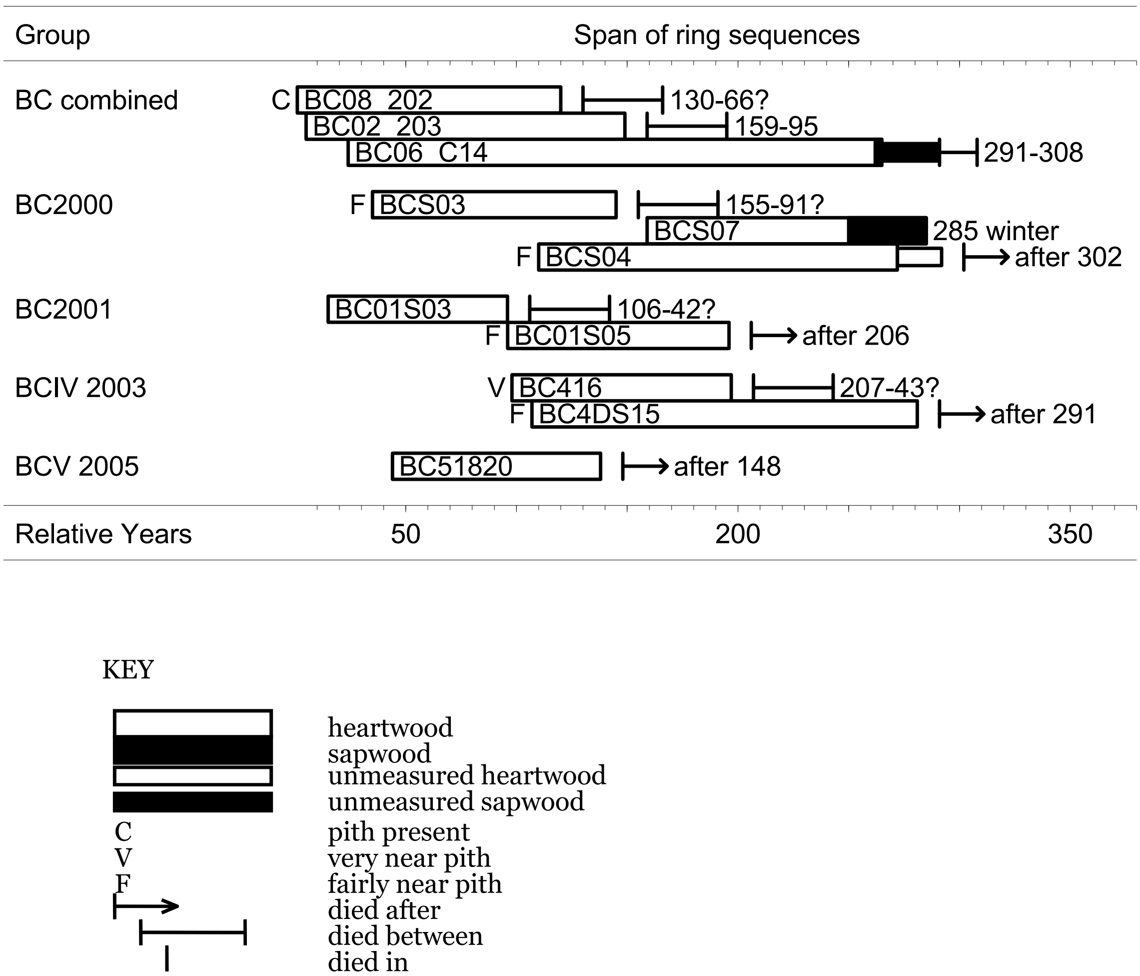

Figure 1: Bar diagram showing relative dating positions of tree-ring sequences from individual trees from Bouldnor Cliff forming the site mean ***Bouldnor_T11***

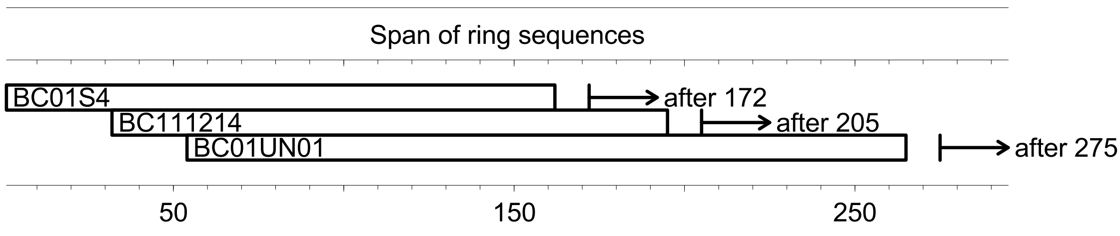

Figure 2: Bar diagram showing relative dating positions of tree-ring sequences from individual trees from Bouldnor Cliff forming the site mean ***Bouldnor_T3***

