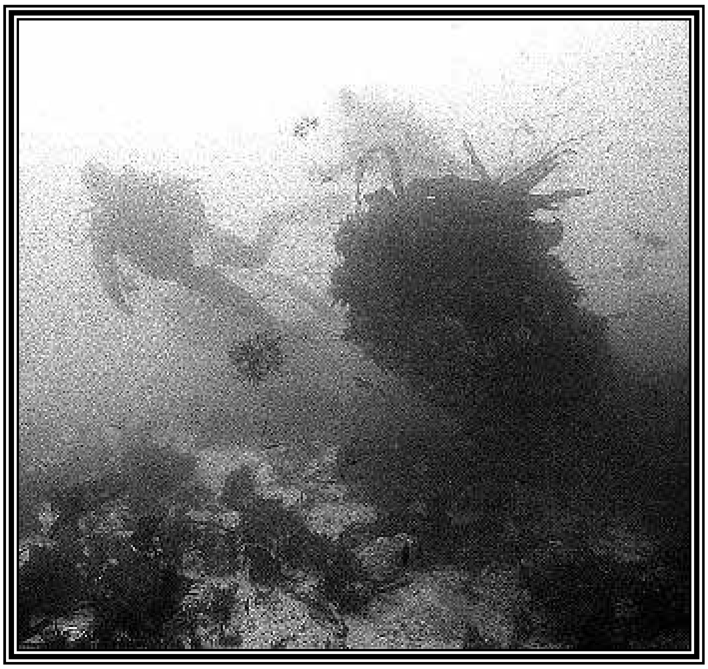
HMS Colossus



Stabilisation Trial
Final Report 2005

Kevin Camidge

With contributions by

Matthew Canti
David Dungworth
Mark Jones
David Precious

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Summary

The broad aim of the stabilisation trial was to determine suitable methods for stabilising the timbers of HMS Colossus exposed on the seabed. These exposed timbers have deteriorated considerably in the four years since survey began in 2001. The most obvious damage to the timbers is from wood boring organisms. Various strategies exist for protecting sites. The specific aim of the trial was to establish the efficacy and economic viability of different protection strategies in the conditions prevailing on this site.

Three different methods of stabilisation were employed in the trials. These were installed on an area of seabed to the south of the exposed timber where there are no visible archaeological remains. The stabilisation materials used were a Terram mat, a synthetic mesh mat and an artificial frond mat system. Each trial mat covered an area 5 x 2.5m and was left in place on the seabed for a period of two years. The trial started in May 2003 and was concluded in May 2005.

To determine the relative performance of the three mats, eight timber sample blocks were installed under each mat. These were retrieved at intervals of 3, 6, 9 and 24 months and analysed to determine the amount of deterioration caused by wood boring organisms, bacteria and fungi. Timber sample blocks were also installed directly on the seabed to act as a control. The results from the analysis of these timber blocks demonstrated that the blocks from the Terram 4000 mat showed no signs of decay even after two years. The blocks from all the other trial areas showed some degree of deterioration.

The conditions under each of the test mats were monitored using a sub-sea data logger, deployed consecutively under each mat for a three month period. The data logger recorded dissolved oxygen, redox potential, pH, temperature and depth at one hour intervals. Results from the Terram and Frond mats showed highly anoxic conditions (less than 0.02 mg/l of dissolved oxygen) within days. Some problems with the data collected were evident, particularly with the pH measurements.

At the same time as the trial areas were monitored, the sediment levels around the wreck were also measured to establish the prevailing sediment variation at the time of the trial. To achieve this, fourteen sediment monitoring points were established around the site and the seabed levels were recorded throughout the trial. It became clear that there was a degree of sediment mobility on the site, the net result of which was a small diminution of seabed levels around the wreck over the last two years. Seabed samples from around the wreck were analysed to establish the nature of these sediments.

The results of the stabilisation trial demonstrated that, of the three stabilisation methods, the Terram 4000 mat was clearly the most efficient and cost effective of the systems trialled on this site.

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Figures

Project background

Introduction

HMS Colossus off Cadiz in 1797, detail from a painting by Thomas Buttersworth National Maritime Museum

HMS Colossus was a 74 gun warship built in 1787 at Gravesend and wrecked off Samson in the Scillies in 1798. These 74 gun ships were one of the most successful types of the period. They were typically about 51m (170 feet) in length and had a crew of about 600. During her relatively short working life (eleven years) she saw action at Toulon, Groix, Cape St Vincent and Cadiz. Colossus also took part in the capture of two enemy ships in 1793[1]. She had no less than nine different captains during her relatively short career. Colossus had a complete refit, which took six months, in 1796.

In December 1798 she was on her way home to England with wounded from the battle of the Nile and with cargo including part of Sir William Hamilton's second collection of Etruscan pottery. She was sheltering from a gale in St Mary's Roads when the anchor cable parted and she was driven aground to the south of Samson. All but one member of the crew were taken off safely before Colossus turned onto her beam ends and proceeded to break up.

Vital Statistics[2, 3]	Length (MGD)	172' 3" (52.5m)
	Breadth	47' 9" (14.6m)
	Tonnage	1703 tons
	Draught (hold)	20' 9½" (6.3m)
	Standard armament	28 x 32lb main gun deck
		28 x 18lb upper gun deck
		14 x 9lb quarter deck
		4 x 9lb forecastle
	Ballast[4]	110 tons of iron ballast and 250 tons of shingle
	Ordered	13th December 1781
	Laid down	October 1782
	Launched	4th April 1787

[1] Le Vanneau, a French 6-gun ship (ADM 52 3006 Masters log) and Vrai Patriot (NMM warships database)
[2] Warships database - National Maritime Museum.
[3] Brian Lavery *Ship of the Line, Vol 1*.
[4] ADM 52 2808 Masters log Colossus to December 1797.

Site location

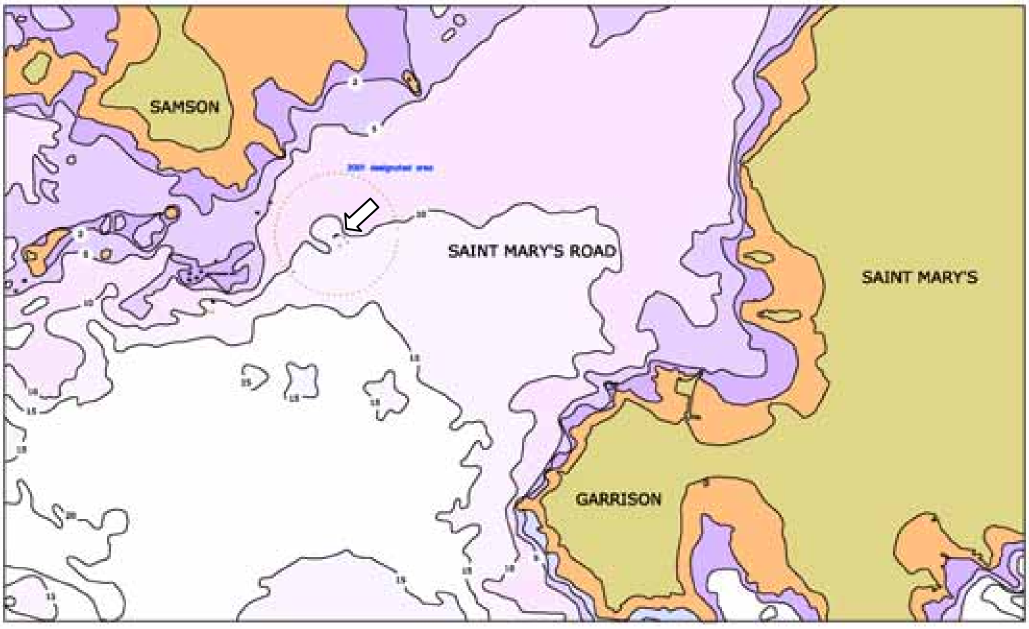


Fig 1 Location Plan – The arrow shows the location of the current site, designated in 2001. The dotted circle shows the extent of the current designated area.

The wreck of HMS Colossus lies to the south of Samson in the Isles of Scilly. To date two main areas of wreckage have been identified, the bow and the stern. In 1975 part of the wreck (probably the bow) was designated under the Protection of Wrecks Act. This designation was revoked in 1984. The current site, the stern, was designated in 2001, and is located at Latitude 49˚ 55'.471N, Longitude 006˚ 20'.505W (260154.906E 5535593.077N UTM zone 30, WGS84[5]).

Site condition

The site lies in a depth of approximately 10m of seawater below chart datum[6]. The seabed around and over the site consists of coarse, white sand with fine crushed shell. Timber elements of the wreck are currently exposed on the seabed. This exposure is recent (otherwise the timber would have decayed) and appears to be due to ongoing erosion of sand from the site. One of the principle aims of the stabilisation trial is to establish what methods of protection could be applied to the surviving wreckage.

[5] The survey work undertaken in 2001-2 used positions and grid references in UTM coordinates using zone 30 based on the WGS84 datum. The designation under the Protection of Wrecks Act gives the position in latitude and longitude.
[6] Chart datum is St Mary's Pool, which is 2.91m below OD (Scilly) and is approximately equal to the height of Lowest Astronomical Tide.

Previous work

Salvage work took place on Colossus from the time of her loss until the early part of last century. Work included Braithwaite and Tonkin 1803-1806, the Dean Brothers in the 1830s and possibly Western Marine Salvage in the early part of last century.

Roland Morris, a marine salver and proprietor of the Penzance Maritime Museum, began searching for the wreck of Colossus in 1967 using a small team of divers. In August 1974 they located material relating to Colossus. The site was designated in 1975 under the Protection of Wrecks Act 1973.[7] A large quantity of pottery, remains of Hamilton's second collection of pottery, was recovered and deposited in the British Museum – where at least one of these reconstructed pots is now on public display. Once Morris' team had finished their work, the site was de-designated in 1984.

Areas of exposed timber and iron guns were discovered by local divers in 2001. This material was some distance to the east of the area worked by Morris and turned out to be part of the stern of Colossus. This was designated in July 2001.

Aims and objectives

The principle aim of the stabilisation trial was to determine suitable methods for stabilising the timbers exposed on the seabed. These exposed timbers have deteriorated considerably in the four years since their discovery in 2001. Various strategies exist for protecting sites. The specific aim of the trial was to establish the efficacy and economic viability of three different protection strategies in the conditions prevailing on this site.

The results of this trial will hopefully inform the ultimate protection strategy for Colossus but may also be of value in suggesting strategies for other submerged maritime sites. There are two main criteria for judging the success of any particular protection scheme. Firstly, how effective is the method at preventing sediment erosion from the site? Secondly, what is the protection offered by each scheme to the timber of the vessel? These have been determined by the placement of standard timber blocks of oak and pine beneath each of the protective coverings. As well as determining the level of protection offered by each scheme, comparison of relative costs and required maintenance were also made. From this information it should be possible to recognise which method is the most appropriate to the conditions, site importance and available resources.

[7] HMS Colossus DBA, Wessex Archaeology 2003.

Methodology

Synopsis of methods

The stabilisation trials were conducted for a two year period between 14th May 2003 and 11th May 2005. Three different protection methods were employed in the trial. The area of the trial was some distance from the surviving timbers, about 25m to the south of the wreck. The designation extends for 300m around the wreck so the trial was within the designated area. Each trial area consisted of a rectangle 5m x 2.5m, spaced evenly across the main tidal flow[8] so that each area was subjected to similar conditions and was not affected by any sediment accumulation engendered by adjacent areas. The trial areas are shown as V1, V2 and V3 on the trial location plan, fig 2 below. A control area, V0, was also marked out but no protection was installed in the control area.

The value of the different stabilisation methods was determined using timber blocks covered by each of the geotextile mats for periods of between three and twenty-four months. The amount of deterioration in the timber was used to indicate the relative efficacy of the different mats. Timber blocks were also fastened to the seabed in the control area, where no geotextiles were employed. Finally, a number of chemical parameters were recorded beneath the geotextile mats (adjacent to the timber sample blocks) using a sub-sea data logger.

There were a number of reasons for conducting the trials away from the structure of the wreck. Firstly, to ensure there would be no effect on the wreck itself should anything go wrong – there was always the possibility that scouring of the seabed might be caused by one of the stabilisation systems. Secondly, had the frond matting performed as claimed, it would, if deployed on the wreck, have buried our existing primary control points rendering any further survey more difficult.

At the same time as the trial areas were monitored, the sediment levels around the wreck were also recorded to establish the prevailing sediment variation at the time of the trial.

Data recovery intervals

Timber sample blocks were recovered at intervals of approximately 3, 6, 12 and 24 months. Measurements using the sub-sea datalogger were taken every hour for approximately 3 months under each of the geotextile mats in turn.

[8] The tide floods across the site roughly west to east and ebbs in the opposite direction.

Positioning of the trial mats

The four trial areas, V0 to V3 were laid out on the seabed using 10mm diameter stainless steel reinforcing bar to mark the corners. The actual positions were established using direct measurements taken from the existing site survey control points. The positions of these pins is shown on the location plan below – for example the points around the control area are marked V0-A to V0-D.

The areas were established in a line running due south from the site with 6m spacing between trial areas. From the wreck moving south, these are V0 (control), V1 (Terram mat), V2 (mesh mat) and V3 (frond mat).

The positions of the trial areas relative to the exposed timber of the stern are shown in Fig 2 below.

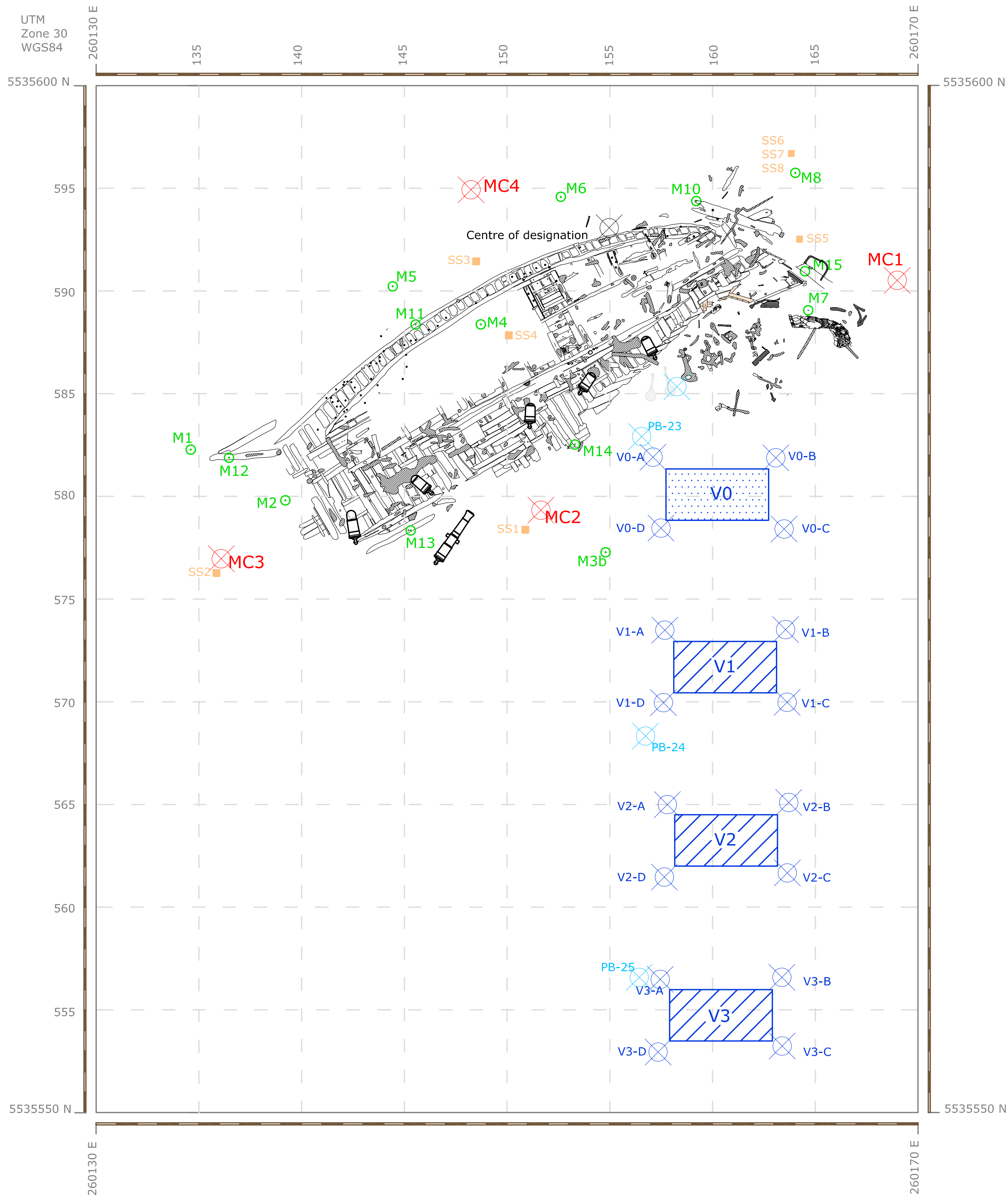
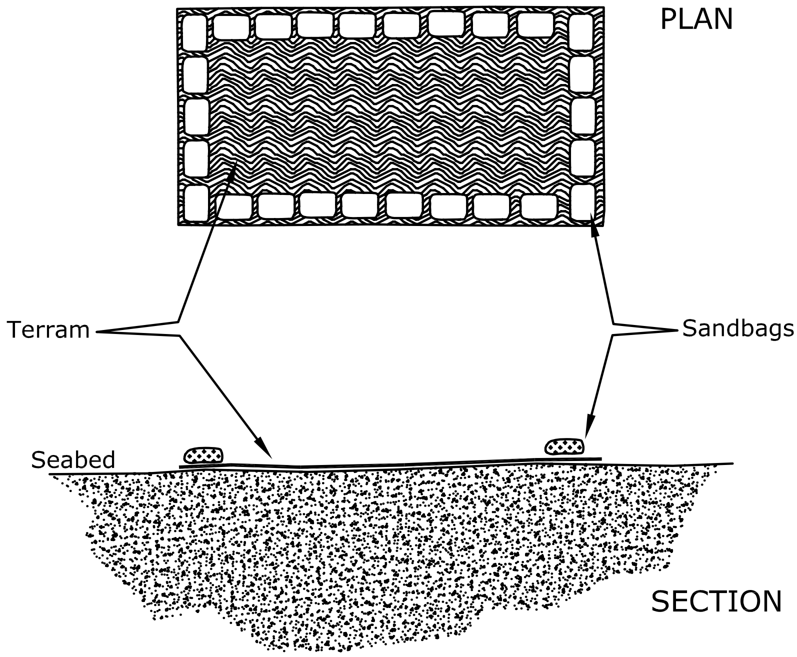


Fig 2
Location of the stabilisation areas, sediment monitoring points and exposed wreckage.
V0 = Control V1 = Terram 4000 V2 = Synthetic mesh V3 = Floating fronds
SS1 – SS8 = Sediment samples
MC1 – MC4 = Master survey control points
M1 – M15 = Seabed height monitoring points
PB23 – PB25 = Proximity test blocks

Stabilisation methods

Terram 4000

Terram was used previously on this site, notably for the reburial of the stern carving in September 2001. It was also used over the backfilled trial excavation in 2002.



