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Coopers Beach Bronze Age Intertidal Trackway: Analysis and Conservation of its Timbers and Associated Brushwood Samples

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East Mersea
Essex

Coopers Beach Bronze Age Intertidal Trackway: Analysis and Conservation of its Timbers and Associated Brushwood Samples

Peter Marshall, Angela Middleton, Ian Tyers, Emma Aitken, Zoë Hazell, Gill Campbell, Irka Hajdas and Sanne W. Palastra

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SUMMARY
Dendrochronological and radiocarbon analysis of oak timbers from a trackway recorded by the Coastal and Intertidal Zone Archaeological Network (CITiZAN) on Coopers Beach, East Mersea, Essex (site code CCB17) was undertaken prior to their conservation. In addition, several samples from associated brushwood material were recovered and analysed. This report presents the methods and results of the dendrochronological, radiocarbon, and brushwood samples (wood identifications and evaluation of other environmental remains), along with the conservation treatment undertaken on three of the trackway timbers. The results of the scientific dating show that the trackway was probably constructed in the second half of the tenth century cal BC, ie the Late Bronze Age.

CONTRIBUTORS
Peter Marshall (radiocarbon dating and chronological modelling), Angela Middleton (archaeological conservation), Ian Tyers (dendrochronology), Emma Aitken (wood identifications), Zoë Hazell (wood identifications), Gill Campbell (general biological analysis), Irka Hajdas (radiocarbon dating) and Sanne W. Palastra (radiocarbon dating).

ACKNOWLEDGEMENTS
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This report was completed in July 2023.

ARCHIVE LOCATION
Essex Historic Environment Record
Historic Environment Specialist Team
Place Services
County Hall
Chelmsford
Essex CM1 1QH

Timbers 1–3 are now held by Mersea Museum, 12 High Street, West Mersea, Essex, CO5 8QD, where they are on display. The brushwood samples have been discarded.

DATE OF INVESTIGATION
2017–2023

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Cover image: Coopers Beach Timbers 1–3 *in situ* prior to removal (January 2017).
Image: Cathy Tyers © Historic England.

CONTENTS

1. INTRODUCTION

This document is a technical report on the analysis (dendrochronology, radiocarbon) and conservation of oak timbers, and analysis (identifications of wood and other environmental remains) of brushwood material and pegs/stakes, from Coopers Beach, Mersea Island, Essex. The material was recovered in January 2017 in works led by the Coastal and Intertidal Zone Archaeological Network (CITiZAN) (site code CCB17). For more information on the fieldwork *see* Hutchinson (2022). The work was undertaken by Historic England as part of their in-kind support for the overarching CITiZAN project (funded by the National Lottery Heritage Fund and run by Museum of London Archaeology, MOLA).

Mersea Island lies approximately 11km south of Colchester and is bordered by the Blackwater river to the south and west, and the Colne river to the east (Fig 1). The western and northern shores are surrounded by tidal saltmarsh whilst the southern shore faces out to sea and is characterised by large mud flats that, at the lowest tides, extend some 700m from the shoreline. Coopers Beach (Fig 1) comprises a large area of mudflats that lie between the Coopers Beach Caravan Park to the east (Church Lane, East Mersea, CO5 8TN, Grid Ref: TM 057 131) and the Essex Outdoors camp to the west (Reswells Lane, East Mersea, CO5 8SX, Grid Ref: TM 040 130). The site falls under the ownership of Colchester Borough Council (CBC) and is within the Site of Special Scientific Interest (SSSI) area of the Colne Estuary ('Colne Estuary SSSI' ref. 1000666). The SSSI aspect is managed on behalf of CBC by Natural England.

1.1 Project background

In late 2016 a group of three worked timbers ('planks') with associated brushwood remains (Feature 1; Table 1; Figs 2–3), was identified in the intertidal zone of the southern edge of Mersea Island, along with two other single timbers (Features 2–3; Table 1; Fig 2). Due to the threat of loss through erosion, the timbers forming Feature 1 – and additional samples – were recovered in works led by CITiZAN in mid-January 2017 and then kept in cold storage at Historic England, Fort Cumberland, Portsmouth. Subsequent analyses and phases of work have included: i) general biological assessment of 'bulk' environmental samples, ii) wood identifications and radiocarbon dating of small diameter roundwood fragments, and iii) dendrochronological and radiocarbon analysis of the 'planks' and their subsequent conservation.

Table 1: Descriptions of Features 1–3, Coopers Beach, based on information from Hutchinson (2022). Note that the directional alignments in the original report do not agree with the accompanying site plans, and so have been adjusted accordingly here. In addition (*), for Feature 1, it is not clear whether "0.25m deep" refers to i) depth below the ground surface or ii) the thickness of the raft itself.

Feature 1: Timbers 1–3 (Figs 2–3)
A row of three planked oak timbers laid northwest–southeast, edge to edge forming a solid trackway surface up to 2.5m wide; Timber 1: 2m x 0.2m x 80mm, Timber 2: 2.4m x 0.26m x 80mm and Timber 3: 2.56m x 0.29m x 55mm. All three timbers had square axe cut sockets at each end measuring 60mm x 60mm with evidence of axe marks clearly visible around the edges of the sockets. The marks measured 5mm in width. The timbers were supported below by a raft of brushwood poles consisting of oak and hazel. The raft covered a total area of c. 8m^2 and on average was 0.25m deep*. Small patches of brushwood were also observed resting above Timber 3.
Feature 2: Timber 4 (Fig 2)
A single oak timber, 2.02m x 0.18m x 60mm laid east–west 27m north of Feature 1. A single socket cut at the western tip as observed prior to lifting.
Feature 3: Timber 5 (Fig 2)
A single timber, dimensions 2.35m x 0.14m x 50mm, laid southwest–northeast. A single complete socket with evidence of a possible socket at the opposite end but since broken off.

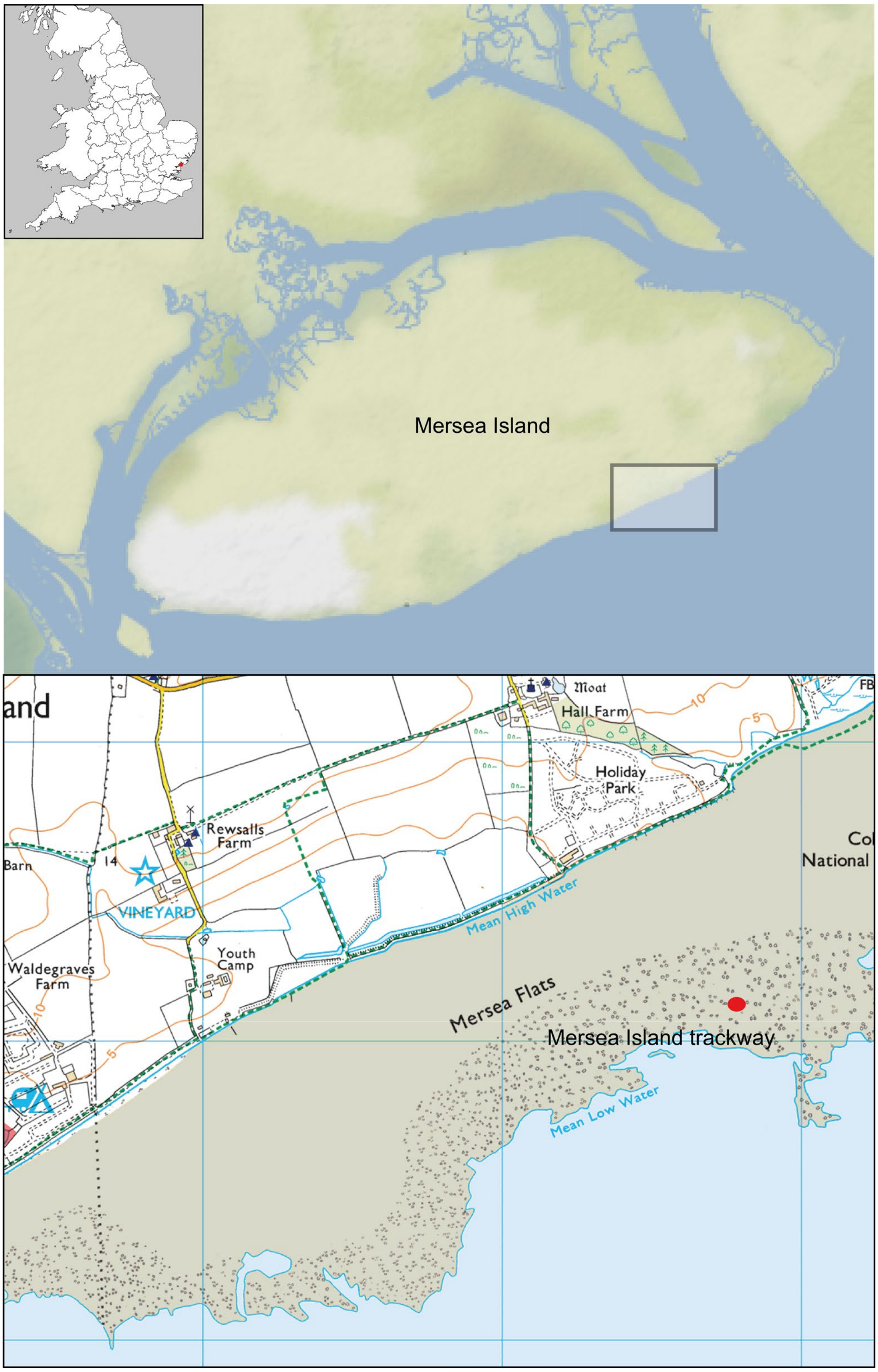

Figure 1: Maps showing the location of Mersea Island, Essex (red dot, top left map), Coopers Beach, and the general location of the trackway (red dot, bottom right map). © Crown Copyright and database right 2023 All rights reserved. Ordnance Survey Licence number 100024900

2. SITE SAMPLING

All the samples taken, analysed, and presented here, are associated with Feature 1.