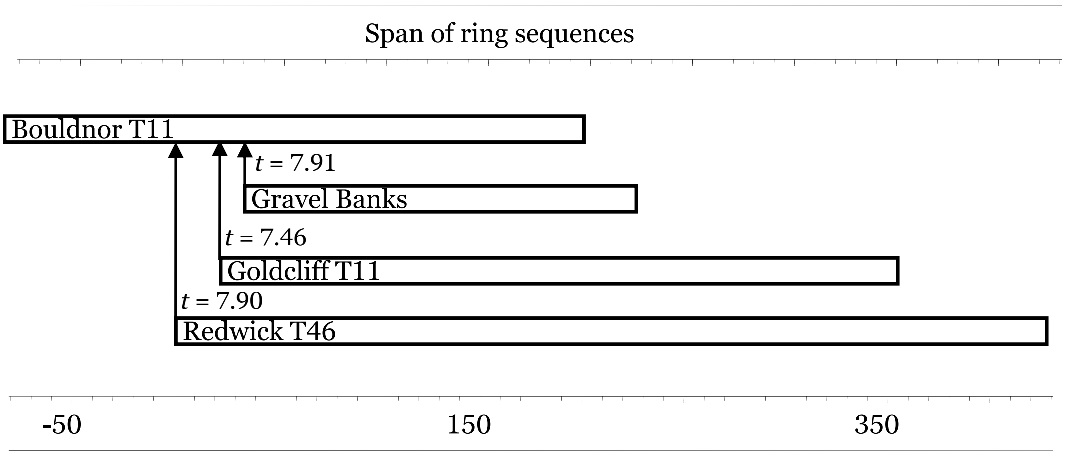

Figure 3: Bar diagram showing relative dating positions of site means from Bouldnor Cliff, Gravel Banks, Avonmouth and Redwick and Golcliff, Gwent Levels.

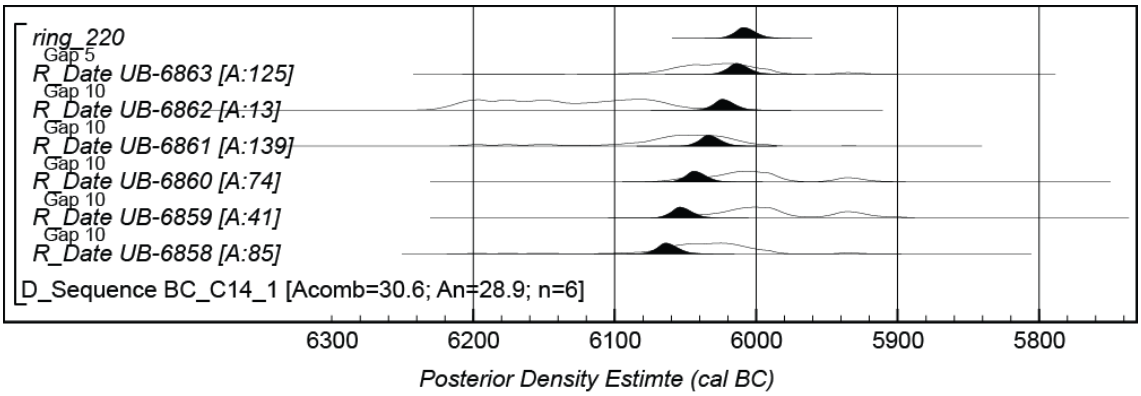

Figure 4: Probability distributions of dates from BC_C14_1. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly