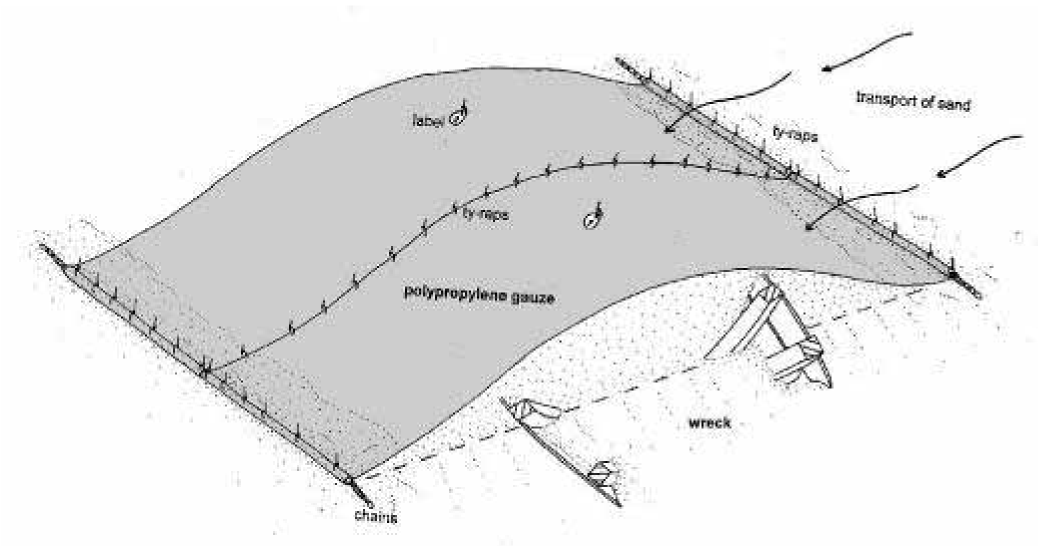
The Terram mat (V1) as deployed in these trials – note the use of sandbags to anchor the mat.

Terram 4000 is a thermally bonded nonwoven geotextile composed of polypropylene (70%) and polyethylene (30%). The Terram mat, 5m x 2.5m, was laid on the seabed and weighted down using continuous lines of sandbags around the edges. The Terram was easy to install. It was transported to the seabed in a roll and unrolled in the appropriate position on the seabed. The sandbags used were 0.75m x 0.45m and constructed of white laminated polypropylene. Each bag was pre-filled with 25kg of coarse builders' sand and closed using a polypropylene tie. Thirty of these sand bags were used to secure this mat, a total weight of approximately 750kg (3/4 tonne).

The manufacturer's data sheet is reproduced in appendix I. Further information can be viewed at http://www.terram.com

Synthetic mesh

This method has been used by Martijn Manders on the BZN 10 and Darsser Cog sites. A fine polypropylene scaffolding or shading net with a density or shading of approximately 50 to 60 %[9] was used. The mesh is anchored to the seabed at its ends – the middle of the mesh is allowed to float above the seabed. This apparently encourages sediment deposition. '*The mesh has positive effects on the protection of wreck-sites; it prevents more wreck sediment being taken away by currents and it even builds up a layer of sand and fine silt under the mesh'* [10].

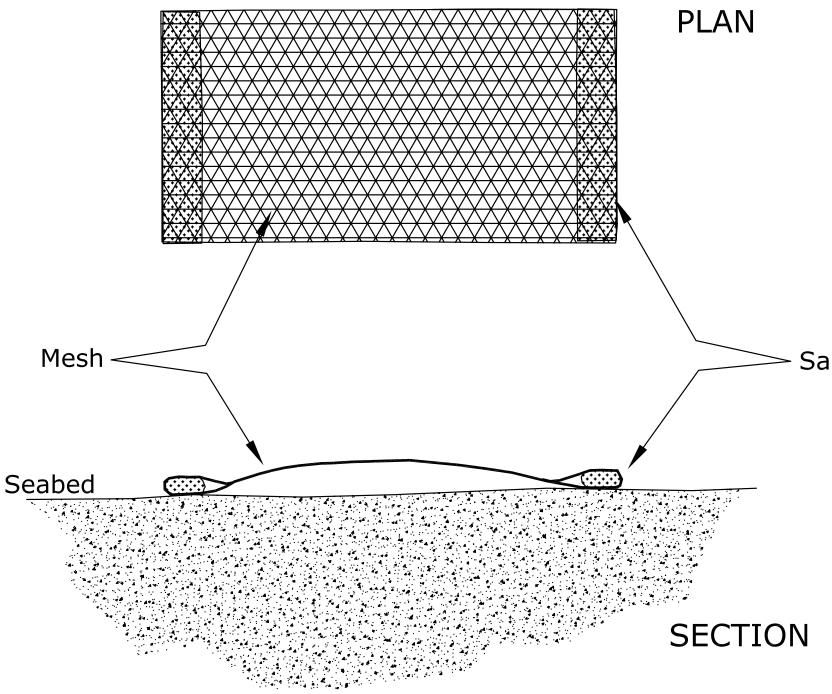


The mesh protection system as deployed on the BZN 10 and Darsser Cog sites by Martijn Manders – note the use of chain to anchor the mat.

This system was successful when deployed on the MoSS project – For the Colossus stabilisation trial the mesh was deployed in exactly the same manner except that sandbags were used to anchor the mat instead of chain. Martijm Manders apparently also used sandbags to anchor the mesh on the Avondster wreck in Sri Lanka.

[9] Martijn Manders & Friedrich Lüth – MoSS Project Final Report 2004
[10] Martijn Manders – Moss Project Newsletter December 2003

A polypropylene mesh with 4mm square aperture size was deployed in a mat 5m x 2.5m. This was held in position by securely enclosing a continuous line of 0.75m x 0.45m sandbags along the short (2.5m) sides of the mat (14 bags)– this amounted to a total weight of 350kg anchoring the mat. Cable ties were used to fasten the mesh around the sandbags. The centre of the mat was allowed to float approximately 0.50m above the seabed. The mesh was transported to the seabed in a small bag and unrolled and anchored without any problems. The ease of deployment is comparable with the Terram 4000 mat.



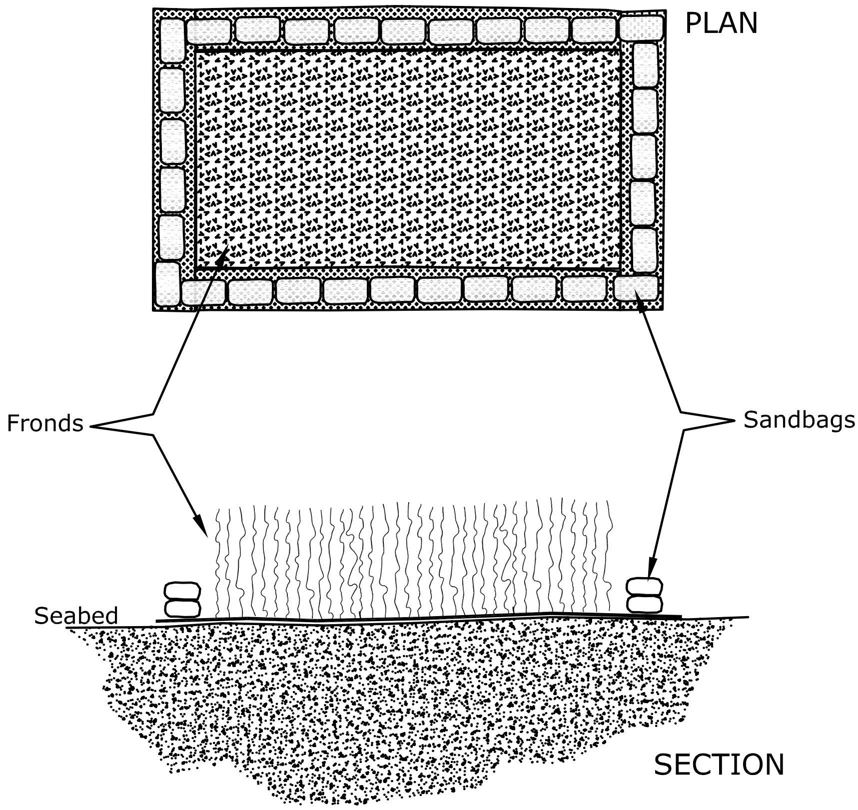
The mesh system (V2) as deployed in these trials – note the use of sandbags instead of chain to anchor the mat..

Martijn Manders very kindly gave advice and supplied details of this system including information not in the MoSS publications. Apparently, the mesh is subject to tearing and the holes can become blocked with weed or 'growth'. If this happens another layer of mesh is simply laid over the top of the old. Further details can be viewed on the MoSS web site at

http://www.nba.fi/INTERNAT/MoSS/bzn10eng.htm#Protecting

Floating frond system

This is a commercially available system developed by Seabed Scour Systems Ltd. These mats consist of a woven polypropylene base material with attached floating fronds, which it is claimed will encourage the rapid deposition of sand. The mats are said to be 'self burying' and the depth of sand deposition can apparently be controlled by the frond length. Standard mats are 5 x 2.5m and cost in the region of £500 each. Seabed Scour Systems generously donated one of these frond matting systems for the stabilisation trial.



The Seabed Scour Systems frond mat (V3) as deployed in these trials – note the double layer of sandbags used to anchor the mat.

The mats are usually anchored to the seabed using a system of intrusive iron fastenings c.1m long called 'safe anchors', or by concrete base mats. Intrusive steel 'safe anchors' are clearly not suitable for use on a fragile wreck site. The concrete base mats may be suitable but could cause difficulties where there are large amounts of upstanding ferrous concretions – as is the case on Colossus. For these reasons we used a double layer of sandbags laid over the edges of the mats, as shown above. Approximately seventy sandbags were used to anchor this mat, containing a total weight of approximately 1750kg (1.75 tonne) of sand.

Deployment was slightly more involved than with either of the other two systems used in this trial. Full details of the deployment procedure are outlined in the manufacturer's installation instructions in appendix II. Installation was nontheless straightforward and was accomplished without any significant problems.

The manufacturer's installation instructions and data sheet are reproduced in appendices II and III respectively.

Further details and data sheets for the frond mat system can be seen at http://www.scourcontrol.co.uk

Monitoring of seabed levels

Sediment levels around the wreck

Seabed monitoring pins were installed at the beginning of the stabilisation trials, 13th May 2003. Eight pins were placed, mostly around the outside of the existing exposed timber of the wreck. The position of the pins was fixed using direct measurements to the existing survey control points; these were validated using Site Surveyor II software (fit to within 23mm). The points were labelled M1 – M8 and are shown on the location plan below. The monitoring points consisted of stainless steel reinforcing bar 10mm in diameter and 500mm long. The pins were driven into the seabed, such that exactly 100mm of the pin was left exposed.

The amount of monitoring pin exposed was measured at each data retrieval visit to the site. This was achieved by placing a 1m bar on the seabed adjacent to the pin and measuring the distance from the top of the pin to the bottom of the bar. This method of measurement avoided distorting the measurements by discounting any localised scouring around the pin itself.

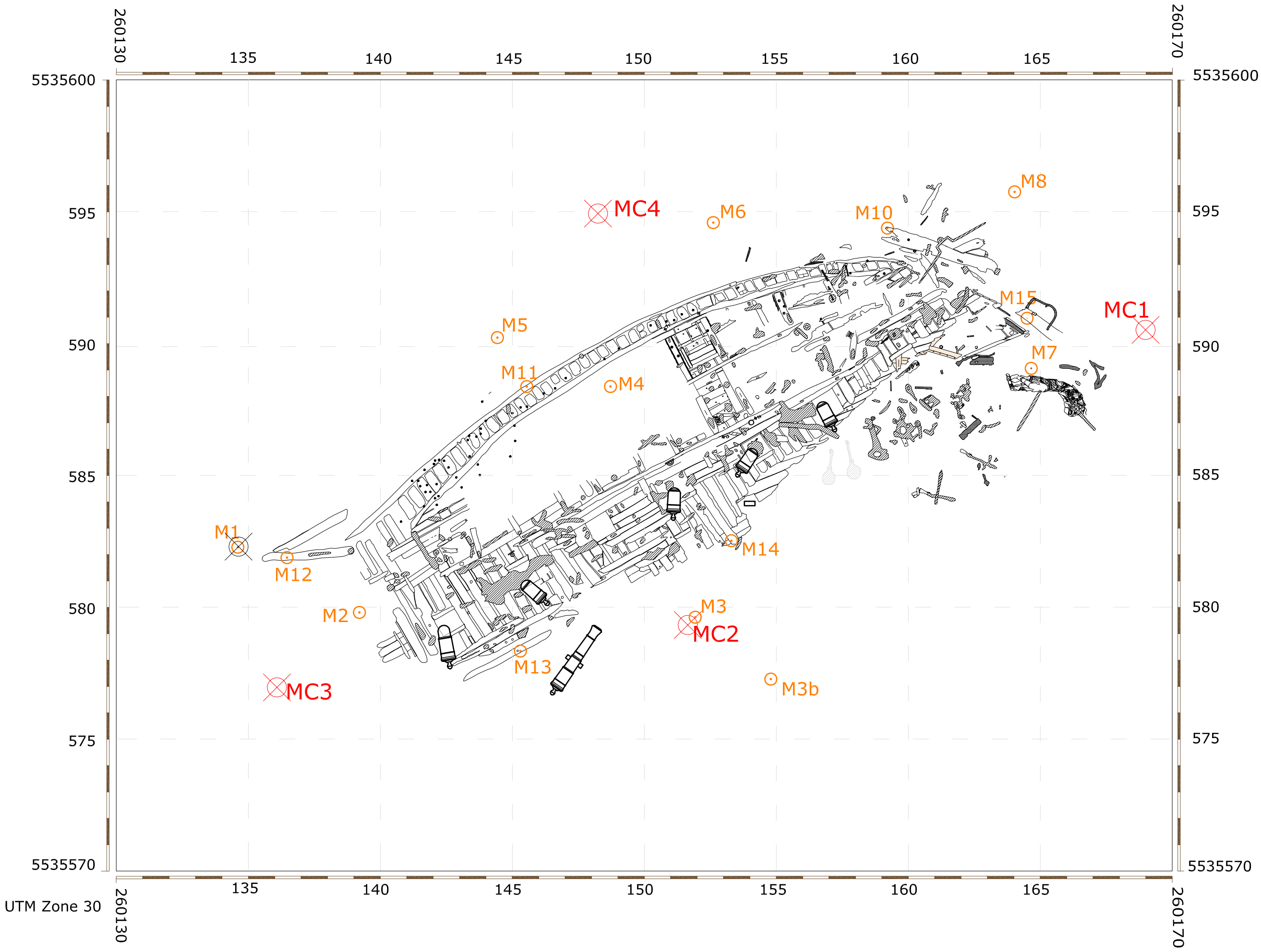


Fig 3 Plan showing the location of the sediment level monitoring pins

In October 2003 a further six monitoring points were established. These were placed adjacent to exposed timber on the wreck itself. The points themselves were galvanised 100mm nails driven into the timber – shown as M10 – M15 on the plan above. Measurements to the seabed were made at an offset distance of 0.50m from the top of the nails using a 1m spirit level; the direction of this offset is shown in the table below.

In August 2003 point M3 was moved 3.67m to the south-east to allow the optimum positioning of the new master control point MC2. The new point was designated M3b to distinguish it from the old point M3.

These additional monitoring points were established as it was noticed that although more of the timber of the wreck was being exposed, the initial sand monitors (around the outside of the wreck) were showing a small increase in sediment levels. It was thought that the sand levels in the immediate vicinity of the wreck were falling while further from the wreck they were rising. By adding the second set of monitor points close to the timber of the wreck it was hoped that this phenomenon could be recorded.

Monitor	**Position (UTM zone 30)**	**Type**	**Offset**
M1	260134.63 / 5535582.30	100mm stainless bar	0
M2	260139.21 / 5535577.81	100mm stainless bar	0
M3	260151.95 / 5535579.60	100mm stainless bar	0
M3b	260154.79 / 5535577.27	100mm stainless bar	0
M4	260148.74 / 5535588.34	100mm stainless bar	0
M5	260144.43 / 5535590.22	100mm stainless bar	0
M6	260152.61 / 5535594.58	100mm stainless bar	0
M7	260164.66 / 5535589.07	100mm stainless bar	0
M8	260164.05 / 5535595.79	100mm stainless bar	0
M10	260158.94 / 5535594.51	10mm nail	0.50m north
M11	260145.54 / 5535588.37	10mm nail	0.50m north
M12	260136.34 / 5535581.65	10mm nail	0.50m south
M13	260145.30 / 5535578.35	10mm nail	0.50m south
M14	260153.30 / 5535582.53	10mm nail	0.50m south
M15	260164.26 / 5535590.60	10mm nail	0.50m east

Fig 4 Table of seabed monitor point positions – note that point M3 was replaced by M3b in October 2003

Sediment levels on the stabilisation mats

The amount of sediment accumulated in the area of each control mat was recorded at each data retrieval visit. In the case of the Terram 4000 (V1) and the frond mat (V3), this was achieved by simply measuring the amount of sediment lying on the mat. This was done at four different points on the mat to determine whether the sediment accumulation was uniform. In the case of the mesh mat (V2), the sediment collected under the mesh so a different measuring strategy was required. The original seabed level was indicated by a number of stainless steel hoops driven into the seabed prior to installation of the mesh mat. The thickness of any sediment accumulation could be recorded by measuring the distance between the top of the stainless steel hoops and the seabed surface.

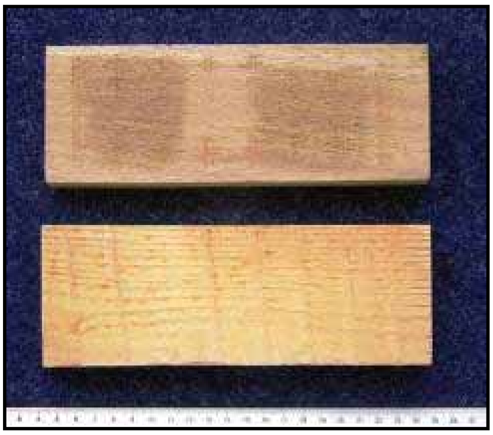
Sediment samples

In June 2004, eight samples of the seabed sediment were taken. These were submitted to Matthew Canti at English Heritage for analysis. The sediment sample report is reproduced in full in appendix IV. More information about the composition of the seabed in the vicinity of the wreck may help us to understand the sediment movements apparent in recent years.