2.1 'Bulk' samples

Four samples of *c* 5–10 litres were taken during fieldwork on 17 January 2017. The samples all derive from the vicinity of Timbers 1–3 (Fig 3; Table 2). Two of these samples – Sample <2> [S2] from a brushwood layer overlying Timber 1, and Sample <4> [S4] from a brushwood layer found beneath Timber 3 – were selected for assessment (see Section 3). The purpose of this assessment was to identify material for radiocarbon dating, to assess the preservation of material within the brushwood layers and determine whether this material could provide information on the nature of the environment in which the trackway was constructed and used.

Table 2: Details of the samples taken during the recovery of timbers from the Coopers Beach trackway (Feature 1)

Sample name	**Alternative name**	**Location description**	**Assessed**
Sample <1>	S1	Taken from brushwood raft 3.5m south of main concentration of timbers forming Feature 1	-
Sample <2>	S2	Taken from brushwood on top of Timber 1	✓
Sample <3>	S3	Taken from beneath Timber 3	-
Sample <4>	S4	Taken from beneath Timber 3	✓

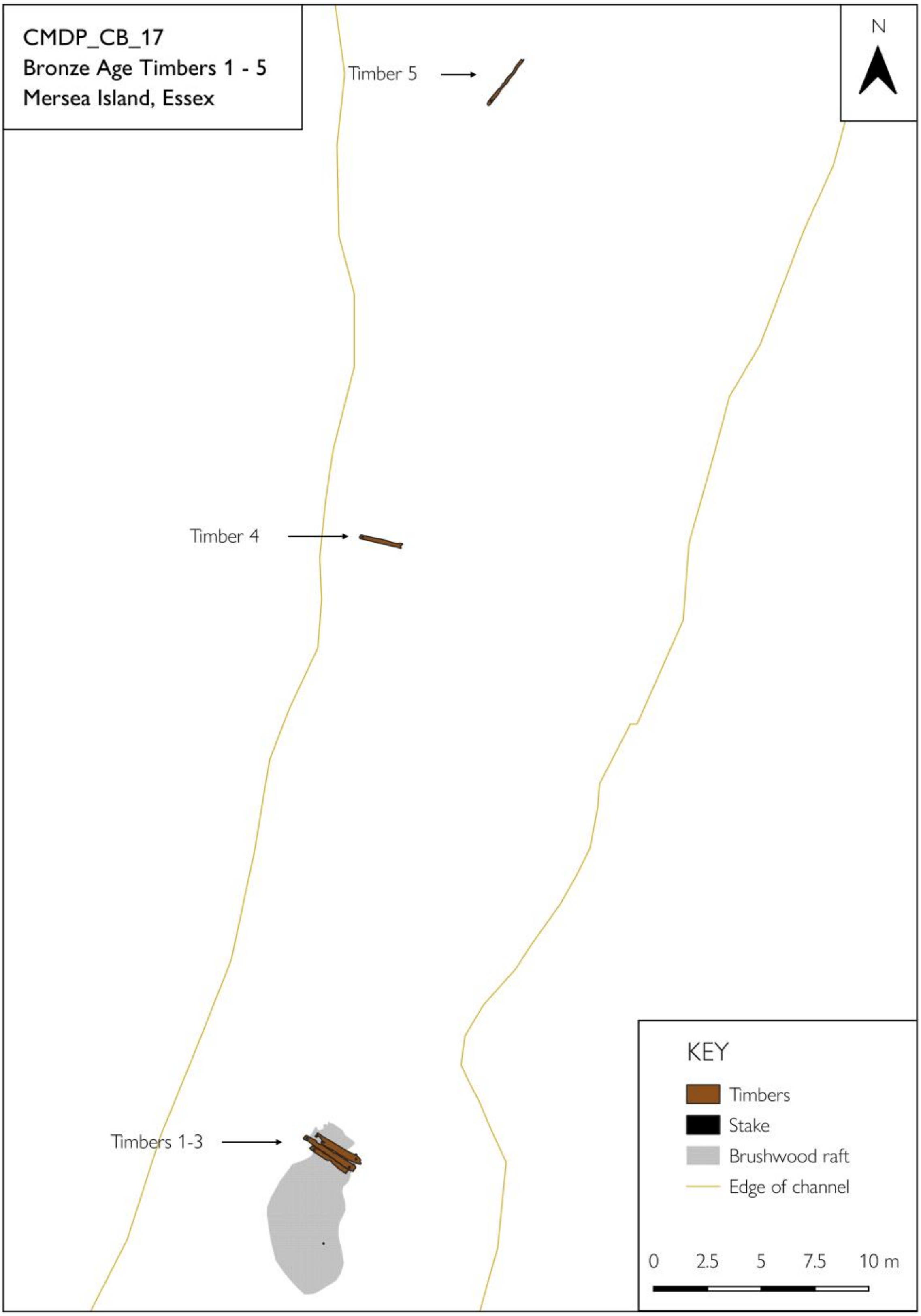

Figure 2: Location of Timbers 1–5 (reproduced from Hutchinson 2022, fig 2). [Note that the site code should read CCB-17]. Thanks to CITiZAN and MOLA for kind permissions to use the plan here.