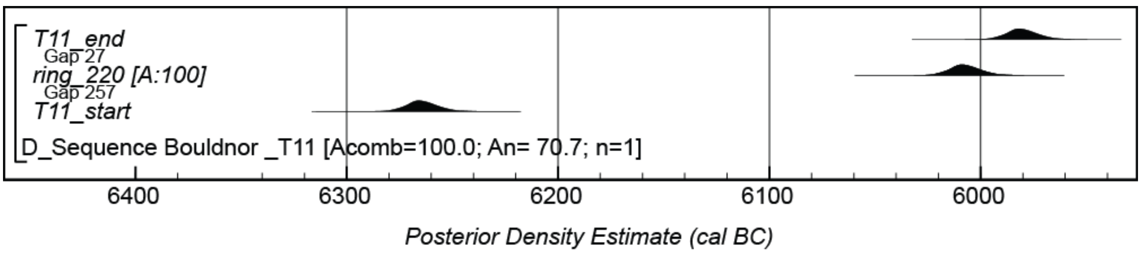

Figure 5: Probability distributions of dates from Bouldnor_T11

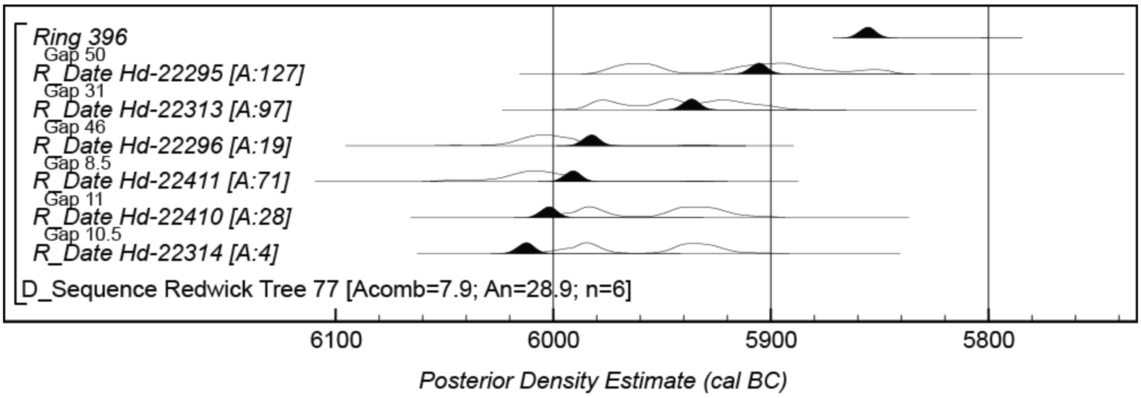

Figure 6: Probability distributions of dates from Redwick tree 77. The format is identical to Figure 4

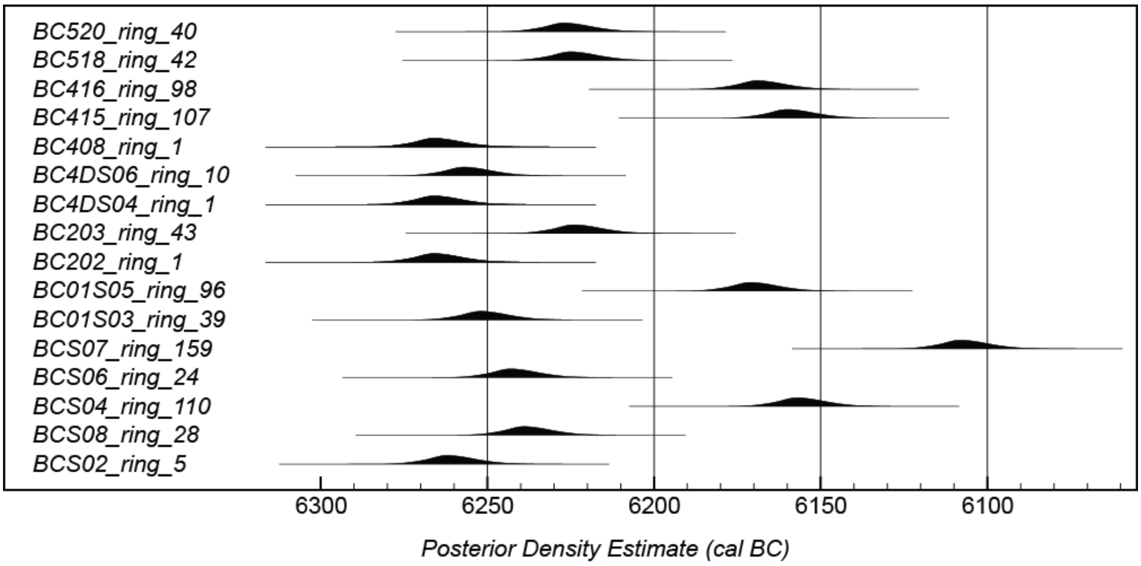

Figure 7: Probability distributions of dates for the germination of trees. Each distribution represents the relative probability that an event occurs at a particular time