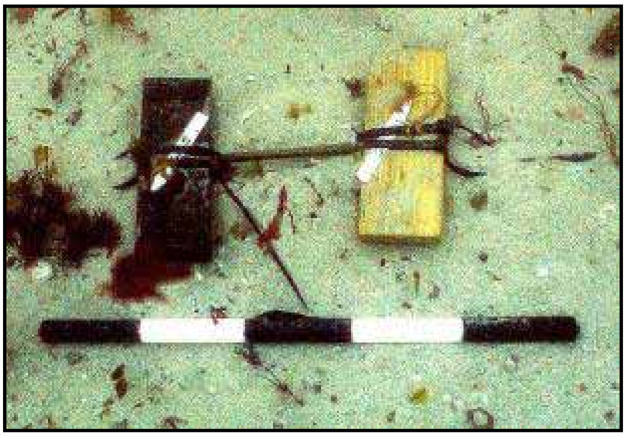
Timber sample blocks

The sample blocks

Oak and pine sample blocks (indicative of timbers used in the construction of historic ships) were used to identify attack by biological agents such as wood boring animals and microbes. Standard wooden blocks of oak and pine were installed under the three 'mats' in each of four separate locations so that they could be retrieved at intervals of 3, 6, 12 and 24 months for analysis. The blocks were each 0.20 x 0.075 x 0.025m. The supply and analysis of the blocks was undertaken by Dr Mark Jones of Mary Rose Archaeological Services. For a detailed methodology for the analysis of the timber blocks see Timber sample analysis – p38. The blocks were placed in pairs (one oak and one pine) towards each of the corners of the mats so that retrieval could be effected without disturbing the remaining blocks. Blocks were also placed on the seabed in the adjacent unprotected area V0, designated as the control area. The blocks were fastened to the seabed with cable ties which were attached to steel staples driven into the seabed.



Timber sample blocks before deployment: oak top, pine below.

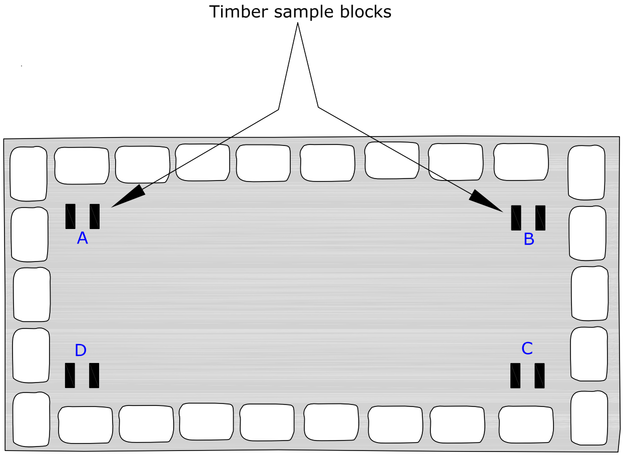


Timber sample blocks on the seabed in the control area V0: oak left, pine right.

The blocks were all weighed at standard moisture content prior to deployment so that total weight loss could be determined after deployment. When recovered, the blocks were kept moist with seawater. They were then placed into a chill box for immediate transport to MRAS for analysis.

Position of the sample blocks

Four pairs of timber sample blocks (one oak and one pine block) were placed under each of the trial mats. The blocks were positioned so that each pair could be retrieved without causing any disturbance to the other sample blocks. Each pair of blocks was identified by a unique number, so for example the NE block under the Terram mat (V1) was designated V1-B (see sketch below). The blocks in the control area (V0) were secured to the seabed so that each pair was at least 0.75m apart.



Position of the timber sample blocks under the trial mats.

Retrieval intervals

The blocks were designed to be recovered from each of the trial areas at intervals of 3, 6, 12 and 24 months. In practice these intervals had to be varied slightly to accord with suitable weather for diving operations. The actual date and duration of deployment is recorded in the table below.

BLOCKS	DATE IN	DATE OUT	DURATION (DAYS)
V0-A	13.V.2003	19.VIII.2003	98
V1-A	14.V.2003	19.VIII.2003	97
V2-A	14.V.2003	19.VIII.2003	97
V3-A	16.V.2003	19.VIII.2003	95
V0-B	13.V.2003	21.X.2003	161
V1-B	14.V.2003	21.X.2003	160
V2-B	14.V.2003	21.X.2003	160
V3-B	16.V.2003	21.X.2003	158
V0-C	13.V.2003	30.III.2004	322
V1-C	14.V.2003	30.III.2004	321
V2-C	14.V.2003	30.III.2004	321
V3-C	16.V.2003	30.III.2004	319
V0-D	13.V.2003	10.V.2005	727
V1-D	14.V.2003	10.V.2005	726
V2-D	14.V.2003	10.V.2005	726
V3-D	16.V.2003	10.V.2005	724

Proximity blocks

It was decided to establish whether proximity to the main area of exposed timber had any effect on the speed of infestation by organisms attacking the timber sample blocks. Three sets of timber blocks were installed on the seabed at varying distances from the exposed timber of the wreck. The blocks were fastened with cable-ties to stainless steel staples driven into the seabed. These samples enabled us to determine whether there was any difference in the rate of attack in relation to their proximity to the wreck.

SAMPLE	TYPE	POSITION UTM zone 30 WGS84	DATE IN	DATE OUT	DURATION (DAYS)	DISTANCE FROM WRECK
P23	Pine	260156.74 E	31.III.2004	10.V.2005	405	2.3m
O23	Oak	5535582.91 N				
P24	Pine	260156.74 E				14.4m
O24	Oak	5535568.33 N				
P25	Pine	260156.43 E				24.3m
O25	Oak	5535556.58 N				

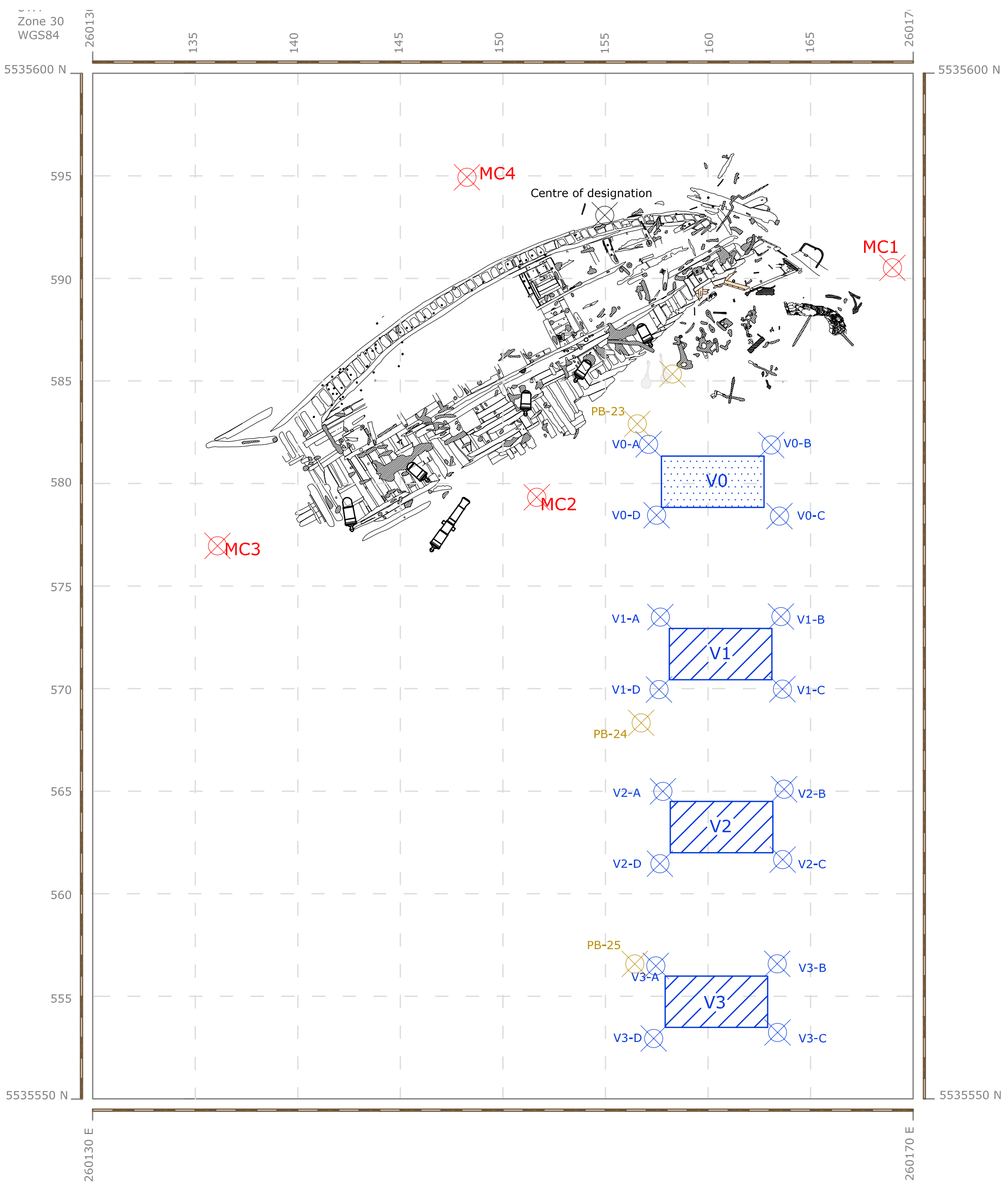
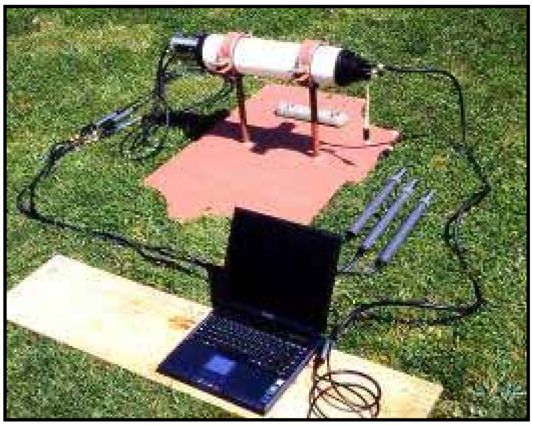


Fig 5 Location plan for proximity sample blocks PB23 – PB25

Data logging

It was decided to monitor the environmental conditions affecting the sample timber blocks placed under the trial mats. Monitoring took place for a three month period under each trial mat in turn. Ideally, this would have been done for all three mats at the same time but three separate instruments would have been required to monitor the three mats simultaneously and the cost of this would have been prohibitive.

The instrument used was a Waterwatch system 2685 subsea data logger custom made by EauxSys Ltd of Camelford. The logger was equipped with sub-seabed probes for redox (ORP), pH, dissolved oxygen, temperature and pressure (depth). A slightly different version of this instrument, the Waterwatch 2680, was used on the MoSS[11] project.



The waterwatch 2685 data logger

The system comprises a measuring and data logging system housed in a cylindrical waterproof housing. Dimensions of the instrument are 115mm diameter and 625mm long. The sensor connections are positioned on one end of the instrument. In this version the pH, redox and dissolved oxygen sensors are supplied on 5 metre long flying leads to allow positioning into the sediment around the site. The data logger has an internal battery pack with a capacity of 12 Amp hours, sufficient for up to 3 months deployment on the seabed. Data is stored on a separate battery-supported PCMCIA memory card.

In operation the data logger powers down to a low power standby mode to minimise battery demand. At the appointed time interval, the data logger switches on, takes a set of readings and stores them onto the memory card. The data logger then reverts to standby mode.

In order to retrieve data, the instrument is recovered from the seabed and connected to a computer running the PC software *TimeTag*. This software also allows the settings and calibration of the instrument to be adjusted.

Batteries are high-capacity metal nickel-hydride type, and the instrument is connected to a special battery charger in order to re-charge the cells. Charging takes 12-14 hours.

In order to safely secure the data logger to the seabed, a steel stand was constructed with a 15mm thick base plate – this resulted in the stand weighing over 60kg. The stand was fitted with a zinc marine sacrificial anode and

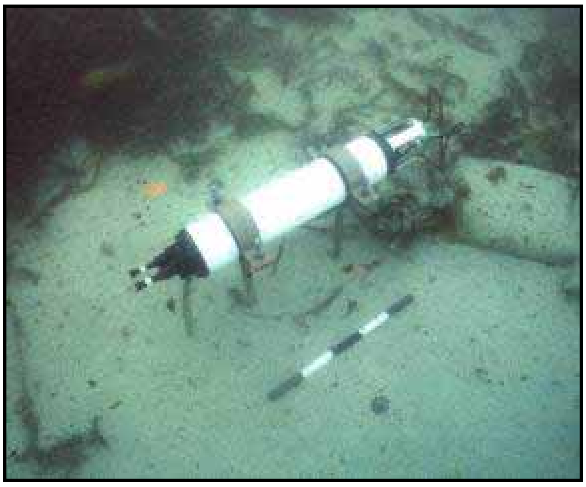
[11] *Monitoring, Safeguarding and Visualising North-European Shipwreck Sites*

painted with marine anti-foul paint. The base-plate of the stand was buried 0.10m into the seabed and further secured using two 1m long, 25mm diameter steel stakes. The data logger was insulated from the steel of the stand with 12mm thick neoprene strips.

The Waterwatch data loggers used on the MoSS project suffered from extensive fouling of the sensors which affected the measurements obtained.[12] To avoid this problem, the Colossus data logger was loosely wrapped in opaque black butyl sheeting (pond liner) on the seabed. This in practice all but eliminated floral and faunal fouling without having any apparent detrimental effects.

The temperature and depth sensors were located on the main body of the instrument, while the pH, redox and oxygen sensors were attached by 5m long flying leads which enabled these parameters to be measured beneath the respective trial mats.

Fitting the butyl cover to the data logger



The data logger on the seabed

TRIAL AREA	DATE IN	DATE OUT	DURATION (DAYS)
V1 Terram	29.III.2004	28.VI.2004	91.00
V2 Mesh	20.VIII.2003	20.X.2003	61.00
V3 Fronds	19.V.2003	18.VIII.2003	91.00

Fig 6 Table of data logger deployment dates and intervals.

[12] David Gregory, *Monitoring Wooden Shipwrecks* in *MoSS Final Report*

Before each deployment, the instrument was calibrated. For the first and final deployments (V3 and V1) the instrument was calibrated by the manufacturer. For the second deployment (V2) the instrument was calibrated by me in Scilly using the calibration standard solutions and calibration manual supplied by the manufacturer.

From the deployment table above it will be seen that the instrument was removed from the seabed for the winter of 2003/2004. This was to avoid the possibility of storm damage to the instrument and the possible difficulties of recovery during the winter months. During this period the instrument was serviced by EauxSys and several internal components were replaced.

The data logger is now the property of English Heritage and I believe that it is currently in use monitoring the wreck of the Mary Rose in Portsmouth.

Results

The stabilisation mats

The three trial mats V1 – V3 were in place on the seabed for two years. At the end of the trial the three mats were removed from the seabed. The 120 sandbags which were used to anchor the mats to the seabed were stacked and left on the seabed to the south of the exposed wreckage so that they can be used in any stabilisation which is undertaken on the wreck[13]. The deployment and removal dates for each of the trial mats are given in the table below.

	Installed	Removed	Duration (days)
V1 Terram	14.V.2003	10.V.2005	726
V2 mesh	14.V.2003	10.V.2005	726
V3 fronds	16.V.2003	11.V.2005	725

Fig 7 Table of deployment and removal dates for the trial mats

Sediment levels

The level of sediment at each trial zone was measured at every inspection visit to the site. At the control area (V0) and the mesh mat (V2) the sediment was measured relative to the top of the stainless steel staples used to secure the timber test blocks. The cross-bar of these staples was set to seabed level on installation; hence the surrounding levels were determined relative to this. In the case of the Terram mat (V1) and the frond mat (V3) the depth of sediment overlying the geotextile mat was measured directly. In each trial area four measurements were taken, one at each of the timber sample block locations. The table below lists the sediment levels over time for each of the trial areas.

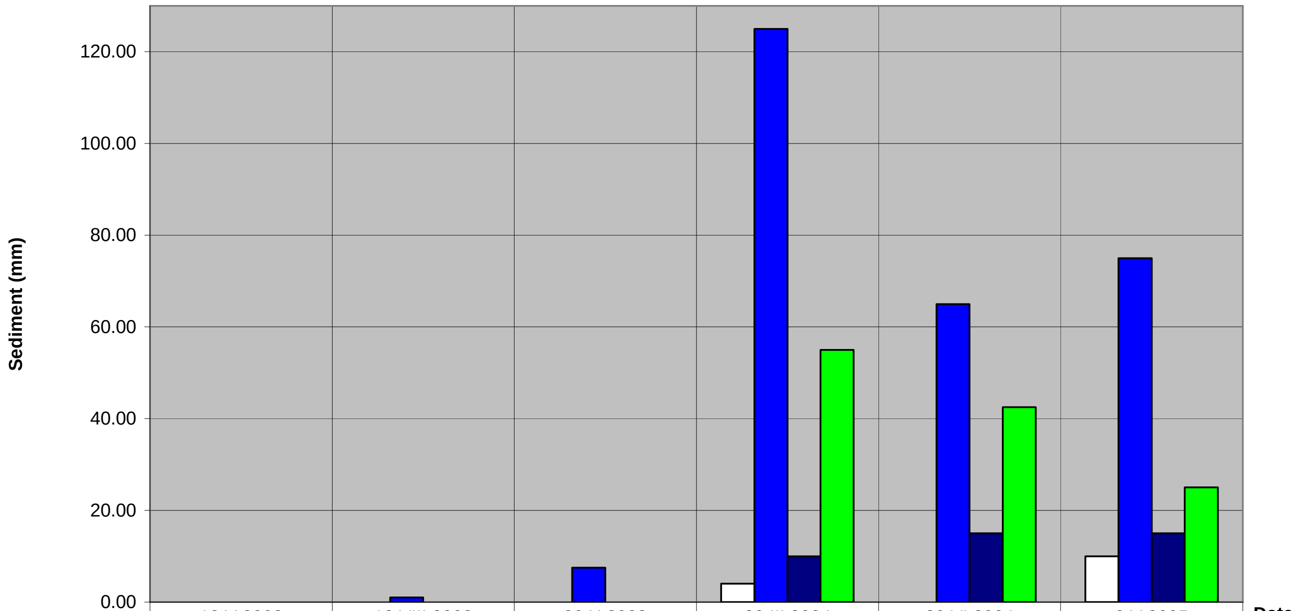
Date	12.V.2003	18.VIII.2003	20.X.2003	29.III.2004	29.VI.2004	9.V.2005
Mats						
V0 Control	0	0	0	3 - 5	0	20
V1 Terram	0	1	5 - 10	100 - 150	60 - 70	50 - 100
V2 Mesh	0	0	0	10	10 - 20	10 - 20
V3 Fronds	0	0	0	50 - 60	0 - 85	0 - 50

Fig 8 Table showing the sediment levels in millimetres for the test areas V0 – V3

The chart of the mean sediment levels (fig 9 below) clearly demonstrates the trend of the sediment levels in the test areas. In each case the stabilisation trial mats (V1 – V3) performed better than the control area (V0) in terms of sediment levels. It should be noted that in no case was the level of sediment over the mat consistent; variation was apparent between the four different measurements. In practice this was usually a relatively small variation, but in the case of the frond mats (V3) often as much as half the mat was completely exposed (zero sediment level over part of the mat).