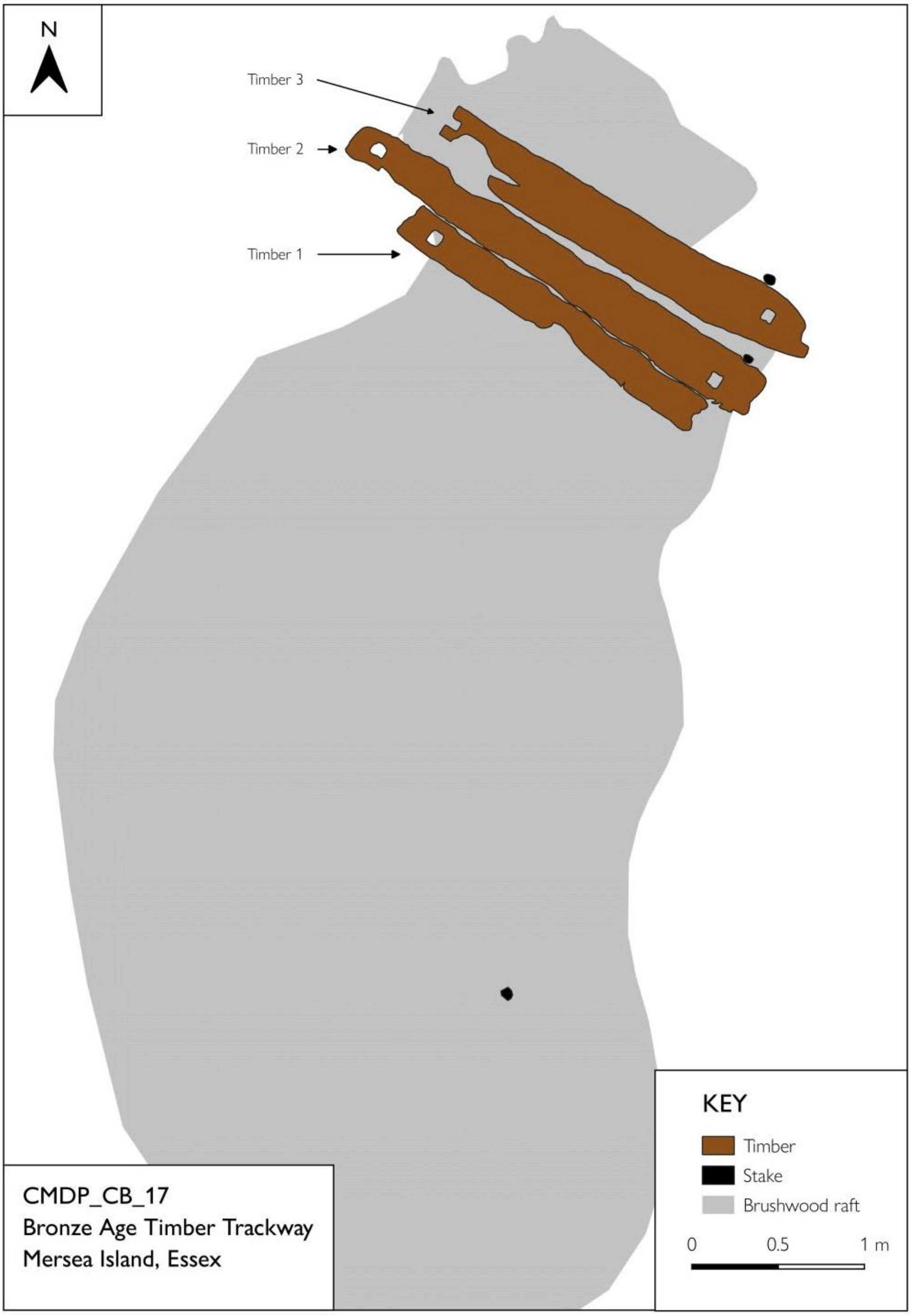

Figure 3: Location of Feature 1's timbers (reproduced from Hutchinson 2022, fig 3). *[Note that the site code should read CCB-17]. The pegs discussed in the main text are referred to as stakes in this plan. Thanks to CITiZAN and MOLA for kind permissions to use the plan here.*

2.2 Timber samples

In total, five timbers were lifted from the site, and moved to Historic England's Fort Cumberland Laboratories, Portsmouth, where they were kept in cold storage for their recording, dendrochronological sampling (see Section 5.1), and conservation (See Section 7). Three of these (Timbers 1–3) were *in-situ* worked timber 'planks' from the trackway (Feature 1) and the other two (Timbers 4–5) were located nearby.

Two wooden pegs (Pegs 1 and 2) associated with the trackway (Feature 1) were also recovered from the site, and on which wood identifications were carried out (Section 4).

3. EVALUATION OF THE 'BULK' SAMPLES

3.1 Methods

0.25 litres of each sample were wet sieved using a mesh of 250µm. Pieces of roundwood within the samples were cleaned of surface 'mud' and briefly examined to determine whether they were likely to be of the same or different wood types, and to record the presence/absence of bark. Two examples from each sample were chosen as possible candidates for radiocarbon dating. These pieces were examined and recorded in detail (see Section 4).

The rest of the sample was examined by eye or with the aid of a binocular-dissecting microscope at magnifications up to x50. The preservation and the nature of any plant, insect and molluscs remains present were recorded. No detailed quantification was made but the amount of different materials present was recorded using the following four-point scale: 1(+) = present, 2(++) = frequent, 3(+++) = common, and 4(++++) = abundant. Identification of plant remains took place with reference to Historic England's modern comparative reference collection held at Fort Cumberland Laboratories, Portsmouth. Nomenclatures follow Stace (1997) (for the plant remains), and the Encyclopaedia Of Life (http://eol.org/) (for the molluscs). The results are presented in Table 3.

3.2 Results of the General Biological Analysis (GBA)

3.2.1 Sample <2> [S2]

A *Salix* sp. (willow) bud was identified as well as some dicotyledonous leaves and indeterminate twigs. The material was generally well-preserved with mite remains present. One very fresh grass floret was present. This is likely to represent very recent contamination and as such is not listed in Table 3. The majority of the roundwood present appeared to be Betulaceae but with one other type present. On further examination these proved to be *Corylus* sp. (hazel) and *Carpinus* sp. (hornbeam) (both Betulaceae), and deciduous *Quercus* sp. (oak) respectively (see Table 4).

3.2.2 Sample <4> [S4]
Remains noted include *Rumex* sp. (dock) seeds and various members of the Chenopodiaceae family, well-preserved mites and moss. This sample contained fewer pieces of roundwood. Two of the larger well-preserved examples were selected for possible radiocarbon dating, both of which were identified as deciduous *Quercus* sp. (oak) (see Table 4).

3.3 Discussion
The results from the two samples suggest that the brushwood layers above and below the timber structure are broadly similar. Biological remains are well-preserved in both samples, with material other than wood present in low numbers as would be expected from a buried landscape surface. There is slightly more evidence of maritime influence in Sample <4>, for example the presence of *Suaeda maritima* (annual sea-blite) and *Peringia ulvae* (laver spire shell), but this may not be significant given the size of the samples and the possibility of some contamination from recent in-wash.

Overall, the impression given by these results is that the trackway was set within tidal scrub or woodland. Given the nature of the sampling conditions, and the nature of the evaluation, no further work on these samples is merited. The sediments may have been subject to reworking during the recent exposure of the structure meaning that some recent in-wash has occurred. The samples from beneath the timbers should have been less affected by this process.

Table 3: Biological remains recorded in Samples <2> and <4>. See Section 3.1 for the explanation of the abundance scale

Taxon (where applicable)	**Common name (where applicable)**	**Abundance**	
		Sample <2>	Sample <4>
Salix sp.	Willow	+	-
Rumex sp.	Dock	-	+
Chenopodium cf. *ficifolium* Sm.	cf. Fig-leaved goosefoot	-	+
Chenopdium cf. *album* L.	cf. Fat-hen	-	+
Chenopodium sp.	Goosefoot	+	+
Atriplex sp.	Orache	-	+
Suaeda maritima (L.) Dumort	Annual sea-blite	-	+
moss		-	+
wood		++++	+++
twig		+	-
dicotyledonous leaf fragment		+	-
bud		+	-
bud scale		++	+
mite		+	+
Peringia ulvae Pennant	Laver spire shell	-	+

4. WOOD IDENTIFICATIONS

4.1 Samples and methods

Wood identifications, together with additional recording, were carried out on a total of nine wooden elements from the site at Coopers Beach: seven pieces of roundwood (Aitken and Hazell 2017) and two pegs (Hazell 2017). The seven roundwood pieces were from two samples associated with two of the timbers: Sample <2> from the brushwood on top of Timber 1, and Sample <4> from below Timber 3 (Fig 2). Peg 1 was from between Timbers 2–3, and Peg 2 was from south of the main group of timbers (Timbers 1–3; Table 1; Fig 3), respectively. A selection of these were used for radiocarbon dating.

Thin sections were taken by hand using a double-edged razor blade, from the three planes of wood required for secure identifications; the transverse section (TS), radial longitudinal section (RLS) and the transverse longitudinal section (TLS). These were then examined under high power magnification (x100–400) using a Leica DM2500. Identifications were made using a combination of the texts and keys by Schweingruber (1982) and Gale and Cutler (2000) and the reference material from Historic England's *Wood and Charcoal Reference Collection*.

The following additional measurements and characteristics of the wood were also recorded where possible, including diameter and/or radius, number of growth rings, presence/absence of bark, and season of felling. Average ring width was calculated using the measured radius (or calculated radius) and ring count results.

4.2 Results

Only three wood types were identified (Table 4), all of which are hardwoods: *Corylus* (hazel), *Carpinus* (hornbeam) and *Quercus* (oak). In the British Isles, both *Corylus* and *Carpinus* have only one native species each (Stace 2010); the native hazel is *C. avellana* (hazel), and the native hornbeam is *C. betulus* (hornbeam). The only native oaks are *Q. petraea* (sessile oak) and *Q. robur* (pedunculate oak) (Gale and Cutler 2000, 204).

In terms of the brushwood elements, most of the fragments (Fragments 1–5) looked as though they came from small diameter roundwood; none had bark attached, but the outer edges of these looked to be the real outer edge of the xylem. Fragments 6 and 7 were incomplete cross-sections and were degraded around their outer edges. All fragments had at least five growth rings; four had eight rings, one had six rings, one had five rings, and one (Fragment 5) was too degraded around the outer edge to be able to thin section well. The maximum average ring-width for the assemblage ranged between 0.15–1.72mm.

Both the pegs were of *Corylus*, with other similarities to each other; both had some bark present in places, and they were of a similar size, with a similar number of growth rings counted. As such, they could have derived from the same individual.