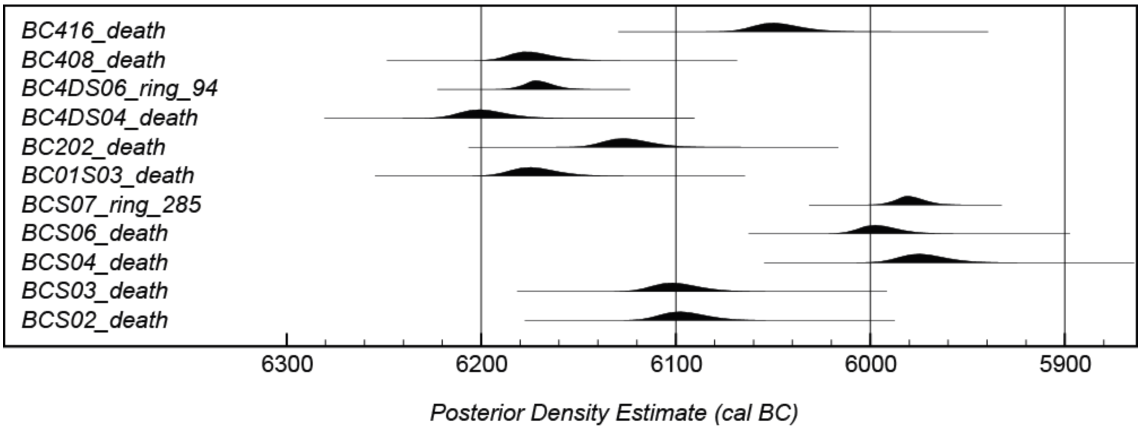

Figure 8: Probability distributions of dates for the death of trees. Each distribution represents the relative probability that an event occurs at a particular time

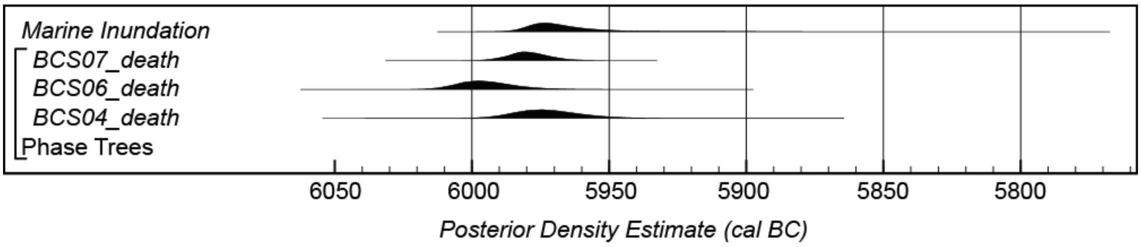

Figure 9: Probability distributions of dates for the death of selected long-lived trees and the estimated date for marine inundation (Momber et al *2011, fig 3.23). Each distribution represents the relative probability that an event occurs at a particular time*

Appendix 1: Ring width data for the 285 year, 11-tree site mean ***Bouldnor_T11***

Relative Date	Ring Width (100=1mm)										Number of trees									
1	316	170	116	111	118	124	140	153	130	96	1	1	1	1	2	2	2	2	2	2
-	83	86	83	122	199	187	156	111	135	145	2	2	2	2	3	3	3	3	3	3
-	210	222	190	188	197	185	231	252	326	271	3	3	3	4	4	4	4	4	4	4
-	295	324	366	284	167	202	234	189	177	85	4	4	4	4	5	5	5	5	5	5
-	183	201	315	173	209	141	149	248	172	153	5	5	5	6	6	6	6	6	6	6
51	182	245	240	264	212	174	135	192	143	203	6	6	6	6	6	6	6	6	6	6
-	158	242	245	245	212	292	243	258	254	201	6	6	6	6	6	6	6	6	6	6
-	255	210	206	172	234	199	197	155	155	158	6	6	6	6	6	6	6	6	6	6
-	159	153	163	228	229	187	219	211	153	114	6	6	6	6	6	6	6	6	6	6
-	172	160	195	179	170	167	159	198	129	134	6	6	6	6	6	7	6	7	7	7
101	116	122	144	132	91	169	202	219	167	146	7	7	7	7	7	7	8	8	8	9
-	169	144	158	120	121	145	200	180	220	188	9	9	9	9	9	9	9	9	9	9
-	156	199	212	152	143	154	193	160	119	148	8	8	8	8	8	8	8	8	8	8
-	172	151	118	140	147	127	106	175	213	169	8	8	8	8	8	8	8	8	7	7
-	117	145	114	145	165	110	106	140	102	117	7	7	7	7	7	6	6	6	6	5
151	169	141	174	152	92	88	133	143	127	86	5	5	5	5	5	5	5	5	6	6
-	87	81	101	146	118	102	146	120	86	98	6	6	6	6	6	6	6	6	6	6
-	65	134	113	167	149	162	146	100	121	100	6	6	6	6	6	6	6	6	6	6
-	133	173	161	162	129	140	140	147	134	112	6	6	6	6	6	6	6	6	6	6
-	120	120	92	70	100	125	131	101	74	70	6	6	6	6	6	6	5	4	4	4
201	101	114	147	127	77	68	93	75	74	91	4	4	4	4	4	4	4	4	4	4
-	111	112	87	77	96	92	113	91	94	94	4	4	4	4	4	4	4	4	4	4
-	96	66	74	55	62	47	73	78	75	67	4	4	4	4	4	4	4	4	4	4
-	88	96	90	87	109	101	81	76	83	88	4	4	4	4	4	4	4	4	4	4
-	76	61	72	93	65	56	62	59	95	78	4	4	4	4	4	4	4	4	4	4