[13] This was discussed in advance with Ian Oxley of English Heritage.

Although the sediment levels vary, at any given inspection the relative performance of the different trial methods was the same. The Terram 4000 consistently outperformed all other methods, followed by the frond mat (V3), then the mesh mat (V2) and finally the control area V0.



	12.V.2003	18.VIII.2003	20.X.2003	29.III.2004	29.VI.2004	9.V.2005
V0 Control	0.00	0.00	0.00	4.00	0.00	10.00
V1 Terram	0.00	1.00	7.50	125.00	65.00	75.00
V2 Mesh	0.00	0.00	0.00	10.00	15.00	15.00
V3 Fronds	0.00	0.00	0.00	55.00	42.50	25.00

Fig 9 Chart showing the sediment levels in the test areas (mean of the four measurements taken)

Terram 4000 (V1)

The Terram remained in place without maintenance throughout the trial. There was no visible deterioration to the mat after two years on the seabed even when the sand covering was removed from the mat at the end of the trial. The Terram was easy to install and to remove from the seabed at the end of the trial.

The surface of the Terram was colonised by fine weed during the first three months of deployment. The weed was firmly attached to the surface of the Terram and remained in place throughout the two years of the trial (see photograph). This weed may well be one of the reasons that the Terram performed so well in terms of entrapping sediment.

The cost of Terram 4000 at the time of writing (June 2005) is £330 delivered for a 4.5 x 50m roll. This works out at approximately £1.50p per square metre. The suppliers are able to offer lower prices for larger quantities. The cost of the 30 sandbags used to anchor the mat was £105 ‘on the seabed’. This cost would be considerably reduced on the mainland as the 3 tonnes of sand used to fill the bags had to be transported to Scilly from Penzance at considerable expense.

Synthetic mesh (V2)

The mesh became torn during the first three months of deployment. As recommended by Martijn Manders a new sheet of mesh was installed over the top, leaving the torn mesh in place. The replacement mesh was of a slightly heavier duty and remained intact during the remainder of the trial. The mesh became colonised by fine weed during the first three months and large kelp fronds gradually became established on the mesh as the trial progressed. The presence of the kelp fronds may account for the relatively poor performance of the mesh in this trial as the kelp seemed to weigh down the mesh and prevent it from floating above the seabed.

The mesh was simple to install but required attention at every site visit. Apart from the extra mesh installed in August 2003 the mesh tended to become tangled due to the attached kelp fronds and had to be untangled to some extent at each visit.

The mesh originally used was a greenhouse shading mesh; the replacement which was somewhat more robust was sold as scaffolding debris netting. Most of these mesh products cost in the region of £2.50p per square metre. In addition, the sandbags used to anchor the mesh cost £49.

Floating frond system (V3)

Installation of this mat was straightforward if somewhat more involved than either of the other mats – appendix II shows the manufacturer’s installation instructions. The mat stayed in place without any maintenance throughout the two years of the trial. The synthetic floating fronds became increasingly colonised by weed and kelp as the trial progressed. The photograph below shows the extent of this colonisation by the end of the trial when the mat was removed from the seabed. It was also noticed that the artificial fronds became tangled after about 12 months and appeared to be unravelling (forming finer strands as the frond unravelled from the free end downwards).

The amount of sediment trapped by the frond mat was disappointing. From the sales literature it seemed that the frond mat would collect in the region of a meter of sediment – the actual results are shown in fig 9 above. One interesting phenomena was that numerous small rocks (0.05 – 0.10 m diameter) were trapped by this mat. Many of these rocks had kelp fronds attached and it seems probable that most of the rocks were transported in the tidal current as scaffs[14].

When sediment was collected by the frond mat it was often very variable in depth – far more so than with either of the other two methods on trial. During the last year of the trial the eastern half of the frond mat had no sediment on it at all.

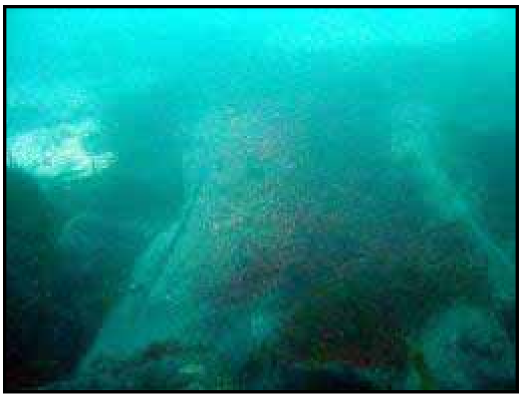
This mat was very kindly donated for the trials by Seabed Scour Control Systems Ltd. The approximate normal cost of one of these 5m x 2.5m mats would be £500, or about £40 per square metre. The cost of the 70 sandbags used to anchor the frond mat was £245.

Top left *Terram mat V1*

Top right *Frond mat on the surface after recovery*

Left *Frond mat V3*

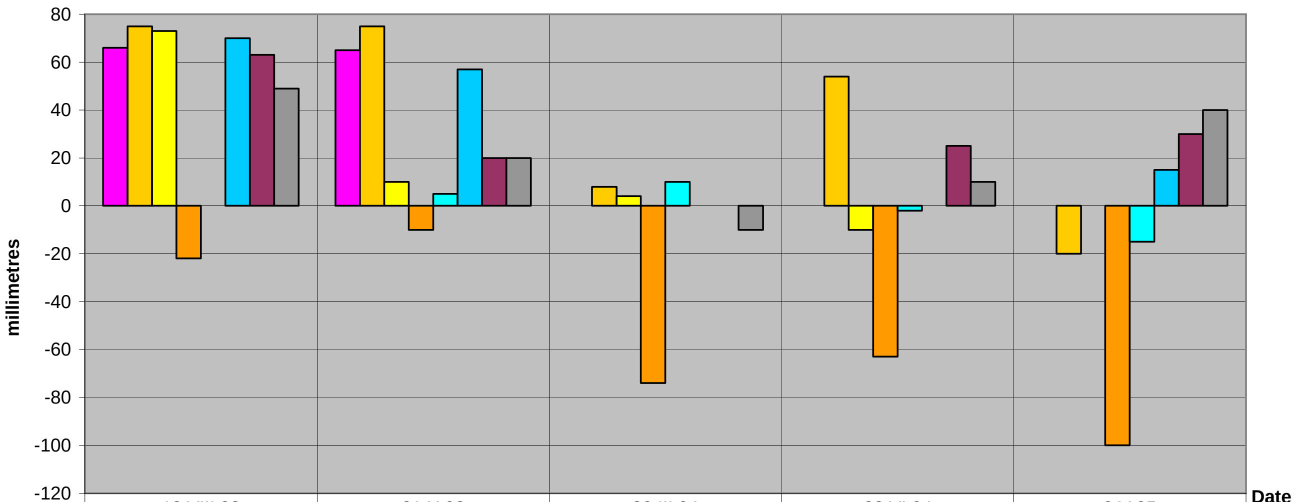
Below *Mesh mat V2*



[14] Scaffs – a local term to describe small stones with kelp fronds attached, often mobile in the tide.

Sediment level monitoring

The chart and table below show the seabed levels recorded at each of the original monitoring points M1 – M8. These points were installed in May 2003, and all measurements are relative to the seabed level at that time. Positive measurements denote a rise in seabed level while negative measurements indicate a fall in seabed level. Where no reading is shown, the monitor point was not located at that inspection. This could be caused by displacement of the pin (in one observed case visiting divers pulled the pin out), or by inability to locate the pin (displaced weed can cover the site to a considerable depth at certain times of the year). The readings were taken at the dates shown, at each of the five monitoring inspections over the two year period of the trial. Ideally, the measurements would have been taken at more frequent, regular intervals. In the event it was only possible to take measurements at the regular, scheduled retrieval intervals for the stabilisation trial sample retrievals. It would have been interesting to see how the sediment levels varied in the winter months.



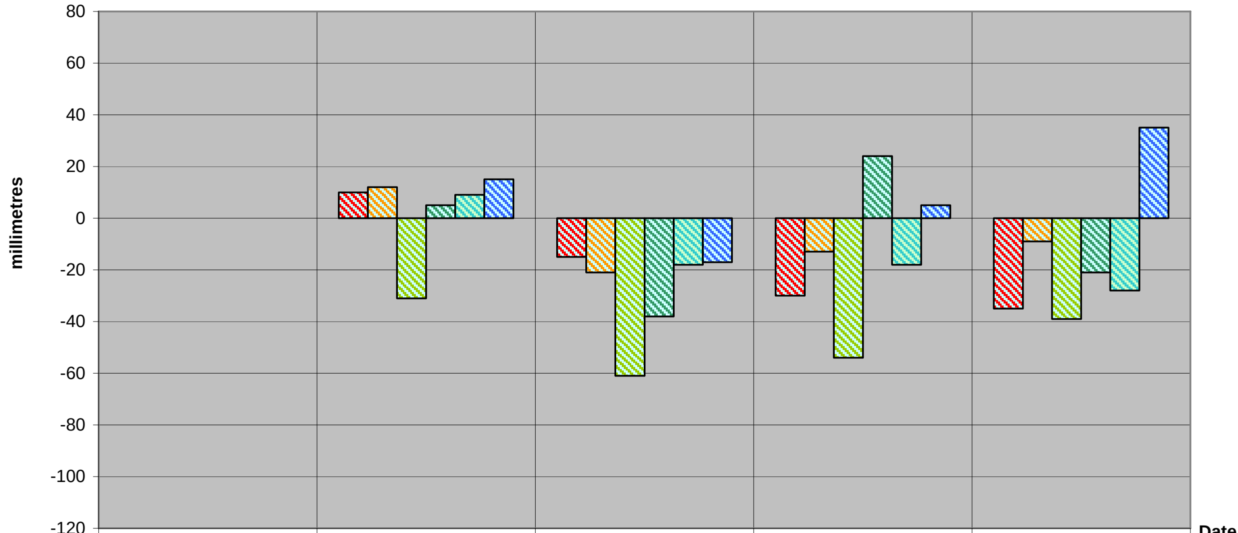
	18.VIII.03	21.X.03	30.III.04	28.VI.04	9.V.05
M1	66	65			0
M2	75	75	8	54	-20
M3	73	10	4	-10	0
M4	-22	-10	-74	-63	-100
M5		5	10	-2	-15
M6	70	57			15
M7	63	20		25	30
M8	49	20	-10	10	40

Fig 10 Seabed levels relative to those in May 2003 at monitor points M1 – M8

All except one of these monitoring points were situated around the outside of the exposed timber of the wreck. The exception was M4 which was placed in the centre of the wreckage (see sediment monitor location plan fig 3). The seabed level at M4 fell fairly consistently throughout the period of the trial.

The other seven points (M1-M3 and M5-M8) all recorded rises in sediment over the first three months of the trial of 49 – 75mm. This accumulation of sediment largely disappeared over the winter (between October 2003 and March 2003); at the March 2004 inspection the levels were roughly comparable with those at installation. The June 2004 inspection revealed a more mixed picture with three of the points (M3, M4 and M5) showing a fall in levels while the other three points (M2, M7 and M8) showed a rise in seabed levels. At the final inspection in May 2005 two points (M1 and M3) were the same level as in May 2003. Three points (M2, M4 and M5) showed decreased seabed levels and three points (M6, M7 and M8) showed a rise in sediment levels. Interestingly, all three of the locations showing a rise in level at this final inspection are all on the eastern side of the wreck. The evidence is not conclusive but it would seem that there is a tendency for sediment to accumulate throughout the summer months and to fall during the winter months. If this is a genuine and ongoing trend then its cause may well be the higher energy conditions generated by winter storms.

After the two years of the trial the mean of the seabed level measurements taken at these eight points (M1- M8) was -6.25mm. This is a relatively small change but can have a major impact on exposing timber which is only just below the surface of the seabed. So although the levels vary, currently the overall trend is one of sediment loss at these original monitor points.



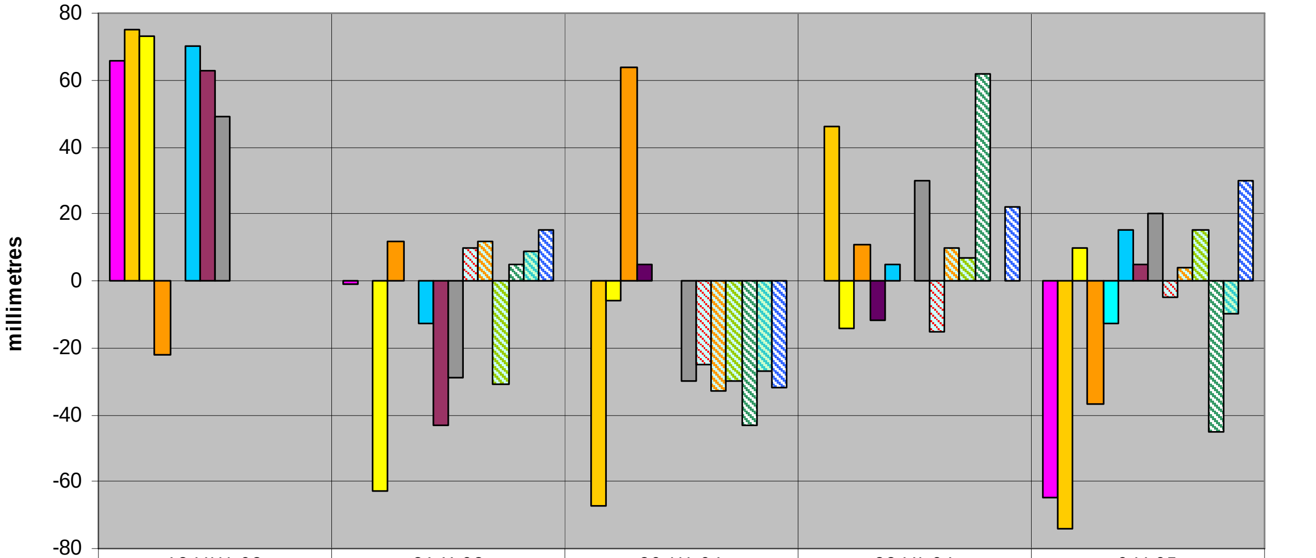
	18.VIII.03	21.X.03	30.III.04	28.VI.04	9.V.05
M10		10	-15	-30	-35
M11		12	-21	-13	-9
M12		-31	-61	-54	-39
M13		5	-38	24	-21
M14		9	-18	-18	-28
M15		15	-17	5	35

Fig 11 Seabed levels relative to those in August 2003 at monitor points M10 –M15

In August 2003 six extra sand monitoring points (M10 – M15) were installed. These were all placed adjacent to the exposed timber on the seabed in an effort to monitor the conditions immediately adjacent to the timber, where continuing seabed level decline had been observed.

After three months (October 2003) all except one of these points showed a small rise in sediment level. The exception, M12, showed a fall of 31mm. At the next inspection in March 2004, sediment levels at all six points had fallen (relative to the levels at installation in August 2003). For the remainder of the trial, the majority of these points showed a fall in the sediment levels since August 2003. This trend is visually more convincing on the sediment level charts (fig 11) for this set of points when compared to those for the original points M1 – M8. After the two years of the trial the mean of the seabed level measurements taken at these six points (M10 - M15) was -16.2mm. So although there is some variation in levels there is a strong overall trend of sediment loss at these six monitor points.

Care should however be taken when comparing these two sets of monitoring points as they were installed at different dates. This means that they are measured relative to different seabed levels: M1 – M8 to that existing in May 2003, while M10 – M15 were recorded relative to the seabed level existing when they were installed in August 2003.



	18.VIII.03	21.X.03	30.III.04	28.VI.04	9.V.05
M1	66	-1			-65
M2	75	0	-67	46	-74
M3	73	-63	-6	-14	10
M4	-22	12	64	11	-37
M5			5	-12	-13
M6	70	-13		5	15
M7	63	-43			5
M8	49	-29	-30	30	20
M10		10	-25	-15	-5
M11		12	-33	10	4
M12		-31	-30	7	15
M13		5	-43	62	-45
M14		9	-27	0	-10
M15		15	-32	22	30

Fig 12 Seabed level changes between inspections recorded at monitor points M1 –M15

In order to compare the two sets of sediment measurements more directly, a chart of the sediment level change since last inspection has been constructed (fig 12). This shows the change in seabed level since the last inspection rather than the change since installation. This allows a direct comparison of all the sediment monitoring points.

From the chart above it is apparent that there is no overall clear cut rise and fall of the seabed levels over the whole site. Considering all fourteen monitor points together, there was not any inspection where all the observations were sediment rises or falls – but always a mixture of the two. What this does illustrate is that there is measurable sediment mobility over the site. The tendency to sediment level falls at the edges of the exposed timber (monitor points M10 – M15) perhaps demonstrates scouring at the edges of the exposed timber.

Sediment samples

Five samples, SS1 – SS5, were taken from the surface of the seabed; from the locations shown on the plan below. These were taken from the top 60mm of the seabed – approximately 500ml of sediment was taken in each sample. The seabed in each sample location was photographed. The location of each of these samples is shown on the location plan below. The samples were submitted to Matthew Canti at English Heritage for analysis. The sediment sample report is reproduced in full in appendix IV.

Two samples were taken from below the surface of the seabed, SS7 and SS8. The stratigraphy on the site has been observed in three different places: to the SE when the stern carving was excavated, the NE where the finds were reburied [AB] and in the centre of the site where the exploratory excavation took place. In each case the observed stratigraphic sequence was similar. The top 0.20-0.25m of the seabed [SS6] consists of coarse sand and broken shell. Below this is a layer 0.15-0.35m deep consisting of very fine, white compact sand or silt [SS7]. Under this there is a layer of coarser, light grey sand [SS8]. Each of these was sampled during the excavation of the finds reburial repository [AB].

Reference to the sediment sample report in appendix IV indicates that the two samples not taken from the seabed surface (SS7 and SS8) clearly show a different composition to those taken from the seabed surface (SS1 – SS6). The surface samples seem to consist of medium sand, while the sub-surface samples SS7 and SS8 both exhibit a significant proportion (42% and 29% silt) of finer material when compared to the surface samples. One possible interpretation is that this is due to the seabed surface mobility already demonstrated by the sediment monitoring, the finer material having been dispersed during sediment transport in the surface layer. If this is the case, it would seem to indicate that - in the areas where stratigraphy has been observed - the top 0.20m of the seabed has been subject to sediment transport. It is tempting to speculate that the presence of this finer material in the buried samples may have some bearing on the remarkable preservation of organic material from this site[15].

[15] Smaller particles in the sediment resulting in smaller void spaces and thus reduced porosity and lower permeability.