*Table 4: Wood identification results of the small diameter 'brushwood' samples and the pegs from the Coopers Beach site. * = incomplete diameter due to the eroding outer edge of the fragment. ARW = Average ring width (calculated, to 2dp). nr = not recorded*

Sample	**Fragment**	**Material**	**Notes**	**Diameter (mm)**	**Radiocarbon dated**
<2>	1	*Corylus*	Pith present. No bark but looks like outer xylem edge where not eroding. 8 growth rings. ARW = 1.18mm	18.8 x 15.3*	No
	2	*Corylus*	Pith present. No bark but looks like outer xylem edge. 8 growth rings. Complete small diameter roundwood. ARW = 1.26mm	20.2 x 18.3	No
	3	*Quercus*	6 growth rings. Innermost ring is the widest; outer rings are much narrower. ARW = 0.93mm	14.9 x 12.0*	No
	6	*Quercus*	5 growth rings. Pith present; no bark. Outer edge is degraded. Incomplete roundwood. Radius measured as 10.3mm. ARW = 0.21mm	2.1 x nr	Yes
	7	*Carpinus*	6 growth rings. Outer edge degraded; missing most of one side lengthways. Radius measured as 8.8mm. ARW = 0.15mm	nr x nr	Yes
<4>	4	*Quercus*	Pith present. No bark but looks like outer xylem edge. Complete small-diameter roundwood. 8 growth rings. Only a single row of earlywood large vessels in the outermost ring (ie felled early in the growth season). ARW = 1.56mm	25.0 x 24.0	Yes

Sample	Fragment	Material	Notes	Diameter (mm)	Radiocarbon dated
	5	*Quercus*	Pith present. No bark but looks like outer xylem edge. ≥ 8 growth rings. Fragment disintegrates. Generally wide rings. ARW = 1.72mm	27.5 x 18.5*	Yes
Pegs	Peg 1	*Corylus*	Pith present. Bark present in places. >35 growth rings (radius 27.7mm). ARW = 0.79mm Outermost 21 rings were the narrowest.	62.5 (max)	Yes
	Peg 2	*Corylus*	Pith present. Bark present in places. >37 growth rings (radius 24.9mm). ARW = 0.67mm Outermost c 24 rings were the narrowest (outermost 13 rings were very narrow).	60.7 (max)	Yes

5. DENDROCHRONOLOGY

5.1 Sampling

The five timbers (Timbers 1–5) were sampled at Fort Cumberland in May 2017. These timbers were sampled by the removal of cross-sectional slices by handsaw at locations that provided a combination of the maximum numbers of rings, and/or retained likely original outer surfaces. Each sample was subsequently placed in a deep-freeze for 48 hours in order to consolidate the timber. A surface equivalent to the original horizontal plane of the parent tree was then prepared with a variety of bladed tools. This preparation revealed the width of each successive annual tree ring. Each prepared sample could then be accurately assessed for the number of rings it contained, and at this stage it was also possible to determine whether the sequence of ring widths within it could be reliably resolved. Dendrochronological samples need to be free of aberrant anatomical features such as those caused by physical damage to the tree, which may prevent or significantly reduce the chances of successful dating.

5.2 Methods

Standard dendrochronological analysis methods (see eg English Heritage 1998) were applied to each suitable sample. The complete sequence of the annual growth rings in the suitable samples was measured to an accuracy of 0.01mm using a micro-computer based travelling stage (see results in Appendix I). The sequences of ring widths were then plotted onto semi-log graph paper to enable visual comparisons to be made between sequences. In addition, cross-correlation algorithms (eg Baillie and Pilcher 1973) were employed to search for positions where the ring sequences were highly correlated. Highly correlated positions were checked using the graphs and, if any of these were satisfactory, new composite sequences were constructed from the synchronised sequences. Any *t*-values reported below were 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 need to have been obtained from a range of independent sequences, and that these positions were supported by satisfactory visual matching.

Not every tree can be correlated by the statistical tools or the visual examination of the graphs. There are thought to be a number of reasons for this: genetic variations; site-specific issues (for example a tree growing in a stream bed will be less responsive to rainfall); or some traumatic experience in the tree's lifetime, such as injury by pollarding, defoliation events by caterpillars, or similar. These could each produce a sequence dominated by a non-climatic signal. Experimental work with modern trees shows that 5–20% of all oak trees, even when enough rings are obtained, cannot be reliably crossmatched. With the additional problems of archaeological material, it is typically found that less than 80% of apparently suitable archaeological oak samples are datable.

Converting the date obtained for a tree-ring sequence into a useful archaeological date requires a record of the nature of the outermost rings of the sample. If bark or bark-edge survives, a felling date precise to the year or season can be obtained. If no sapwood survives, the date obtained from the sample gives a *terminus post quem* for its use. If some sapwood survives, an estimate for the number of missing rings can be applied to the end-date of the heartwood. This estimate is quite broad and varies by period and region.

5.3 Analysis

All five of the dendrochronological samples are oak (*Quercus* spp.) and all were analysed and one (Timber 1) was successfully dated (Table 5; Fig 4). This dated timber is late Bronze Age and matches contemporaneous tree-ring sequences from Flag Fen and elsewhere (Table 6). Another pair of timbers (Timbers 4 and 5) were cross-matched to each other (*t*-value 9.03; Fig 5) but could not be dated conclusively when compared to reference sequences either individually or as a combined series, CCB45m. One of these two cross-matched, but undated, timbers (Timber 4) is the only timber in the assemblage with some sapwood present. The two shortest sequences, from faster growing trees, were not matched to the other timbers from the site or to reference sequences.

Table 5: Details of the Quercus *sp. (oak) dendrochronological samples from Coopers Beach*

Sample	Cross-section (mm)	Rings	Sapwood	Growth rate (mm)	Date of measured sequence	Interpreted result
Timber 1	185 x 75	112	-	1.63	1073BC–962BC	after 952BC
Timber 2	260 x 75	85	-	2.97	undated	-
Timber 3	280 x 45	82	-	3.37	undated	-
Timber 4	180 x 65	184	27	0.98	undated	-
Timber 5	135 x 35	150	-	0.90	undated	-

Table 6: Showing t*-values (Baillie and Pilcher 1973) between the Timber 1 sequence and contemporaneous reference data*

	Timber 1 1073–962 BC
Cambridgeshire, Peterborough, Flag Fen and Fengate (Neve 1999)	8.42
Nottinghamshire, Newington Quarry nr Misson (Tyers 2003)	5.51
Cambridgeshire, Cambridge St Clement's Gardens (Tyers 2016)	5.39
Cambridgeshire, Whittlesey, Must Farm MUS15 2711 (Tyers *et al* 2020)	5.10
Cambridgeshire, Whittlesey, Must Farm MAP08 100 (Tyers *et al* 2020)	4.48

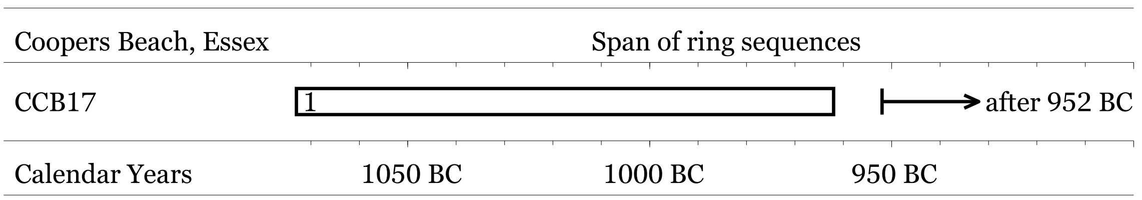

Figure 4. Bar diagram showing the absolute dating position of the dated tree-ring sequence from Timber 1 from Coopers Beach. The interpreted terminus post quem *date for felling is also shown for this sample.*
KEY: White bar is oak heartwood

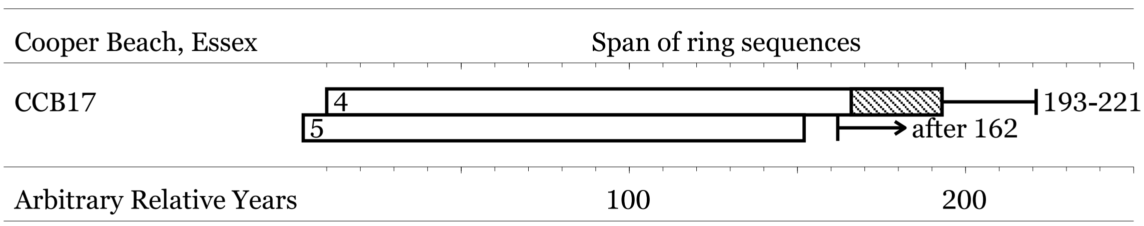

Figure 5. Bar diagram showing the relative dating positions of two undated tree-ring sequences from Timbers 4 and 5 from Coopers Beach. An illustrative interpreted felling date range relative date is shown for Timber 4, whilst an interpreted terminus post quem *date for felling is shown for Timber 5.*
KEY: White bars are oak heartwood; hatched bar is oak sapwood

5.4 Interpretation

The dated slice from Timber 1 does not retain bark-edge, or identifiable sapwood. The interpretation given here to the dated sample is a *terminus post quem* date for felling of the timber based on the likely minimum amount of missing sapwood, taken here as ten years (English Heritage 1998, 11; Arnold *et al* 2019, fig 9). This interpretation suggests this timber was felled after 952BC.