Relative Date	Ring Width (100=1mm)										Number of trees									
251	68	78	87	90	83	70	56	53	66	89	4	4	4	4	4	4	4	4	4	4
-	74	56	65	64	73	64	55	50	49	49	4	4	4	4	4	3	3	3	3	3
-	51	54	43	46	39	38	40	35	29	36	3	3	2	2	2	2	2	2	2	2
-	30	57	43	25	34						2	1	1	1	1					

Appendix 2: Ring width data for the 265 year, 3-tree site mean Bouldnor_T3

Relative Date	Ring Width (100=1mm)										Number of trees									
1	134	143	86	57	67	51	41	66	39	60	1	1	1	1	1	1	1	1	1	1
-	69	84	61	56	51	45	40	37	50	39	1	1	1	1	1	1	1	1	1	1
-	60	89	96	73	84	43	47	47	68	53	1	1	1	1	1	1	1	1	1	1
-	49	87	73	59	71	57	75	118	88	132	1	2	2	2	2	2	2	2	2	2
-	141	111	70	104	134	73	91	100	146	111	2	2	2	2	2	2	2	2	2	2
51	82	87	85	111	99	81	150	85	100	81	2	2	2	3	3	3	3	3	3	3
-	122	90	121	172	108	95	75	115	106	143	3	3	3	3	3	3	3	3	3	3
-	110	125	141	138	196	133	102	161	154	190	3	3	3	3	3	3	3	3	3	3
-	111	96	79	85	107	164	146	137	106	137	3	3	3	3	3	3	3	3	3	3
-	84	91	99	87	73	113	102	77	98	89	3	3	3	3	3	3	3	3	3	3
101	147	108	134	101	120	129	109	86	101	120	3	3	3	3	3	3	3	3	3	3
-	96	99	111	102	99	79	115	119	137	72	3	3	3	3	3	3	3	3	3	3
-	74	73	69	79	99	102	92	87	115	89	3	3	3	3	3	3	3	3	3	3
-	95	121	72	65	53	58	91	90	112	93	3	3	3	3	3	3	3	3	3	3
-	85	81	65	104	96	110	100	57	80	97	3	3	3	3	3	3	3	3	3	3
151	109	89	62	64	83	100	92	106	106	73	3	3	3	3	3	3	3	3	3	3
-	95	87	66	63	64	58	66	59	75	103	3	3	2	2	2	2	2	2	2	2
-	65	92	77	90	105	60	77	95	105	101	2	2	2	2	2	2	2	2	2	2
-	89	73	66	62	75	73	84	76	83	105	2	2	2	2	2	2	2	2	2	2
-	101	127	78	97	117	150	148	97	113	84	2	2	2	2	2	1	1	1	1	1
201	82	118	95	129	112	73	74	82	83	72	1	1	1	1	1	1	1	1	1	1
-	58	72	94	64	83	90	86	93	112	90	1	1	1	1	1	1	1	1	1	1
-	83	82	83	57	85	67	69	110	176	139	1	1	1	1	1	1	1	1	1	1
-	91	64	62	80	67	88	107	78	78	81	1	1	1	1	1	1	1	1	1	1
-	54	45	71	56	65	71	69	71	64	97	1	1	1	1	1	1	1	1	1	1

Relative Date	Ring Width (100=1mm)										Number of trees									
251	60	65	66	91	95	76	70	88	108	113	1	1	1	1	1	1	1	1	1	1
-	99	112	89	100	79						1	1	1	1	1					






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ISSN 2398-3841 (Print)
ISSN 2059-4453 (Online)