Sediment transport

Sediment is likely to be subject to movement in a number of ways. It can be transported in suspension or by bottom traction. Particles in suspension settle at different rates depending on their size and density. For example very fine sand settles at a rate of 3.8mm/sec while silt at a rate of about 0.5mm/sec. Clearly, finer particles will travel further in a tidal stream than coarser particles[16].

From observations of the exposed timbers of Colossus it is also apparent that crabs are digging holes around the timbers and are probably contributing to local scouring around them. This phenomenon has been observed on a number of occasions during the stabilisation trials. Some of the observed holes dug by crabs are of an impressive size.

Edible crab digging a hole between frame timbers east of Gun 1.

When the Terram 4000 mat was being removed from the seabed a copper alloy musket trigger guard [406] was found in the sediment over the mat. This object had been drawn, measured and tagged on the seabed in August 2003. Its original location was over 17m away from where it was found on the Terram mat. This is a relatively heavy object and the distance it has been transported is perhaps illustrative of the forces at work on this site.

In 2001 nine ‘soundings’ or bore holes were sunk into the sand around the outside of the wreck. This was done to establish the depth of the sand around the area of the newly exposed timber. The soundings were affected by pumping water through a 3m length of 22mm plastic tube. This could then be pushed with ease vertically down through the sand. Once the tube stopped, the depth and position was recorded. These soundings are shown in red on the plan below, along with their recorded depth. What these soundings demonstrate is an appreciable depth of ‘soft’ sediment underlying the exposed timber of the wreck. As the limited excavation on the site to date has not extended outside the hull of the vessel, it is not at all clear to what depth archaeological material extends within this sediment.

[16] C Dunbar & J Rodgers *Principles of Startigraphy* London 1957

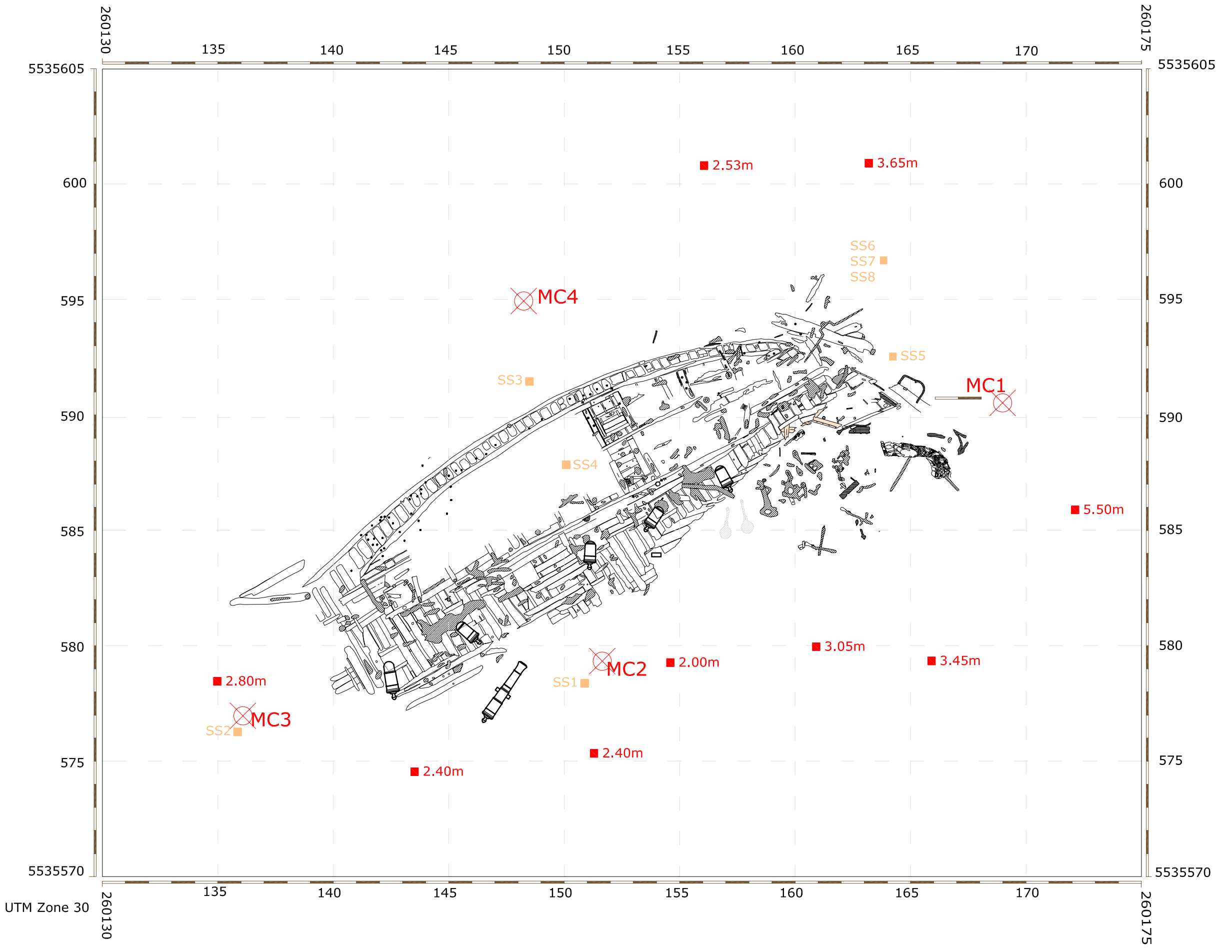


Fig 13 Location plan of sediment samples and soundings. SS1-SS8 are the sediment samples The soundings are shown in red and show the depth to which the probe reached.

Timber sample analysis – Mark Jones

Deterioration of a wreck site will continue if steps are not taken to alleviate or, at least reduce, the major degradation forces acting on this site. Therefore, devising a conservation *in-situ* management plan to significantly reduce the deterioration of this historic shipwreck site is of paramount importance.

Due to the relatively high profile of the wreck site of HMS Colossus and the sediment transport processes occurring on-site mobilizing sediment away from the area, the proposed remediation strategy needs to maintain sediment coverage of at least 50 cm above over the entire site to ensure that the degradation of the wooden wreck material are significantly reduced. Alternatively, *in-situ* protection involving geo-textiles need only maintain sediment coverage of 5-10cm above the textile to ensure no attack by wood boring animals.

Marine wood-boring animals

Wood-boring molluscs and crustaceans are the most destructive agents of timber submerged in seawater. Indeed the marine environment is recognised as the most hazardous situation for exposed timber. The rate at which these organisms attack is dependent primarily on water temperature and the natural durability of the wood species, notably the heartwood which has greater natural resistance than sapwood.

The wood-boring molluscs comprise the teredinids or shipworms (family Teredinidae), and the pholads or piddocks (family Pholadidae). Both groups are bivalves and burrow into wood through the rasping action of the two valves or shells at the anterior end of the animal. Although the teredinid family is the larger of the two groups and is distributed world-wide, the occurrence of individual species can be restricted within a range of water temperatures. In contrast, the pholads are found mainly in the warmer waters of the tropics and sub-tropics although some members do occur in cold water situations, either at depth or in higher latitudes. Most of the wood-boring crustaceans are members of the Isopoda - the family Limnoriidae or gribble and the family Sphaeormatidae or pill-bugs. A third group, the family Cheluridae are members of the Amphipoda. The wood-boring crustaceans have segmented bodies and are able to move over the surface of wood unlike the molluscs which remain in their burrows for life. Gribble attack of wood is superficial and the animals excavate a network of narrow galleries on the wood surface to produce an hour-glass shape in the inter-tidal portion of vertical structural timbers. The chelurids excavate wider galleries, often enlarging those formed by limnoriids, and are known to ingest the faecal pellets of limnoriids. The sphaeromatids are larger in size than the limnoriids or chelurids and usually burrow into wood by tunnelling across the grain sometimes producing a honeycomb of tunnels in softened timber. Species of limnoriid, and to a great extent the chelurids, have a world-wide distribution from cold temperate to tropical zones, whereas the sphaeromatids occur in tropical, especially brackish waters. In short, the main hazard to archaeological timbers in cooler temperate waters exists from shipworm, gribble and chelurids, whilst in warm-termperate - tropical zones, pholads and sphaeromatids pose an aggresive additional threat. Only a marked reduction in the salinity of major bodies of water, such as the northern part of the Baltic Sea, offers any natural defence against wood-boring animals in non-polar regions.

This report deals with damage to oak and pine timber samples caused by the activities of wood-boring animals exposed near the wreck site of HMS Colossus and assesses the efficacy of 3 physical barrier systems tested at this site.

In-situ methods under investigation

VO – Control – no protection
V1 – Terram 4000
V2 – Raised netting
V3 – Floating Fronds

Methodology

Exposure of wood test blocks

Oak and pine (indicative of timbers used in the construction of historic ships) samples placed at each test site were used to identify attack by biological agents such as wood boring animals and microbes. Timber samples were exposed for periods of 3,5,12 and 24. On retrieval from the marine environment, the samples were wrapped in a damp cloth soaked in seawater, sealed plastic containers and placed in a cold container and shipped to MRAS immediately for examination and analysis.

All exposed samples were examined for the following features:

(i) Bacterial Activity and fungal activity
(ii) Wood-borer attack (physical damage)
(iii) Weight loss
(iii) Contaminants
(iv) Chemical deterioration

Bacterial and fungal activity

Scanning electron microscopy was used to identify both bacterial and fungal activity in exposed wood test samples. Sections of exposed wood, 0.5 to 1 mm thick, were fixed using 4% glutaraldehyde in 0.1 M phosphate buffer at 4 hours. Following a buffer wash, samples were post-fixed using 1% osmium tetroxide in 0.1 M phosphate buffer overnight. Dehydration was then carried out in a graded ethanol series, 15 minutes in each of 10% steps. Absolute ethanol was gradually substituted with acetone, and then critically dried in a Polaron E3000 apparatus using liquefied carbon dioxide. Dried material was then examined under a scanning electron microscope.

Wood-borer attack and physical damage

The degree of attack on wood blocks by crustaceans and molluscs was assessed by visual examination and x-radiography. The extent of surface destruction was evaluated as a function of the number of galleries and their distribution (Fig 14). The five point rating scheme of ASTM D 2481 was adopted.

Rating	Classification	Condition and appearance of test sample
0	No attack	No sign of attack
1	Slight attack	Single or a few scattered tunnels covering not more than 15% of the area of the specimen as it appears on the X-ray film.
2	Moderate attack	Tunnels covering not more than about 25% of the area of the specimen as it appears on the X-ray film.
3	Severe attack	Tunnels covering between 25% and 50% of the area of the specimen as it appears on the X-ray film.
4	Failure	Tunnels covering more than 50% of the area of the specimen as it appears on the X-ray film.

Fig 14 Rating system for attack by Teredinids and other wood boring animals (BS 1992)

Identification of marine wood borers

Wood-boring organisms were removed from the timber samples and fixed in 4% glutaraldehyde in phosphate buffer. Identification of the organisms was based on the keys of Turner (1966,1971) and Kuhne (1971).

Weight Loss

Weight loss experiments will be carried out on exposed samples to determine the rate of biological degradation at each wreck site.

Contaminants

Salt and mineral infiltration of test wood sample timbers was analysed using x-ray microprobe analysis and XANES. Certain major and minor constituents of seawater are involved in the process of wood degradation in seawater. Their presence or absence will help identified future preservation strategies.

Chemical Deterioration

Wood is composed of complex mixtures of polysaccharides (sugars) and lignin (cross linked phenolic polymers. Exposure to the marine environment and to wood degrading organisms will result in changes to the chemistry of archaeological wood. Exposed wood samples were analysed using FTIR spectrometry.

Results

Bacterial and fungal activity

***Scanning electron microscopy*.** This technique was used exclusively to illustrate bacterial and fungal activity in both oak and pine samples.

Microbial degradation at the Wreck site

Similar patterns of degradation were observed for both oak and pine control samples exposed at the wreck site for periods of 3 to 24 months. Differences did occur, however, and three distinct features were recognised.

- Erosion bacteria were the dominant decay micro-organism for oak and pine samples (control test samples, unprotected). These bacteria caused substantial superficial degradation during early stages of exposure, especially in pine
- No evidence of bacterial or fungal decay in oak samples protected by a physical barrier system (Terram 4000, mesh system and frond mat).
- Only pine samples protected by Terram 4000 prevented microbial decay.

Oak: Bacterial activity

Bacterial activity was found on oak wood samples exposed at the wreck site of HMS Colossus. Colonisation by bacteria was evident after 3 months exposure and these organisms were associated with pit membrane degradation of unprotected oak samples. After 24 months exposure (fig 15), severe degradation of the outer surface by bacterial activity had occurred. By this period, decay was most advanced as most of the bacterial activity had resulted in severe attack of the secondary wall layers.

The activity of bacteria on oak samples physically protected by the 3 barrier systems was extremely low (figs 17-19). Although bacteria were occasionally found in the vessels of oak samples exposed for periods of 3 to 24 months, no decay patterns were observed indicating wood samples had become exposed very quickly to an anaerobic environment, preventing the activity of erosion bacterial and marine soft rot activity.

Oak: Fungal activity

Fungal activity of both unprotected and protected oak samples was extremely low process until 5 months exposure period. Although hyphae were found in vessels protected by tyloses, no fungal decay was observed even after a 24 month exposure period.

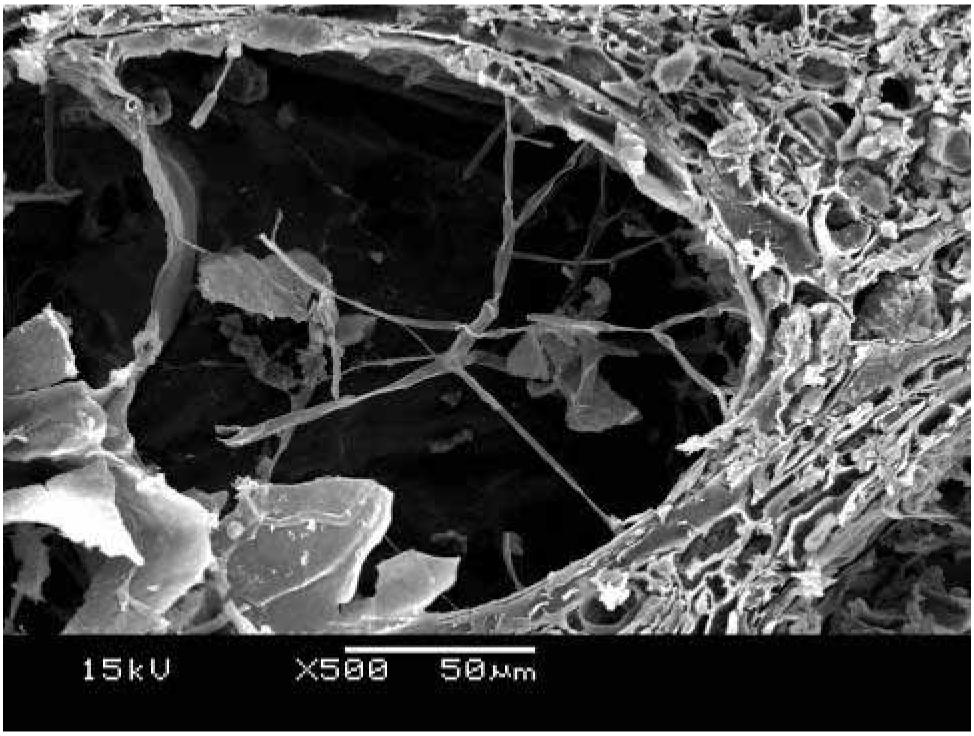


Fig 15 Scanning electron micrograph of oak sample (control) exposed for a period of 24 months. Bacterial erosion of secondary wall layers very advanced. Fungal hyphae present in vessel.

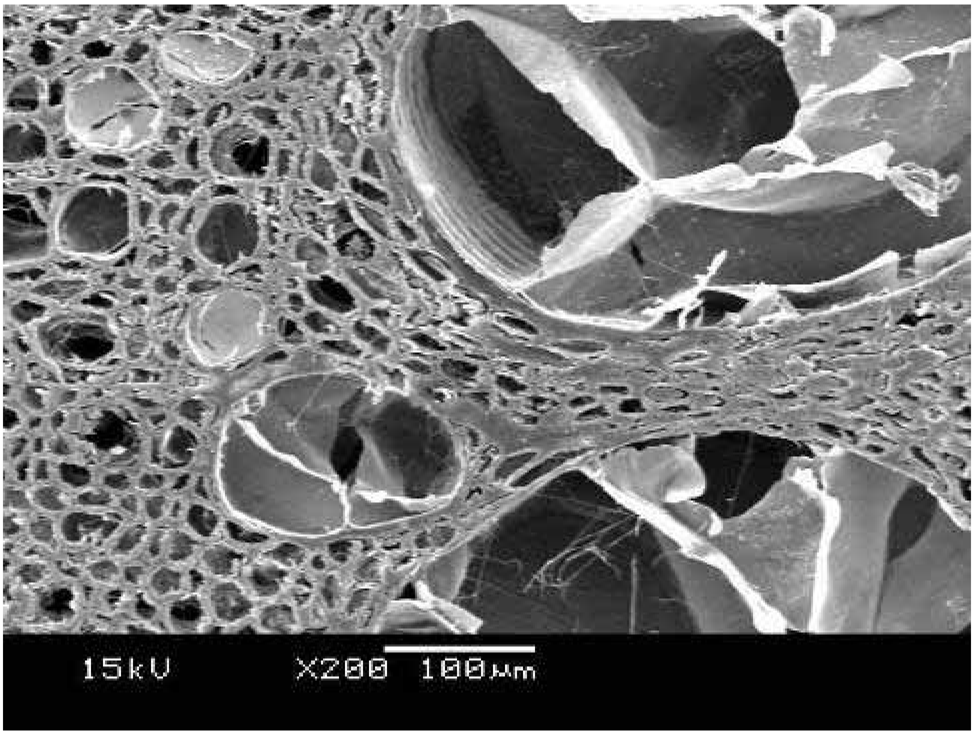


Fig 16 Scanning electron micrograph of oak sample protected by Terram 4000. No evidence of bacterial and fungal decay (24 month exposure).