6. RADIOCARBON DATING

6.1 Sampling

As the ring-width dendrochronology only provided conclusive calendar dating for a single timber (Timber 1), four of the five sampled timbers from the trackway remained undated, although a pair of timbers (Timbers 4 and 5) were cross-matched to each other (*t*-value 9.03) but could not to be dated conclusively when compared to reference sequences. As Timber 4 is the only timber in the assemblage with some sapwood present and as it is also the longest tree-ring sequence from the undated combined sequence it was selected for radiocarbon dating and wiggle-matching (Table 5; Table 7).

In addition, a number of other samples were selected for radiocarbon dating (Table 7):

- Peg 1 found between Timbers 2 and 3;
- Peg 2 driven through the brushwood raft to the south of the main group of timbers (Timbers 1–3);
- Two wood fragments (Sample <4>: Fragments 4 and 5) from the large brushwood raft beneath Timber 3;
- Two wood fragments (Sample <2>: Fragments 6 and 7) from the brushwood layer that was on top of Timber 1.

6.2 Methods

A total of 13 radiocarbon results have been obtained from samples of waterlogged wood from Coopers Beach. Details of the dated samples, radiocarbon ages, and associated stable isotopic measurements are provided in Table 7. The radiocarbon results are conventional radiocarbon ages (Stuiver and Polach 1977), corrected for fractionation using $\delta^{13}C$ values measured by Accelerator Mass Spectrometry (AMS).

Table 7: Radiocarbon and stable isotope results from Coopers Beach. Replicate measurements have been tested for statistical consistency and combined by taking a weighted mean before calibration as described by Ward and Wilson (1978)

Laboratory Code	**Sample, material & depth**	**$\delta^{13}C_{IRMS}$ (‰)**	**$\delta^{13}C_{AMS}$ (‰)**	**Radiocarbon Age (BP)**
Timber 4				
ETH-96040	Timber 4: rings 1–10 Waterlogged wood, *Quercus* sp. heartwood rings 1–10 (I Tyers) part of 184 ring undated chronology CCB45m		−26.8±1.0	2903±23
GrM-17203	Timber 4: rings 41–50 Waterlogged wood, *Quercus* sp. heartwood rings 41–50 (I Tyers) part of 184 ring undated chronology CCB45m	−25.2±0.15		2916±18
ETH-96041	Timber 4: rings 81–90 Waterlogged wood, *Quercus* sp. heartwood rings 81–90 (I Tyers) part of 184 ring undated chronology CCB45m		−26.1±1.0	2897±23
GrM-17204	Timber 4: rings 121–130 Waterlogged wood, *Quercus* sp. heartwood rings 121–130 (I Tyers) part of 184 ring undated chronology CCB45m	−24.5±0.15		2810±18
ETH-96042	Timber 4: rings 161–170 Waterlogged wood, *Quercus* sp. heartwood rings 81–90 (I Tyers) part of 184 ring undated chronology CCB45m		−27.6±1.0	2828±23
Brushwood below Timber 3				
ETH-96039	Sample 4: Fragment 5 Waterlogged wood, *Quercus*, complete small diameter roundwood, 8 growth rings and outer xylem edge (E Aitken/Z Hazell) from brushwood under Timber 3		−25.1±1.0	2815±23
GrM-17205	Sample 4: Fragment 4 Waterlogged wood, *Quercus*, complete small diameter roundwood, 8 growth rings and outer xylem edge (E Aitken/Z Hazell) from brushwood under Timber 3	−26.0±0.15		2861±19
GrM-17785	Replicate of GrM-17205	−25.7±0.15		2826±15
Sample 4: Fragment 4	Weighted mean of GrM-17205 and GrM-17785: ^{14}C: 2847±15 BP; T'=1.4; $\delta^{13}C$: −25.85±0.1 T'=2.0			

Laboratory Code	Sample, material & depth	$\delta^{13}C_{IRMS}$ (‰)	$\delta^{13}C_{AMS}$ (‰)	Radiocarbon Age (BP)
Brushwood above Timber 1				
ETH-96038	Sample 2: Fragment 7 Waterlogged wood, *Carpinus*, 6 growth rings, outer edge degraded, missing most of one side lengthways, radius 8.8mm (E Aitken/Z Hazell), from brushwood on top of trackway Timber 1		−27.7±1.0	2813±23
GrM-18840	Sample 2: Fragment 6 Waterlogged wood, *Quercus*, incomplete roundwood, 5 growth rings, pith present: outer edge is degraded (E Aitken/Z Hazell), from brushwood on top of Timber 1	−25.4±0.19		2860±30
GrM-17787	Replicate of GrM-18840	−26.0±0.15		2829±15
Sample 2: Fragment 6	Weighted mean of GrM-18840 and GrM-17787: ^{14}C: 2841±19 BP; T'=1.4; $\delta^{13}C$: −25.8±0.1 T'=6.1			
Pegs				
GrM-17781	Peg 1 Waterlogged wood, *Corylus* sp. (Z Hazell) bark, from peg found between Timbers 2 and 3	−26.1±0.15		1529±15
ETH-96037	Peg 2 Waterlogged wood, *Corylus* sp. (Z Hazell) bark, from peg found south of the main group of timbers *in situ*.		−27.9±1.0	1561±23

Five samples were dated at the Centre for Isotope Research, University of Groningen, the Netherlands in 2019 as follows:

- Timber 4: rings 41–50 (GrM-17203) and Timber 4: rings 121–130 were converted to α-cellulose (Dee *et al* 2019, 68–9),
- one sample (Peg 1; GrM- 17781) was pretreated using an acid-base-acid protocol (4% HCl, 1% NaOH, <1% HCl) followed by bleaching (Dee *et al* 2019, 67–8),
- two samples (Sample <2>: Fragment 6 and Sample <4>: Fragment 4) were divided and converted to α-cellulose (GrM-18840 and GrM-17205) and pretreated using an acid-base-acid protocol (4% HCl, 1% NaOH, <1% HCl) followed by bleaching (GrM-17787 and GrM-17785),
- two samples (Timber 4: rings 41–50 and rings 121–130) were converted to α-cellulose using an intensified aqueous pretreatment,
- one sample (Peg 1) was pretreated using an acid-base-acid protocol (4% HCl, 1% NaOH, <1% HCl) followed by bleaching, and
- two samples (Sample <2>: Fragment 6 and Sample <4>: Fragment 4) were divided and were both converted to α-cellulose using two different pretreatment methods: i) an intensified aqueous pretreatment, and ii) using an acid-base-acid protocol (4% HCl, 1% NaOH, <1% HCl) followed by bleaching (Dee *et al* 2019). These two different pretreatment methods were used to investigate their effect on the resulting radiocarbon measurements.

The two different pretreatment methods employed on Sample <2>: Fragment 6 and Sample <4>: Fragment 4 were used to investigate their effectiveness on the resulting radiocarbon measurements.

Following pretreatment all samples were combusted in an elemental analyser (IsotopeCube NCS), coupled to an Isotope Ratio Mass Spectrometer (Isoprime 100) and the resultant CO_2 was graphitised by hydrogen reduction in the presence of an iron catalyst (Dee *et al* 2019). The graphite was then pressed into aluminium cathodes and dated by AMS (Synal *et al* 2007; Salehpour *et al* 2016).

Six samples were dated at ETH Zürich, Switzerland in 2019. They were pretreated using the acid-base-acid protocol described by Hajdas (2008), combusted and graphitised as outlined in Wacker *et al* (2010a), and dated by AMS (Synal *et al* 2007; Wacker *et al* 2010b).

Data reduction was undertaken at both laboratories as described by Wacker *et al* (2010c). Both facilities maintain continual programmes of quality assurance procedures, in addition to participation in international inter-comparison exercises (Scott *et al* 2017). Details of quality assurance data and error calculation at Groningen are provided by Aerts-Bijma *et al* (2021), and similar details for ETH are provided in Synal and Wacker (2010). Replicate radiocarbon measurements are available on two samples, both of which are statistically consistent at the 5% significance level (Ward and Wilson 1978; Table 7), suggesting that these different pretreatments are effective in extracting an endogenous fraction that is likely to have remained chemically unmodified during deposition (de Vries and Barendsen 1954; van Klinken and Hedges 1998; Brock *et al* 2018). Although the two pretreatment methods appear to have been effective, Bayliss and Marshall (2019, fig 3d) reported the poorer than statistically anticipated reproducibility of radiocarbon results on waterlogged wood (n=91). There are indications that this may be related to cellulose preservation on some sites (Bayliss and Marshall 2019, 1156), and thus decisions on what pretreatment to use on waterlogged wood should be made on a site-by-site basis with the radiocarbon laboratory.

One of the pairs of $\delta^{13}C$ values (Sample <4>: Fragment 4) measured by Isotope Ratio Mass Spectrometry (IRMS), is statistically consistent at the 5% significance level, and the other pair (Sample <2>: Fragment 6) is statistically consistent at the 1% significance level.