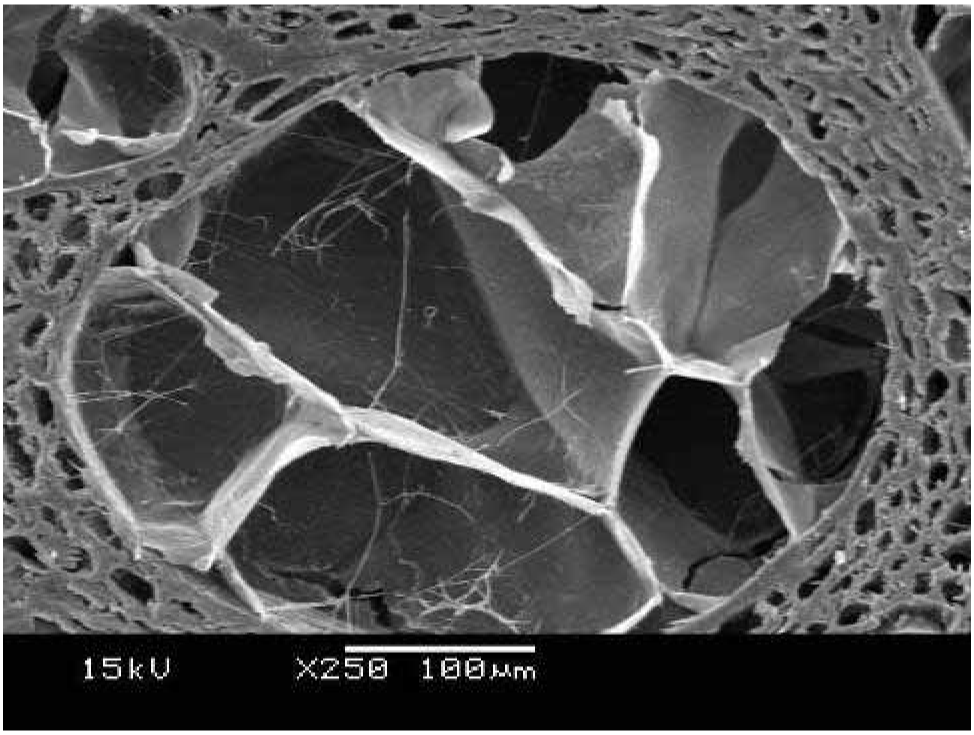


Fig 17 Scanning electron micrograph of oak sample protected by a mesh system. Cellular structure well preserved, no evidence of bacterial or fungal decay (24 months exposure)

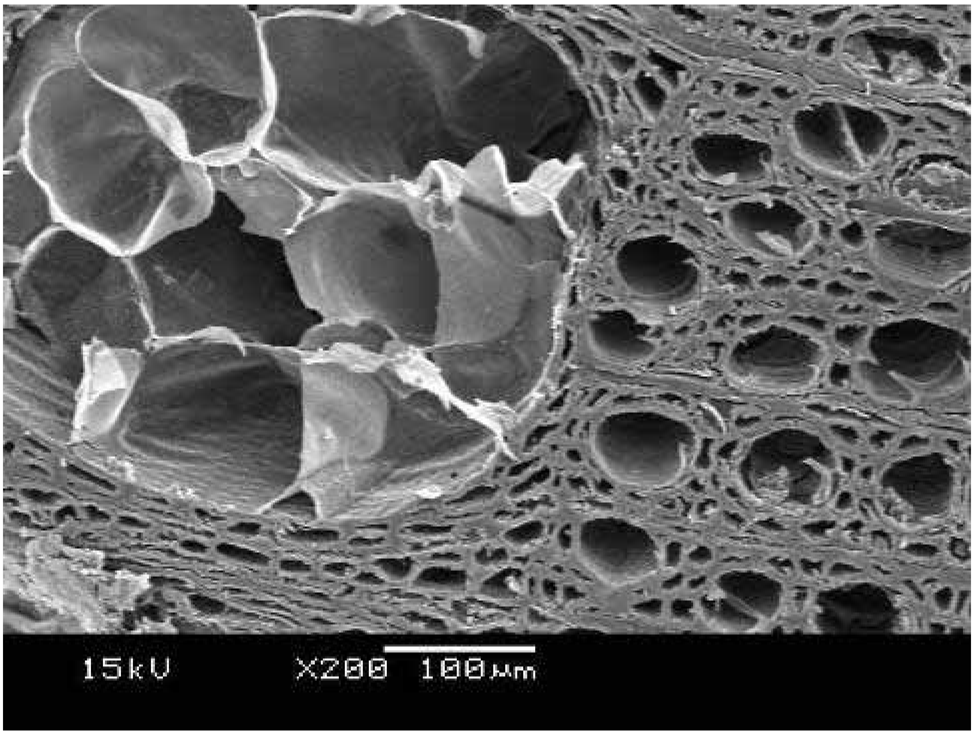


Fig 18 Scanning electron micrograph of oak sample protected by a frond mat (24 months exposure). No evidence of bacterial or fungal decay.

Pine: Bacteria

Colonisation by erosion bacteria was evident after a 3 month exposure period of control samples (unprotected). By 12 months the bacteria had penetrated 3mm into the pine sample. The decay pattern (fig 19) shows extensive damage to the cellular structure. By 24 months, the S_2 layer of the secondary wall has been severely degraded in the outer 5-6mm layers. The best preserved cell wall layer is the middle lamella.

Of the physical barriers used to protect pine sample at the Colossus wreck site, Terram 4000 (figure 6) prevented bacterial and fungal decay. Although bacteria had colonised the samples in low numbers there was no evidence of erosion degradation patterns of the secondary cell wall layers. However, pine samples protected by a mesh netting and a frond matt showed initial signs of bacterial decay in the outer surface layers (figs 21 - 22). This suggests that pine samples protected by Terram 4000 became anaerobic very quickly preventing aerobic decay by bacteria.

Pine: Fungi

Fungi were not the dominant primary coloniser or degrader of pine samples at the Colossus wreck site.

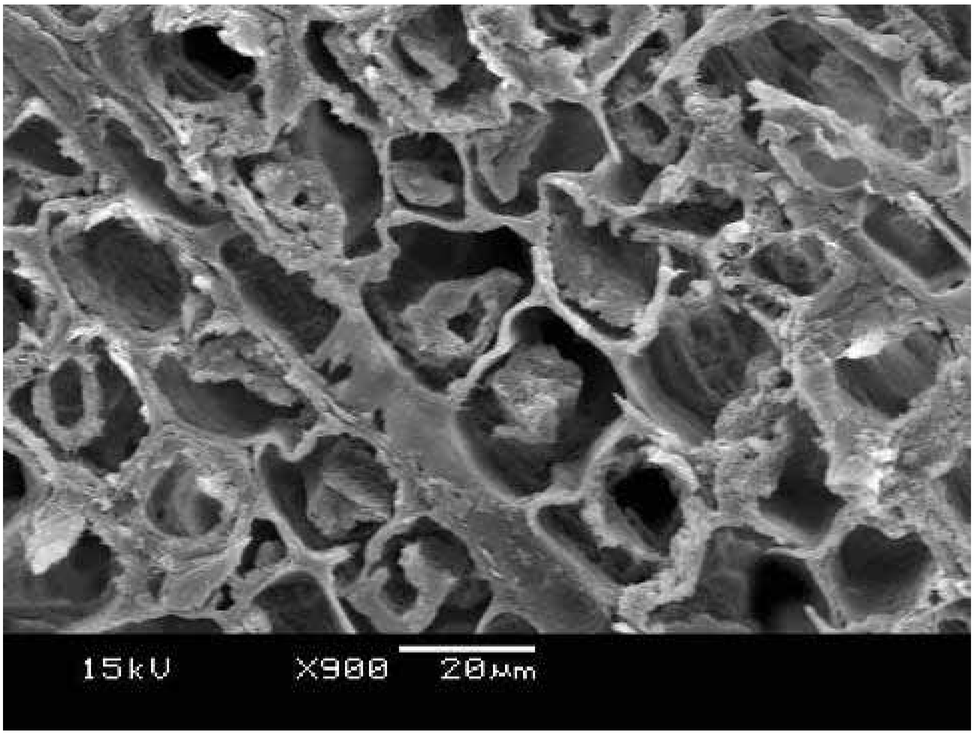


Fig 19 Scanning electron micrograph of pine sample (control-24 month exposure). Note erosion to secondary wall layers.

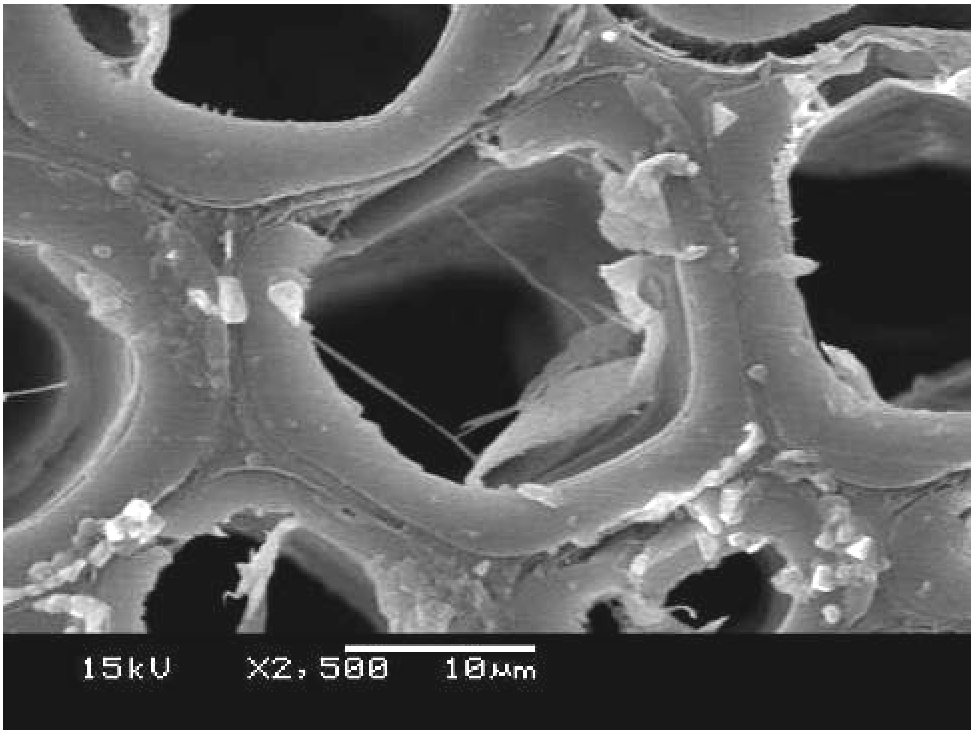


Fig 20 Scanning electron micrograph of pine sample protected by Terram 4000 (24 month exposure). Micro-organisms present but no decay.

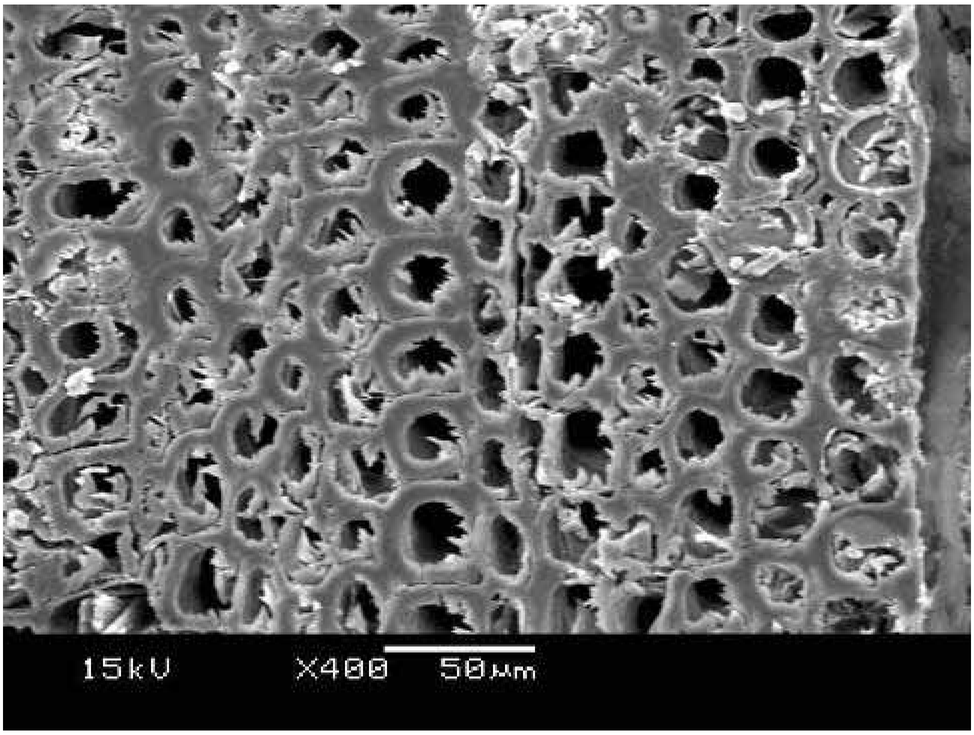


Fig 21 Scanning electron micrograph of pine sample protected by a mesh netting (24 months exposure). Note decay of some cells.

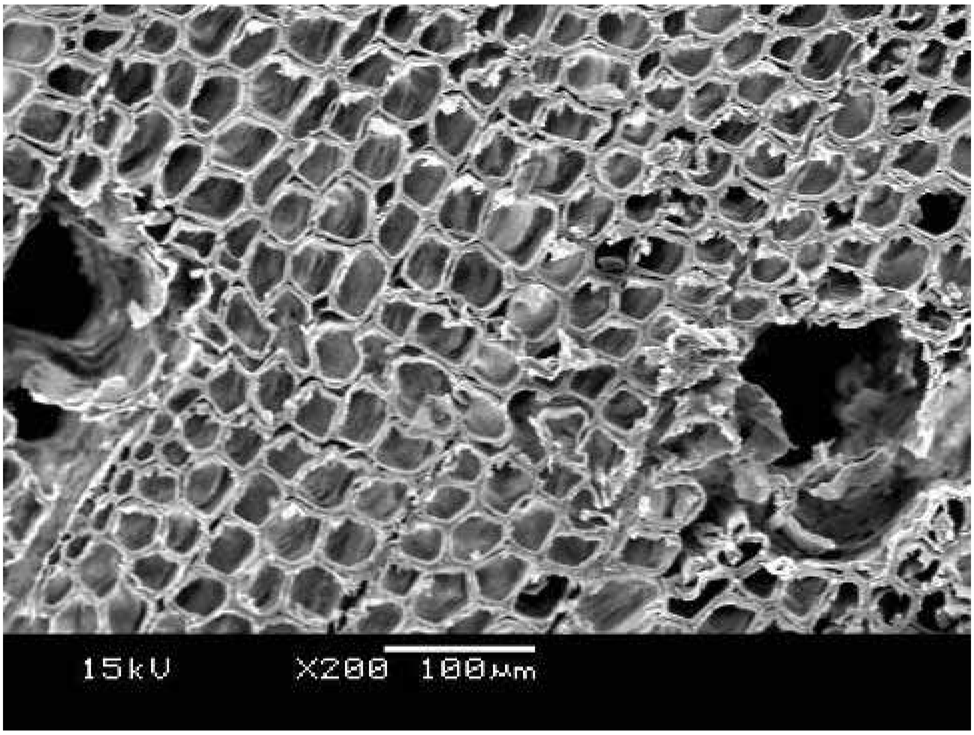


Fig 22 Scanning electron micrograph of pine sample protected by a frond mat (24 months exposure). Early signs of decay by erosion bacteria.

Wood boring activity

The sequence of colonisation and degradation of oak and pine test blocks was compiled from data obtained from X-ray radiography carried out by Karla Graham (conservator, English Heritage). This technique was used almost exclusively to illustrate wood boring activity at the Colossus wreck site.

Degradation of wood samples at the Colossus site

Similar patterns of wood boring attack were observed in both species of wood.

- Teredo and limnoria sp. were the two wood boring animals active at the wreck site.
- Oak and pine samples after 24 months exposure showed complete failure without protection from a physical barrier
- Terram 4000 provided complete protection against borer attack for both oak and pine samples

The extent of degradation of exposed and covered wood test samples varied considerably during the two year study. Data of biological degradation (wood-boring animal infestation) of all samples placed at the site are summarised in Figs 23 and 24.

Oak sample blocks

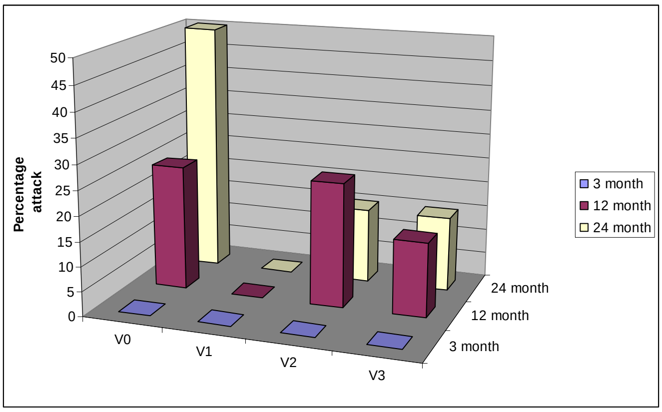
Physical Barrier System	**Exposure** (months)	**Teredo Infestation**
Control (V0)	3	No attack
Control (V0)	5	Slight attack
Control (V0)	12	Moderate attack
Control (V0)	24	Failure
Terram 4000 (V1)	3	No attack
Terram 4000 (V1)	12	No attack
Terram 4000 (V1)	24	No attack
Mesh (V2)	3	No attack
Mesh (V2)	12	No attack
Mesh (V2)	24	Slight attack
Scour Control Mat (V3)	3	No attack
Scour Control Mat (V3)	12	Slight attack
Scour Control Mat (V3)	24	No attack

Fig 23 Infestation assessment of Oak wood blocks exposed at HMS Colossus site.

Pine sample blocks

Physical Barrier System	**Exposure** (months)	**Teredo Infestation**
Control (V0)	3	No attack
Control (V0)	5	Slight attack
Control (V0)	12	Moderate attack
Control (V0)	24	Failure
Terram 4000 (V1)	3	No attack
Terram 4000 (V1)	12	No attack
Terram 4000 (V1)	24	No attack
Mesh (V2)	3	No attack
Mesh (V2)	12	Moderate attack
Mesh (V2)	24	Slight attack
Scour Control Mat (V3)	3	No attack
Scour Control Mat (V3)	12	Slight attack
Scour Control Mat (V3)	24	Slight attack

Fig 24 Infestation assessment of Pine wood blocks exposed at HMS Colossus site.



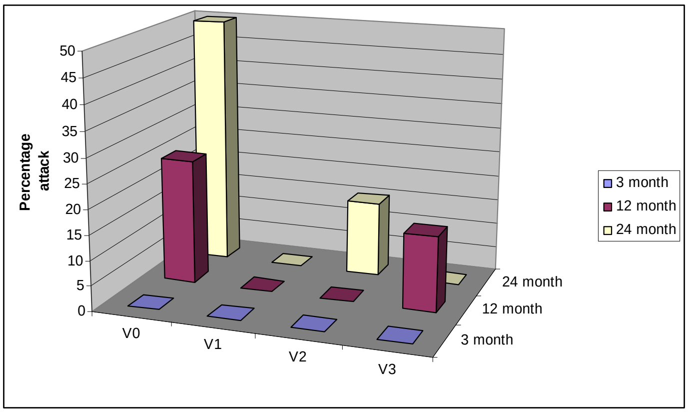


Fig 25   Charts illustrating the approximate percentage attack for the test blocks in each of the trial areas V0 – V3. Note that the only trial area blocks to show no attack are those from V1, the Terram 4000.

Samples

Control - VO

These samples were left unprotected in the aerobic environment for periods of 3 to 24 months (figs 26-31) were subjected to extensive colonisation by marine organisms. After 5 months exposure, both oak and pine samples showed initial signs of wood borer attack (figs 23 and 24). After 24 months exposure, oak (fig 30) and pine wood (fig 31) samples showed considerable wood boring activity and extensive damage to the wooden blocks. Two types of wood-boring animals have been identified at the site, namely the mollusc *Teredo* and the crustacean *Linmnoria*. Without sediment cover or *in-situ* protection, the archaeological timbers of HMS Colossus would be destroyed very quickly by the biological activity of marine wood boring animals and microbes present in the aerobic wreck environment.

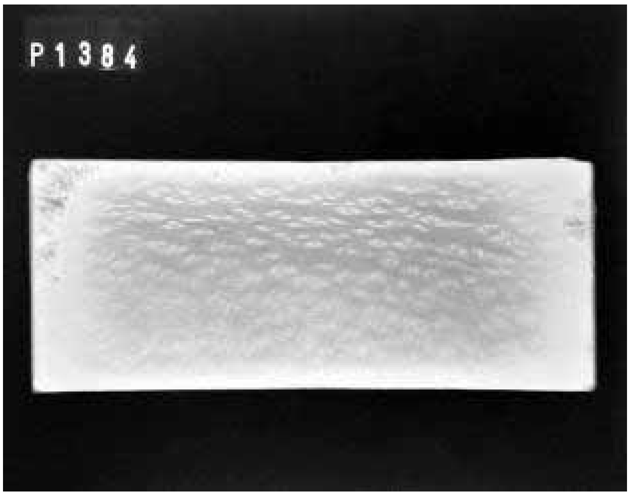


Fig 26 X-radiograph of Oak after 5 months exposure (no protection). Slight attack

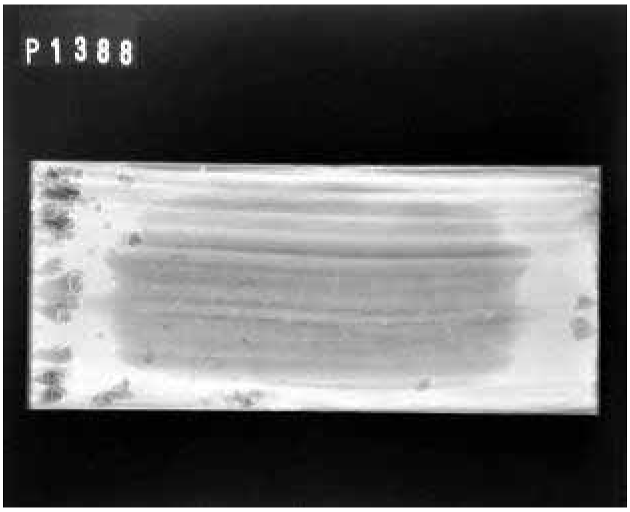


Fig 27 X-radiograph of Pine after 5 months exposure (no protection). Moderate attack

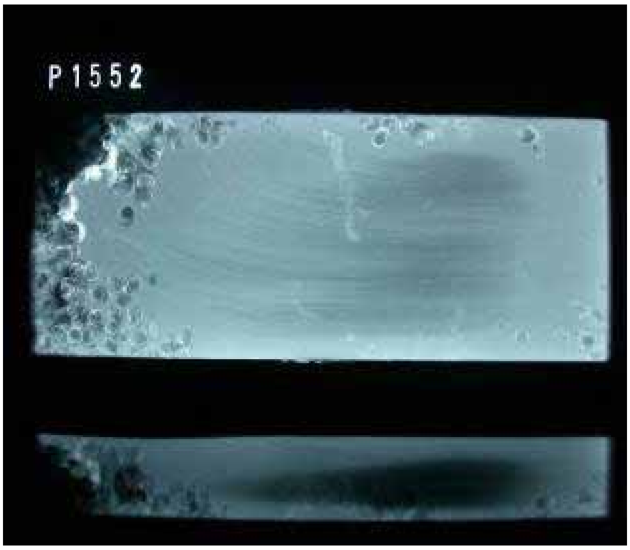


Fig 28   X-radiograph of Oak sample after 12 months exposure (no protection). Severe attack

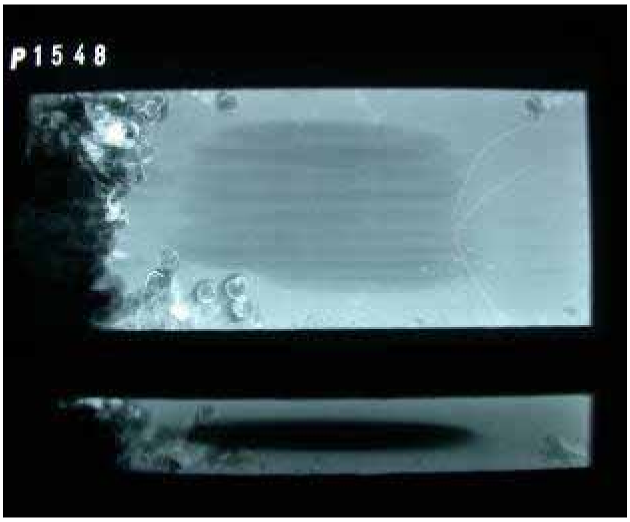


Fig 29 X-radiography of Pine after 12 months Exposure (no protection). Severe attack

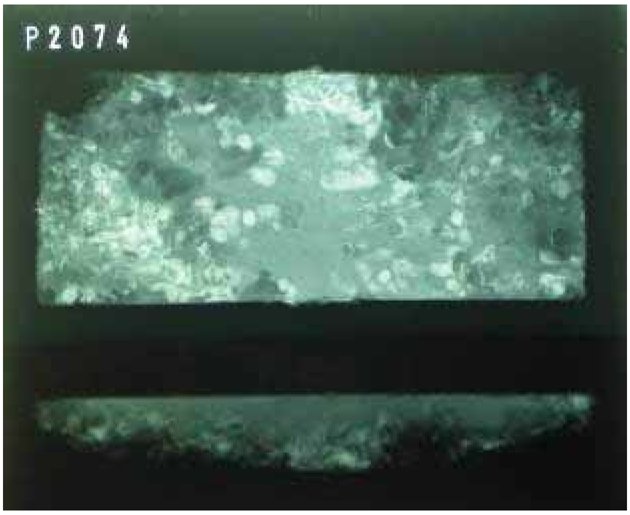


Fig 30 X-radiograph of oak after 24 months exposure (no protection). Failure

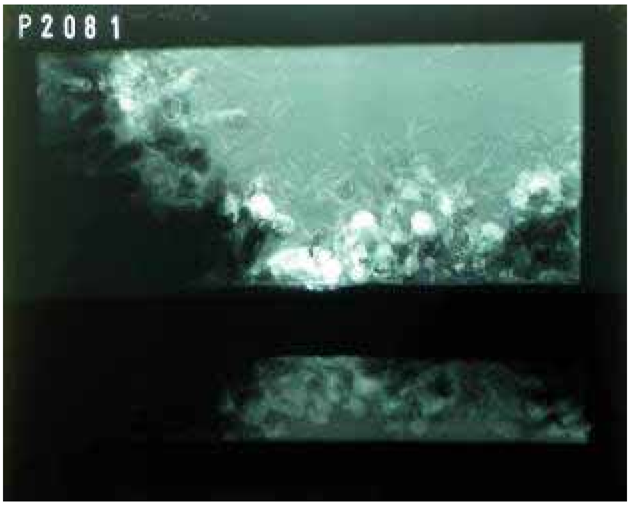


Fig 31 X-radiograph of pine after 24 months Exposure (no protection). Failure

Terram 4000 (V1)

Oak and pine samples protected by the geotextile Terram 4000 were examined both visually by stereo light-microscopy and x-radiography. After a period of 24 months no wood boring attack had occurred to both oak and pine wood samples (figs 36 and 37).

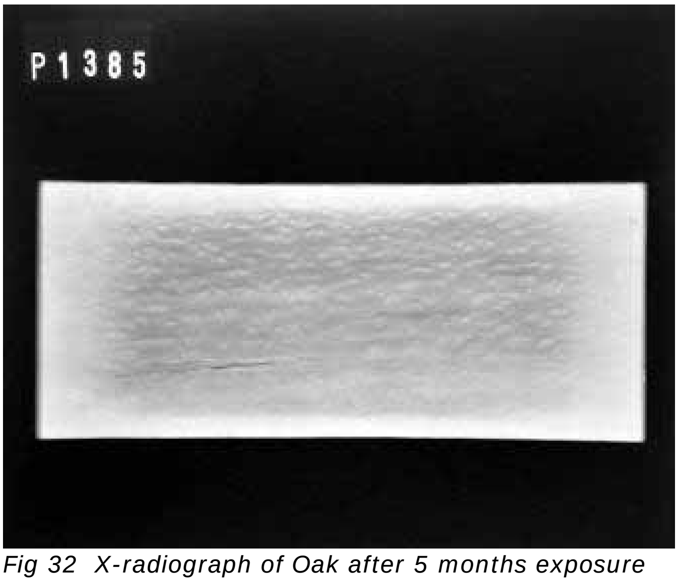


Fig 32 X-radiograph of Oak after 5 months exposure protected by Terram 4000. No Terredo attack

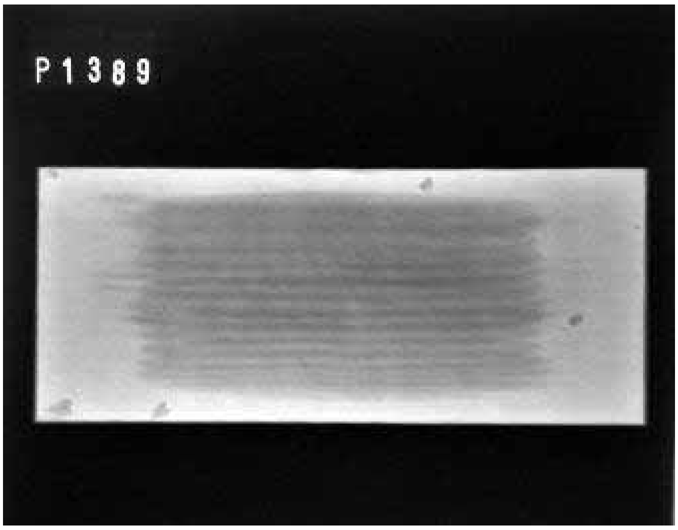


Fig 33 X-radiograph of Pine after 5 months exposure protected by Terram 4000. Slight attack

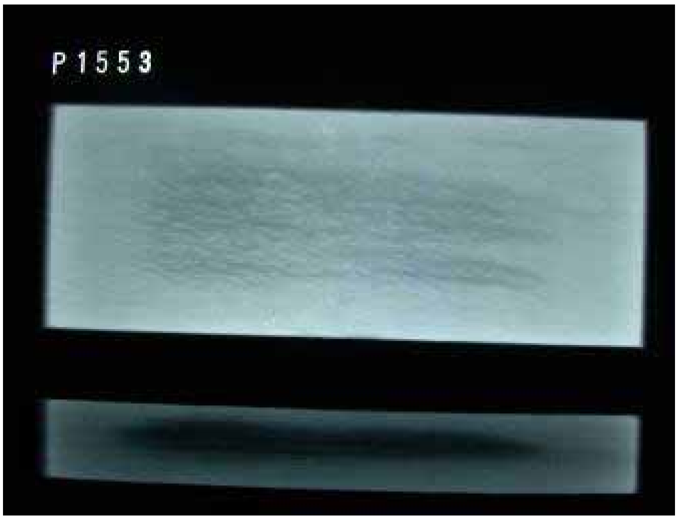


Fig 34 X-radiograph of Oak after 12 months exposure protected by Terram 4000. No Terredo attack

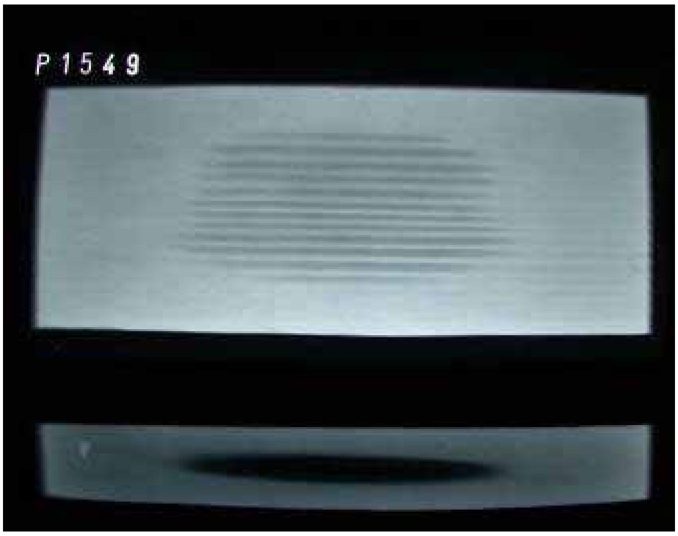


Fig 35 X-radiograph of Pine after 12 months exposure protected by Terram 4000. No Terredo attack

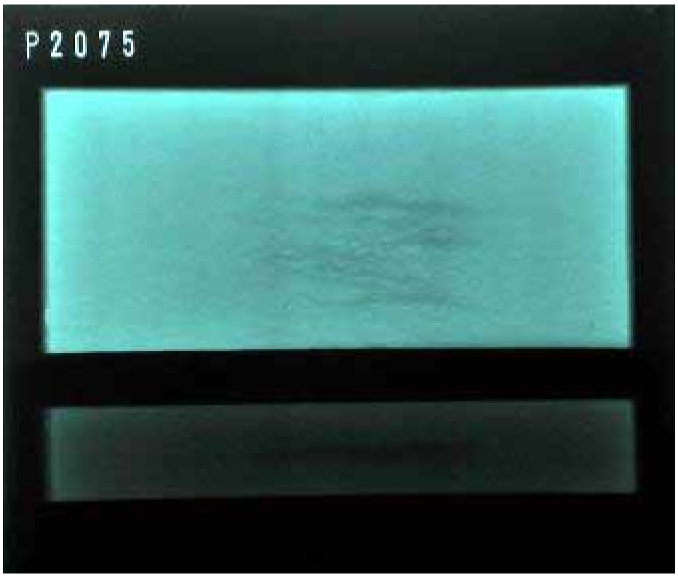


Fig 36   X-radiograph of oak test block protected by Terram 4000 (length of exposure 24 months). No terredo attack

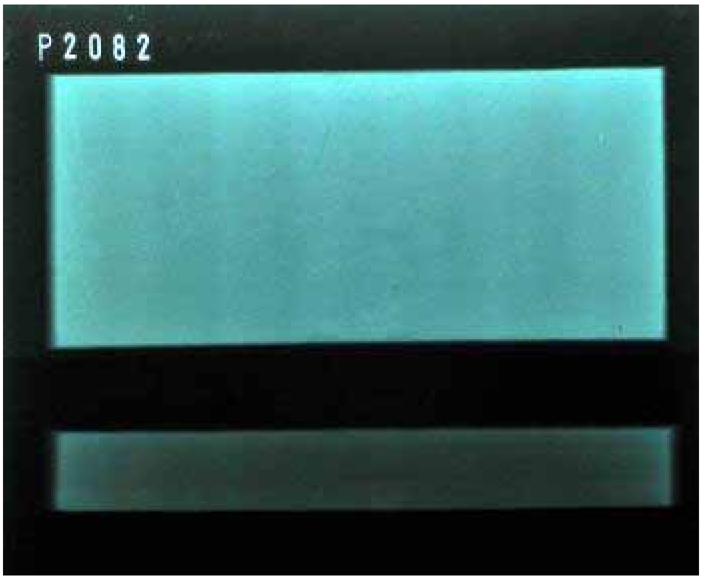


Fig 37 X-radiography of Pine test block protected by Terram 4000 (length of exposure 24 months). No Terredo attack

Mesh (V2)

Oak and pine samples protected by raised mesh netting were also examined both visually by stereo light-microscopy and x-radiography. After a period of 24 months there was slight attack to both pine (fig 43) and oak samples (fig 42) by wood boring animals

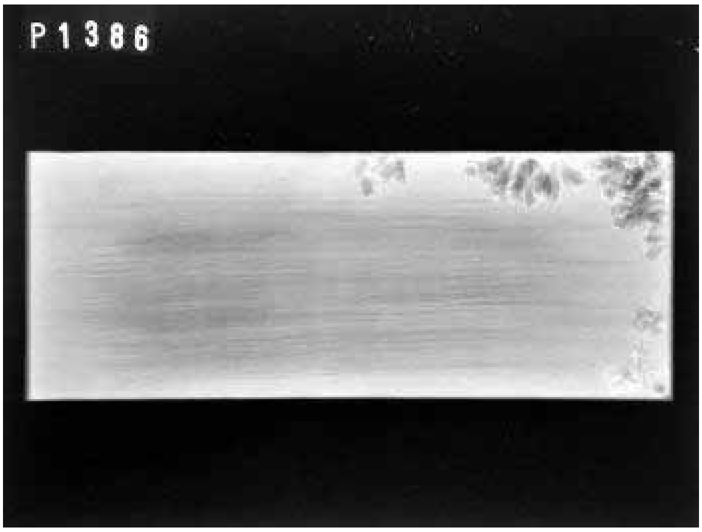


Fig 38 X-radiography of Oak wood block protected by mesh (after 5 months). Slight attack

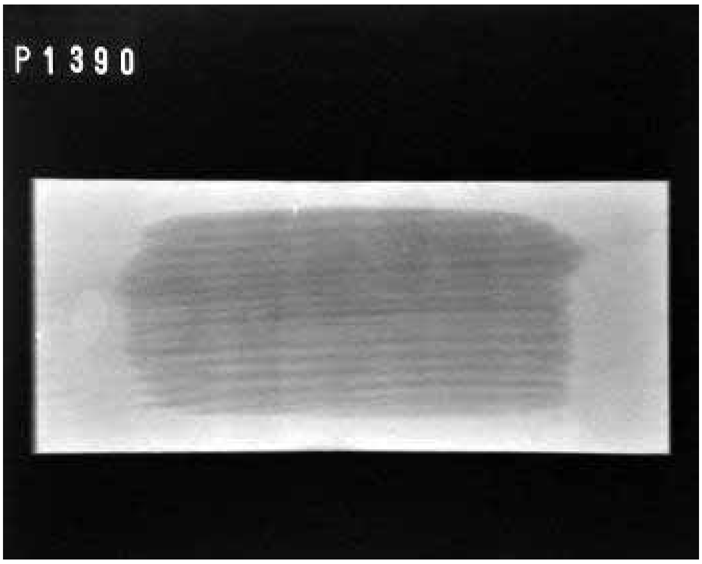


Fig 39 X-radiography of Pine wood block protected by mesh (after 5 months). No terredo attack