6.3 Chronological modelling

The chronological modelling described below has been undertaken using OxCal 4.4 (Bronk Ramsey 1995; 2009), and the internationally agreed calibration curve for terrestrial samples from the northern hemisphere (IntCal20; Reimer *et al* 2020). The models are defined by the OxCal CQL2 keywords and by the brackets on the left-hand side of Figures 6 and 8. In the diagrams, calibrated radiocarbon dates are shown in outline and the posterior density estimates produced by the chronological modelling are shown in solid black. The Highest Posterior Density intervals which describe the posterior distributions are given in italics.

6.4 Wiggle matching Timber 4

Wiggle-matching is the process of matching a series of calibrated radiocarbon dates which are separated by a known number of years to the shape of the radiocarbon calibration curve. At its simplest, this can be done visually, although statistical methods are usually employed. Floating tree-ring sequences are particularly suited to this approach as the calendar age separation of tree-rings submitted for dating is known precisely by counting the rings in the timber. A review of the method is described in Galimberti *et al* (2004).

Figure 6 illustrates the chronological model for Timber 4. This model incorporates the gaps between each dated block of 10 rings from tree-ring dating (eg that the carbon in rings 1–10 of the measured tree-ring series (ETH-96040)) was laid down 40 years before the carbon in ring 41–50 of the series (GrM-17203), with the radiocarbon measurements (Table 7) calibrated using the internationally agreed radiocarbon calibration data for the northern hemisphere, IntCal20 (Reimer *et al* 2020).

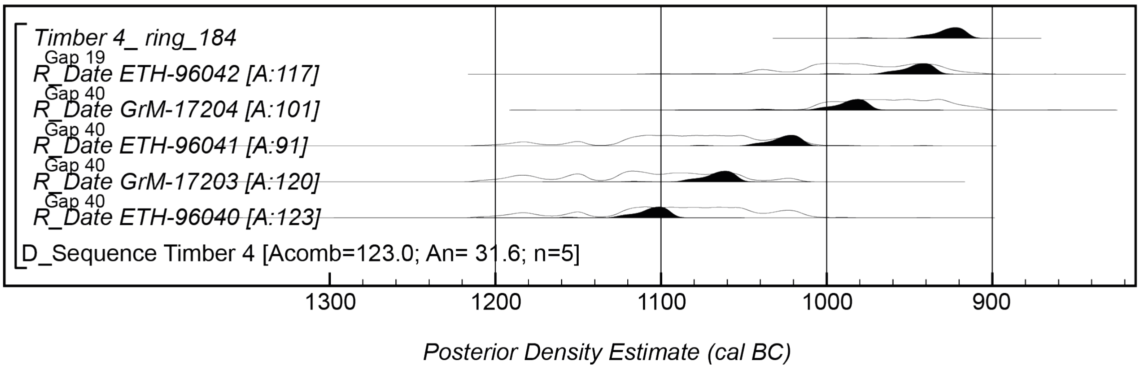

Figure 6: Probability distributions of dates from Timber 4. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. Distributions other than those relating to particular samples correspond to aspects of the model. For example, the distribution 'Timber_4_ring_184' is the estimated date for the last ring, 184, of Timber 4. The large square brackets down the left-hand side along with the OxCal keywords and the description of the sapwood estimates in the text defines the overall model exactly

The model has good overall agreement (Acomb: 123.0, An: 31.6, n: 5), and all five dates have good individual agreement (A: > 60.0). The Acomb statistic shows how closely the assemblage of calibrated radiocarbon dates as a whole agree with the relative dating provided by the tree-ring analysis that has been incorporated 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 calibrated radiocarbon date agrees its position in the sequence (most values in a model should be equal to or greater than 60). It suggests that the final ring of Timber 4 formed in *955–905 cal BC (95% probability; Timber 4_ring_184*; Fig 6), probably in *935–910 cal BC (68% probability).*

As Timber 4 retains 27 sapwood rings we can estimate its felling dates by adding the probability distribution of the expected number of sapwood rings in ancient oak timbers from England (Arnold *et al* 2019, fig 9) truncated to allow for the surviving sapwood rings (Bayliss and Tyers 2004, 960–1) to the estimated date of its last surviving ring. The resulting distribution is shown in Figure 7 and estimates the felling of Timber 4 occurred in *950–890 cal BC (95% probability; Timber 4_felling*; Fig 7), probably in *930–905 cal BC (68% probability).*

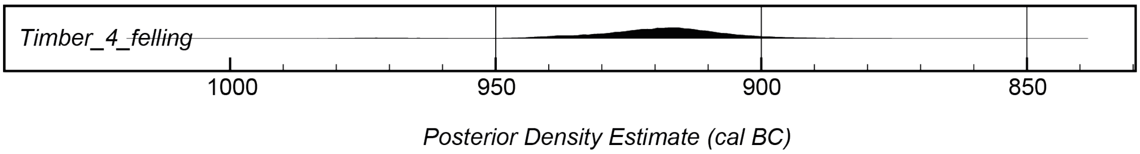

Figure 7: Probability distribution for the estimated felling date of Timber 4

6.5 Chronological model for the Coopers Beach trackway sequence

The chronological model for activity associated with the Coopers Beach trackway is shown in Figure 8. The model includes radiocarbon dates and a tree-ring date on samples from stratigraphically-related deposits. As described below our modelling also incorporates relationships between deposits based on our understanding of the structural sequences documented.

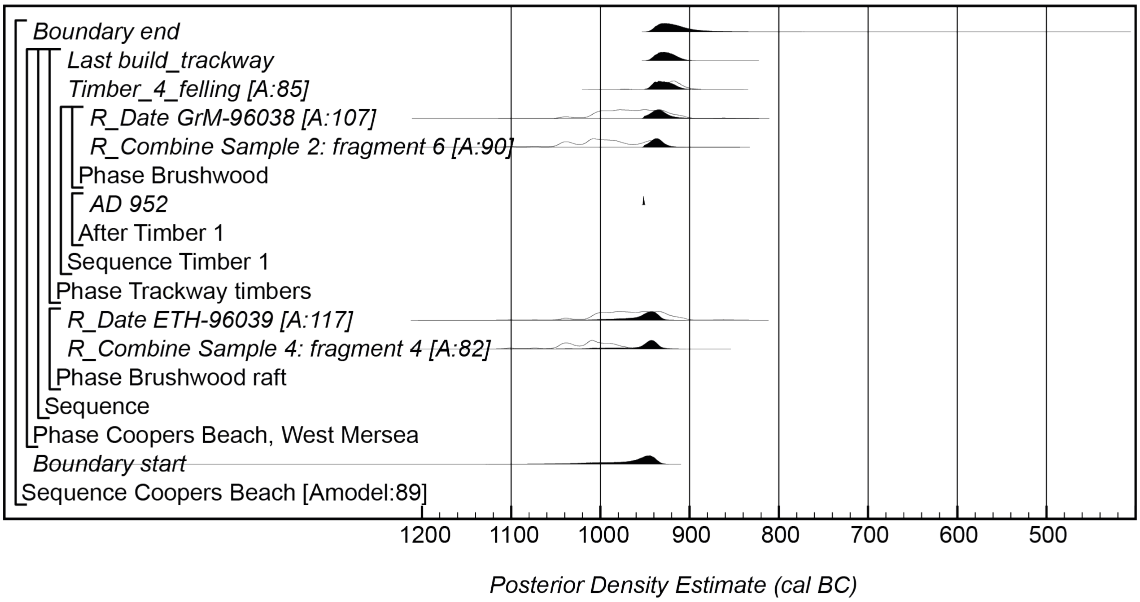

Figure 8: Probability distributions of dates from Coopers Beach. The format is as described in Figure 6

Two samples (Sample <4>: Fragments 4 and 5) were dated from the large brushwood raft beneath Timber 3 that is presumed to be the base on which the they were originally laid. The two measurements on Sample <4>: Fragment 4 (GrM-17205 and GrM-17785), from sub-samples that went through different pretreatment protocols, alpha cellulose and ABA-bleach respectively (Section 6.2), are statistically consistent at the 5% significance level (Table 7) and a weighted mean (Sample <4>: Fragment 4; 2847±15 BP) has therefore been taken as the best estimate for the age of the complete *Quercus* roundwood sample. The two radiocarbon measurements on samples from the brushwood raft (Sample <4>: Fragment 4; 2847±15 BP and ETH-96039; 2815±23 BP) are statistically consistent at the 5% significance level and could be of the same actual age (T'=1.4 T'(5%)=3.8, ν=1).

In addition to the estimated felling date for Timber 4 derived from the wiggle-match described above, dendrochronology provided a *terminus post quem* date for the felling of Timber 1, of 952 BC. Given that Timber 4 is likely to be part of the same trackway, it has been constrained to be later than the two dated samples from the brushwood raft in the model shown in Figure 8.

Two samples (Sample <2>: Fragments 6 and 7) were also dated from the brushwood layer that was on top of Timber 1. The two measurements on Sample <2>: Fragment 6 (GrM-18840 and GrM-17787), from sub-samples that went through different pretreatment protocols, alpha cellulose and ABA-bleach respectively (see above), are statistically consistent at the 5% significance level (Table 7) and a weighted mean (Sample <2>: Fragment 6; 2841±19 BP) has therefore been taken as the best estimate for the age of the incomplete *Quercus* roundwood sample. The two radiocarbon measurements on samples from the brushwood above Timber 1 (Sample <2>: Fragment 6; 2841±19 BP and ETH-96038; 2813±23 BP) are statistically consistent at the 5% significance level and could be of the same actual age (T'=0.9 T'(5%)=3.8, ν=1).

Radiocarbon determinations on the two pegs found between Timbers 2 and 3 (Peg 1) and south of the main group of timbers driven through the brushwood raft (Peg 2) are statistically consistent at the 5% significance level and could be of the same actual age (T'=1.2 T'(5%)=3.8, ν=1). They are though clearly much later than the trackway timbers and brushwood raft and have therefore been excluded from the model for activity associated with the trackway (Fig 9).

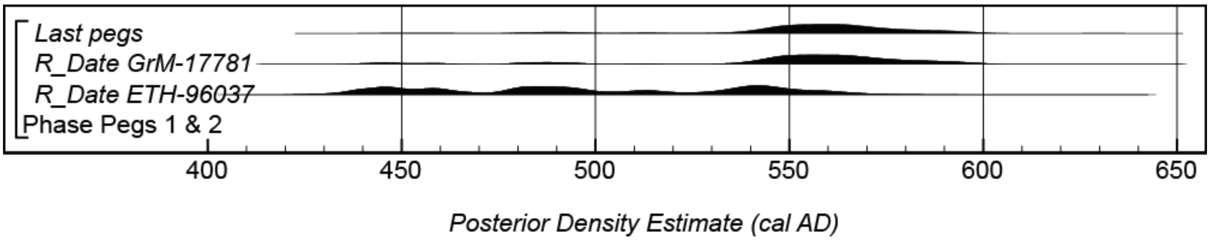

Figure 9: Probability distributions of the dates of the pegs inserted between the trackway and through the brushwood raft

The model incorporating the scientific dates and stratigraphic relationships has good overall agreement (Amodel: 89; Fig 8) and provides an estimate for the construction of the trackway of *945–860 cal BC* (*95% probability*; *build_trackway*; Fig 10) probably *940–915 cal BC* (*68% probability*). The pegs were driven through the trackway and brushwood raft a millennium and a half later (*1405–1435 years* (*5% probability*; *trackway-pegs*; Fig 11) or *1445–1535 years* (*90% probability*), probably *1470–1510 years* (*68% probability*), in *cal AD 475–500* (*4% probability*; *last_pegs*; Fig 9) or *cal AD 505–520* (*1% probability*) or *cal AD 530–605* (*90% probability*), and probably *cal AD 540–575* (*68% probability*).

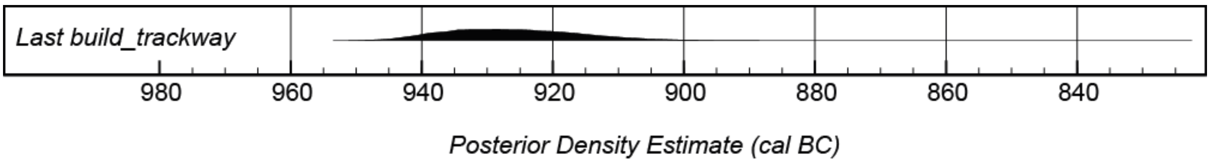

Figure 10: Probability distribution for the date of construction of the Coopers Beach trackway. The estimate is derived from the model defined in Figure 8

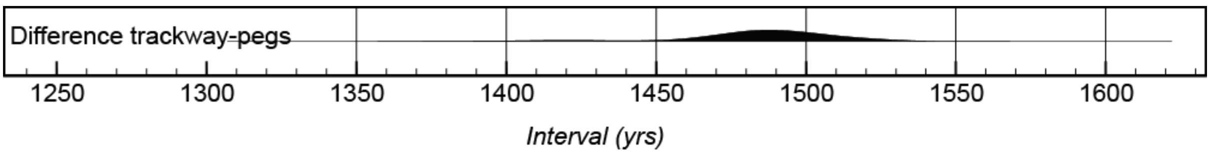

Figure 11: Probability distribution of the number of years between the construction of the Coopers Beach trackway and the insertion of the later pegs

7. CONSERVATION

The conservation of three timbers (Timbers 1–3) forming the principal trackway was undertaken by Historic England. The other two timbers (Timbers 4–5) were conserved by the local Mersea CITiZAN volunteer group using the sucrose method (Dixon *et al* 2020).

7.1 Visual assessment

An initial assessment of the timbers was undertaken on arrival at Fort Cumberland Laboratories (Historic England, Portsmouth). This showed that all five timbers were well packaged, using bubble wrap, plastic sheets, and scaffolding boards.

A slight mould infestation was noticed, as the bubble wrap had been applied with the bubbles facing the wood. This allowed for air to be trapped between the bubbles and resulted in superficial development of mould (Fig 12). This was easily removed by simply sponging the timbers down under running tap water.

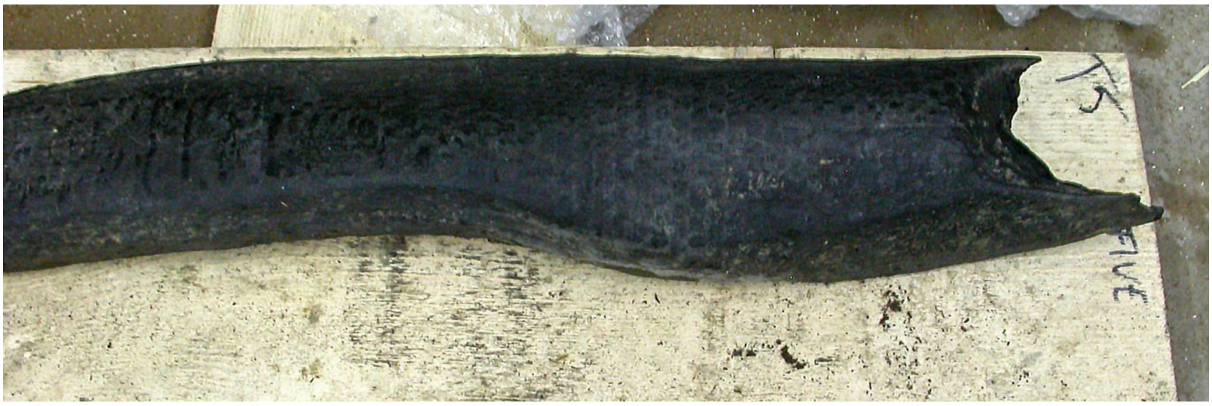

Figure 12: Superficial mould formed around the bubbles of the bubble wrap, shown on Timber 5

During this initial, visual assessment several large cracks running vertically through the timbers were also noted (Fig 13). Timber 3 was particularly affected and as a result was fragile and difficult to handle.

Figure 13: Large cracks running across the grain of Timber 3

The commonly encountered decay pattern in waterlogged wood – a well preserved inner core and decayed outer layer (Hoffman and Jones 1990, 38; Grattan 1987, 67) – was observed during sampling for dendrochronology. This revealed a tough, lightly coloured inner section, surrounded by a darker and softer outer section (Fig 14).

7.2 Conservation

7.2.1 Impregnation

Archaeological waterlogged wood can rarely be dried without a pre-treatment. When water evaporates on drying, it exerts strong surface tension on the weakened wood structure, resulting in splitting, shrinking and warping. To avoid this, archaeological wood is commonly impregnated with polyethylene glycol (PEG). This bulks out the internal cell structure and provides support during drying.

The three timbers (Timbers 1–3) were impregnated using a two-step method: 30% PEG 400 (v/v) followed by 30% PEG 4000 (w/v), for roughly 3 months each. Lower grade PEG 400 has shorter molecule chains and can penetrate deeply into well preserved areas of wood. Higher grade PEG 4000 has longer molecule chains and can support heavily degraded wood. After dating, the slices taken for dendrochronology were conserved alongside the timbers from which they were removed. Impregnation was carried out by submersion in a large tank.

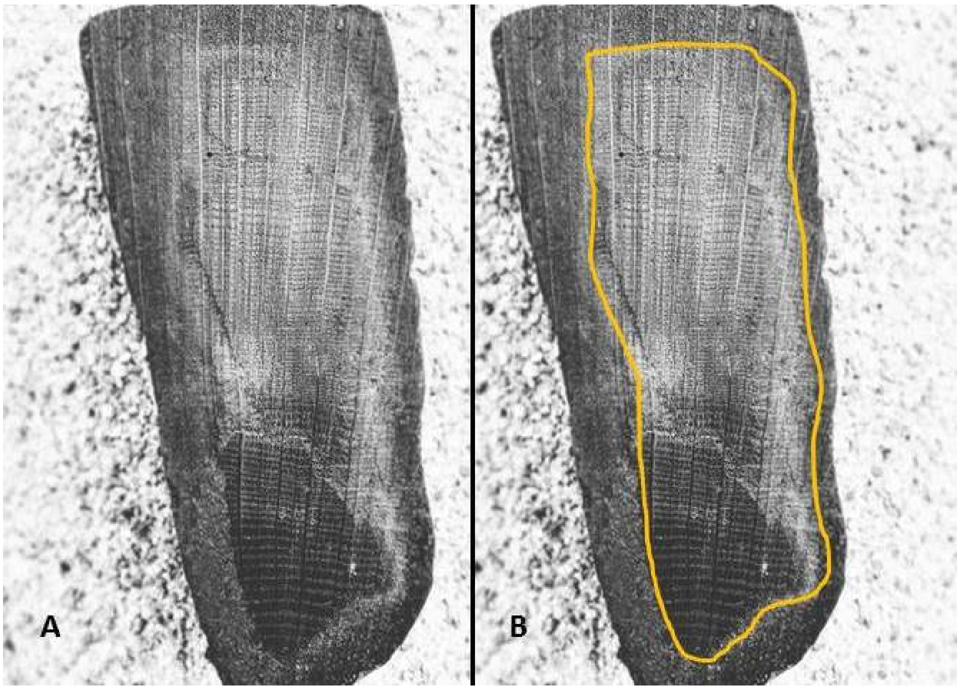

Figure 14: Cross section of dendrochronological sample Timber 1, showing the well-preserved inner core (A), highlighted in yellow (B). Image taken by O. Hutchinson (CITiZAN). Thanks to CITiZAN and MOLA for kind permissions to use the image here.

7.2.2 Vacuum freeze-drying

Following PEG impregnation, the timbers were vacuum freeze-dried. This eliminates drying stress as the frozen water is removed by sublimation. The timbers were first pre-frozen for one week, at −30°C. Freeze-drying commenced in a LyoDry Midi Freeze Dryer s/n F012. The chamber temperature was set at −30°C and the condenser temperature was set to −45°C.

The drying cycle was interrupted regularly to weigh the timbers. The endpoint was determined when weight loss plateaued or slowed down significantly. During this process the wood surfaces were regularly inspected for any further cracking.

The differential preservation (well preserved inner core and decayed outer layer) caused splits to appear along this interface during drying (Fig 15). The most likely explanation is that the two differently preserved sections dried at different rates during the vacuum freeze-drying process resulting in a split at the interface.

7.2.3 Post-drying cleaning

Following vacuum freeze-drying, excess PEG was cleaned off the timbers using brushes and an air-puffer. Some compacted dirt, which was more readily visible in the dried state, was also removed at this stage, using wooden skewers.

Figure 15: Splits along the interface of the well-preserved inner core and decayed outer layer, visible in the cross sections of Timber 3

7.2.4 Post-drying consolidation

The surface of all timbers was very fragile and prone to flaking. This was the result of much higher degradation in the outer layers as became evident during dendrochronological sampling (see above). In order to protect the surface and prevent material loss, larger fragments were attached with 30% Paraloid B72 in Acetone (w/v). After the application of the Paraloid B72, fragments were weighed down with rice-filled bags to ensure good adhesion (Fig 16). Then a final coat of 30% PEG 6000 (w/v) was applied. This darkened the wood slightly but offered further protection of the timber surfaces (Fig 17).

See Appendix II for the after-conservation photos.

7.3 Packaging

A bespoke packaging system was devised for the timbers, consisting of a custom made Corex® support, allowing the timbers to be lifted in/out of their respective boxes (Figs 18–19). The gaps between timber fragments have been cushioned with acid free tissue paper. To avoid movement inside the boxes, bags, filled with polystyrene foam beads, were placed alongside and on top of the timbers.

Figure 16: A timber during the re-attachment of some loose wooden fragments, which have been weighed down with rice-filled bags to achieve good adhesion

Figure 17: The timbers during consolidation. The timbers in the foreground have been consolidated with 30% PEG 6000 and appear darker

Figure 18: Timber 3 inside its Corex tray and wooden box

Figure 19: Timber 3 inside its Corex tray and with polystyrene foam beads in bags for extra support

8. SUMMARY AND CONCLUDING REMARKS

A suite of analyses has been used to investigate and scientifically date three worked oak timbers recovered from remains of an intertidal trackway at Coopers Beach. The results show that the trackway was laid down in the Late Bronze Age, with the hazel pegs inserted 1,500 years later. These three conserved timbers have since been deposited with Mersea Museum, Essex, where they have been included in a permanent display – demonstrating the interest in them, the recognition of their value, and their role in local public engagement.

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APPENDIX I: TREE-RING DATA

Measurements of individual tree ring widths, in 0.01mm units eg ‘337’ = 3.37mm

CCB1 = Timber 1

337	430	435	274	280	338	387	297	269	316
284	277	294	237	208	257	240	207	149	174
156	124	195	135	118	117	182	146	189	207
170	193	184	176	212	143	91	83	92	85
110	107	113	112	125	89	105	115	106	114
100	128	108	150	106	101	130	166	140	228
143	146	120	112	153	138	146	150	136	147
252	223	204	115	103	184	137	89	89	135
143	143	126	163	128	124	117	123	107	107
147	114	122	112	118	134	125	157	167	138
97	142	168	129	106	86	103	182	180	178
137	123								

CCB2 = Timber 2

265	321	538	335	390	474	426	374	563	502
367	462	571	529	371	329	411	452	409	493
414	383	364	216	142	106	69	111	234	297
356	337	231	228	350	366	293	472	367	395
248	180	213	324	149	70	72	71	114	93
117	189	287	358	409	257	338	289	282	397
453	429	317	303	342	243	270	253	239	178
241	300	231	260	247	178	180	186	210	202
237	261	177	243	303					

CCB3 = Timber 3

255	206	208	235	173	243	370	282	398	353
213	230	397	345	383	545	486	197	304	314
308	197	231	219	234	359	297	265	453	443
309	211	440	397	449	552	662	281	189	119
237	406	457	679	580	490	498	519	667	406
381	443	337	213	253	335	404	317	290	280
312	319	267	264	219	167	289	254	251	328
167	277	363	302	303	249	473	380	452	395
327	303								

CCB4 = Timber 4

79	52	43	33	49	106	77	90	102	99
120	44	104	162	66	80	65	126	112	85
103	194	141	109	72	65	82	88	102	132
142	177	99	87	99	116	115	127	120	128
115	125	70	75	102	105	64	82	76	70
73	93	83	102	135	113	80	91	67	54
74	81	83	73	76	73	69	86	82	78
47	50	45	54	58	57	51	50	102	136
177	148	117	165	150	74	55	52	47	71
78	106	93	73	87	97	104	160	86	79
97	103	156	157	213	221	273	257	211	174
169	189	197	209	233	151	105	128	148	189
123	172	220	130	77	67	61	64	141	96
118	124	152	185	167	96	91	108	107	90
87	91	58	41	47	82	57	64	82	77
72	60	53	53	69	64	45	57	49	43
63	62	59	62	90	113	95	97	110	55
41	33	43	36	51	46	47	59	74	88
69	64	72	51						

CCB5 = Timber 5

235	229	334	130	46	51	60	76	63	61
62	81	115	86	82	102	171	189	101	109
155	89	69	60	83	84	71	77	134	91
143	117	76	81	84	103	116	92	89	78
80	97	126	105	115	123	122	95	86	78
45	78	55	50	54	68	70	55	66	55
58	67	60	61	56	49	44	60	56	52
45	62	49	43	57	66	73	49	74	86
71	89	66	84	67	92	103	138	136	104
144	143	97	67	64	68	92	82	111	86
107	104	87	72	101	68	81	67	65	77
102	124	105	106	101	124	130	121	101	86
110	88	91	69	83	76	96	93	105	143
126	128	109	68	90	107	91	98	108	103
121	119	55	41	44	32	42	44	53	63

APPENDIX II: POST-CONSERVATION PHOTOS OF TIMBERS 1–3

Figure A1: Timber 1, side 1 (as in situ*)*

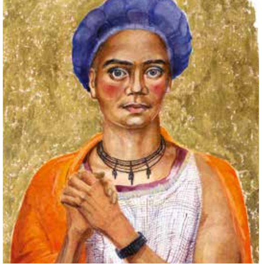
Figure A2: Timber 1, side 2

Figure A3: Timber 2, side 1 (as in situ*)*

Figure A4: Timber 2, side 2

Figure A5: Timber 3, side 1 (as in situ*)*

Figure A6: Timber 3, side 2



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