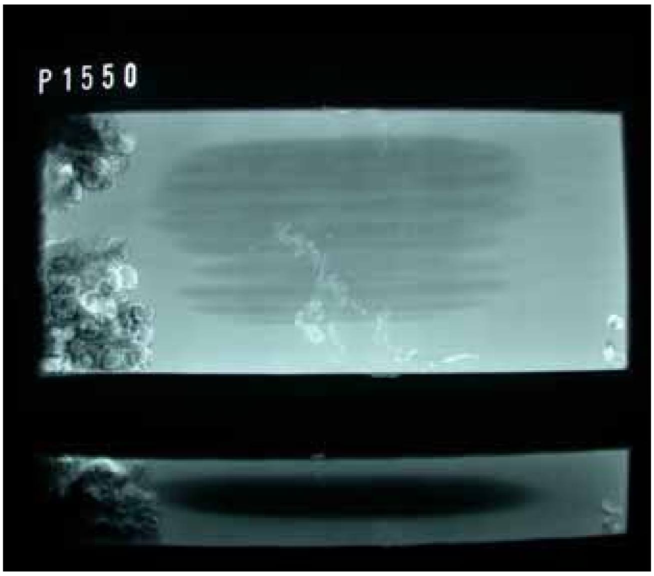


Fig 40 X-radiography of Oak wood block protected by mesh (after 12 months). Moderate attack

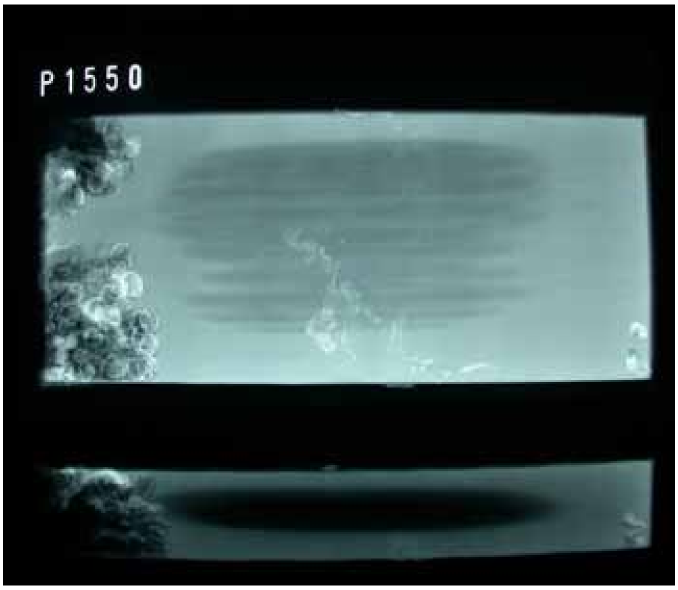


Fig 41 X-radiography of Pine wood block protected by mesh (after 12 months). Moderate attack

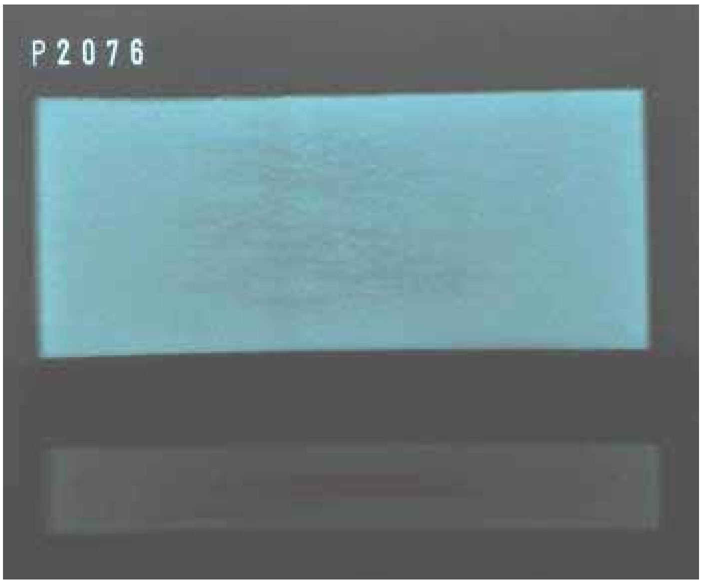


Fig 42 X-radiography of Oak wood block protected by mesh (after 24 months). No attack.

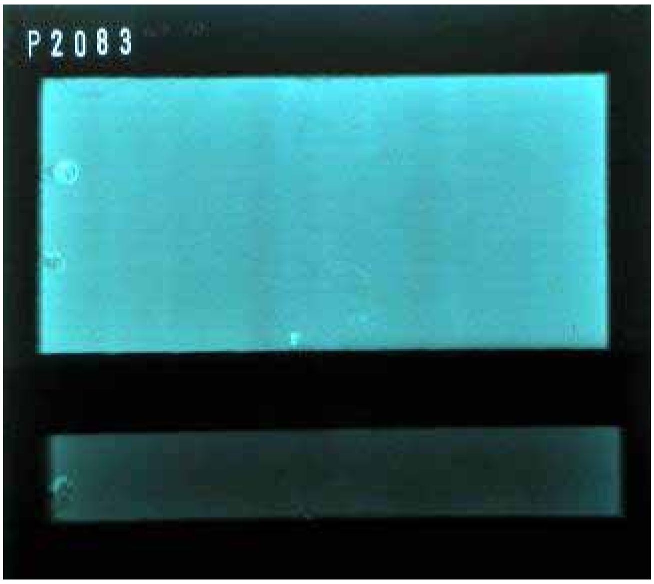


Fig 43 X-radiography of pine wood block protected by mesh (after 24 months). Slight attack

Floating Fronds (V3)

Oak and pine samples protected by the floating frond textile were examined both visually by stereo light-microscopy and x-radiography. After a period of 24 months no wood boring attack had occurred to the oak sample whilst the pine wood block showed slight wood-boring infestation (figs 48 and 49).

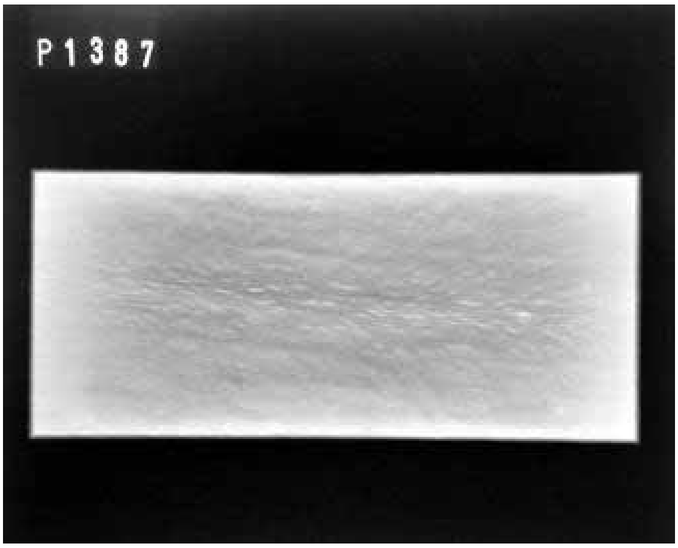


Fig 44 X-radiograph of oak test block protected by frond matting (after 5 months). No attack

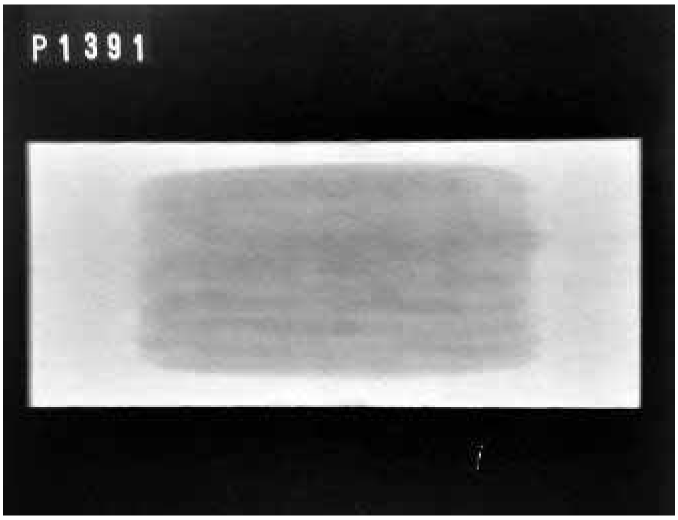


Fig 45 X-radiograph of Pine test block protected by frond matting (after 5 months). No attack

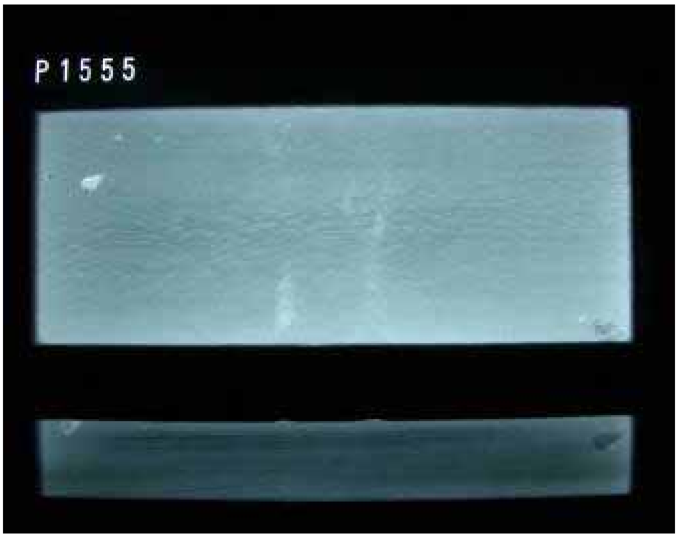


Fig 46 X-radiograph of Oak test block protected by frond matting (after 12 months). Slight attack

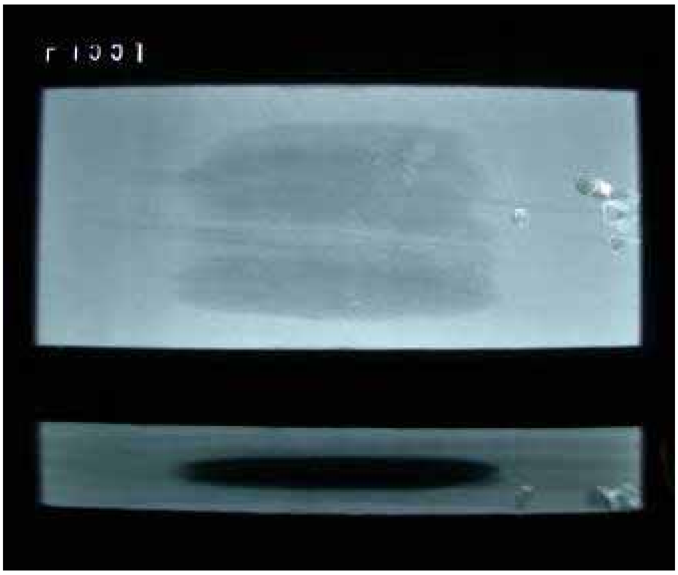


Fig 47   X-radiograph of Pine test block protected by frond matting (after 12 months). Slight attack

Fig 48 X-radiograph of oak test block protected by frond matting (after 24 months). No attack

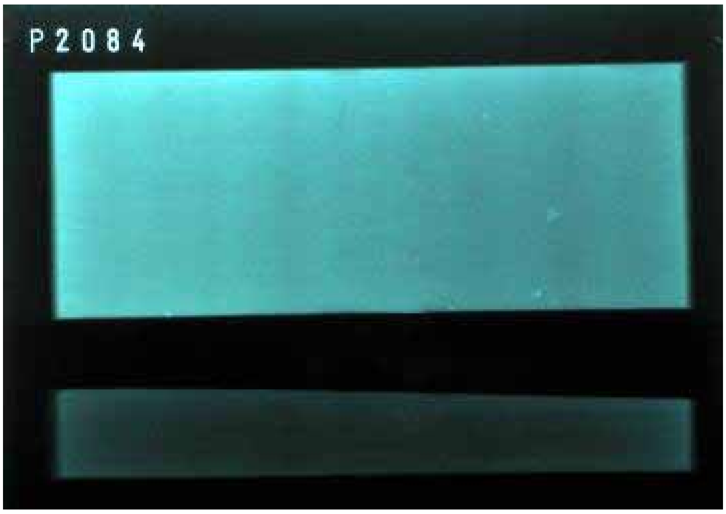


Fig 49 X-radiograph of pine wood block protected by frond matting (length of exposure 24 months). Slight attack

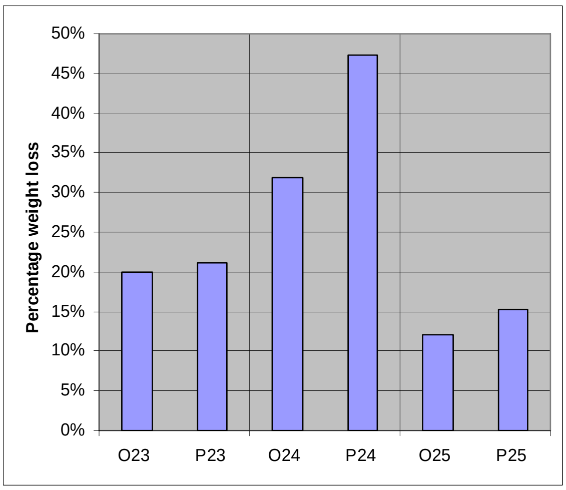
Wood boring activity at varying distances from wreck site.

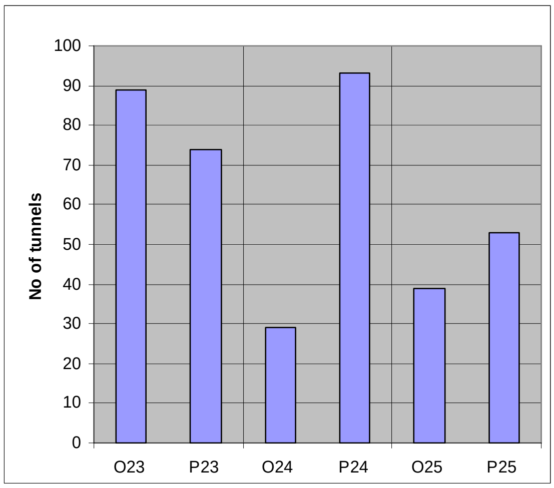
Analysis of data of showed no relationship between borer activity and distance from wreck timbers infested with wood borers. Fig 50 shows no decrease in borer activity with increasing distance from infested wreck timbers.

Sample	**Distance from wreck**	**Exposure** (months)	**Weight loss** (%)	**Surface condition**	**Surface destruction**	**Tunnel count**
O23	2.3m	13	20	Failure	75%	89
O24	14.4m	13	32	Moderate	25%	29
O25	24.3m	13	12	Severe	More than 50%	39
P23	2.3m	13	21	Failure	More than 75%	74
P24	14.4m	13	47	Failure	More than 95%	93
P25	24.3m	13	10	Severe	More than 50%	53

Fig 50 Oak and pine Control samples % weight loss

The proximity block tunnel count and weight loss data is illustrated graphically in the charts below.





From the above, it is apparent that there is no clear relationship between proximity to the wreck and level of attack by wood borers. The attack is greater in the 2m blocks than in the 24m blocks but the 14m blocks have the greatest level of attack.

Weight loss experiments

Figs 51-58 illustrate the loss in weight of wood test samples exposed and protected at the Colossus wreck site for varying periods of time. Similar patterns of weight loss were observed for both pine and oak samples. Unprotected samples were the most susceptible to wood borer attack and significant weight losses (28%) were recorded after a 24 month exposure period.

Oak and pine samples protected by the various physical barrier systems showed significant decreases in weight loss due to the protection provided against wood borer attack.

Exposure (months)	**Control** % weight loss	**Terram-4000** % weight loss	**Mesh** % weight loss	**Fronds** % weight loss
3	0	2	0	0
5	9	0	7	0.4
12	9.2	0	0	0
24	28.5	0	0	0

Fig 51 Oak samples % weight loss

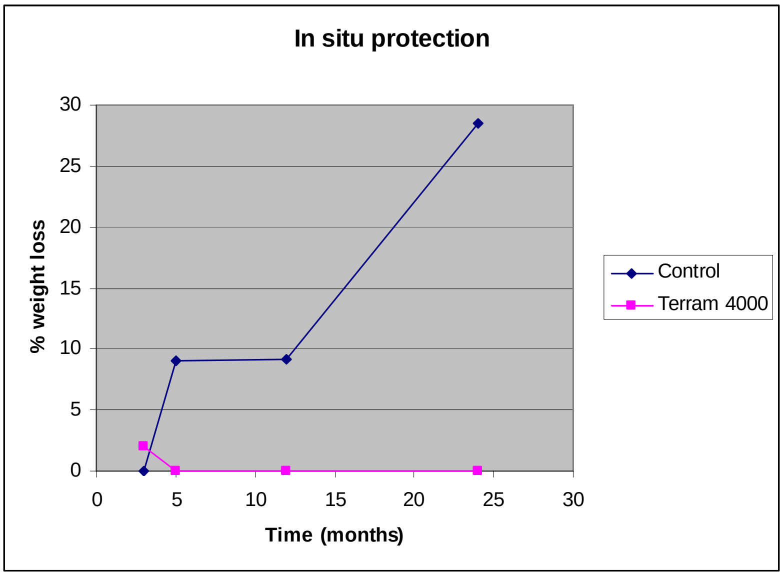


Fig 52 % weight loss of Oak comparing Terram 4000 with the Control sample

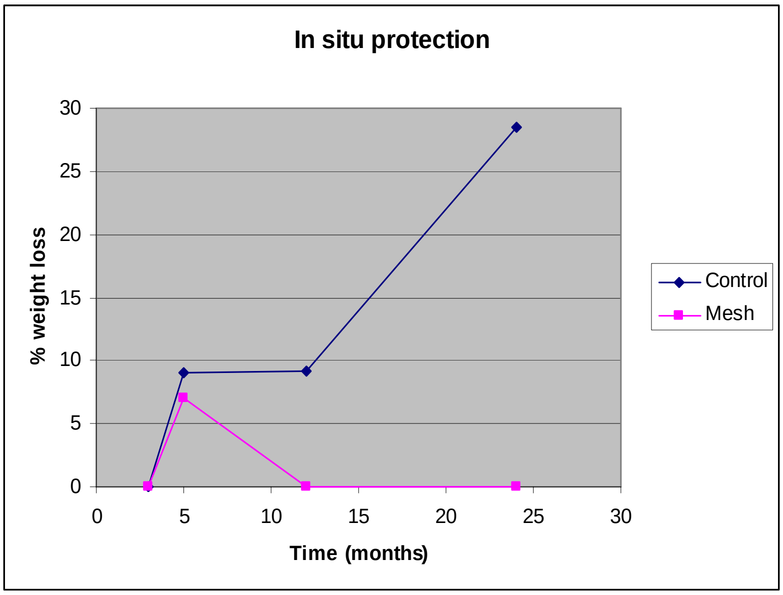


Fig 53 % weight loss of Oak comparing Mesh with the Control sample

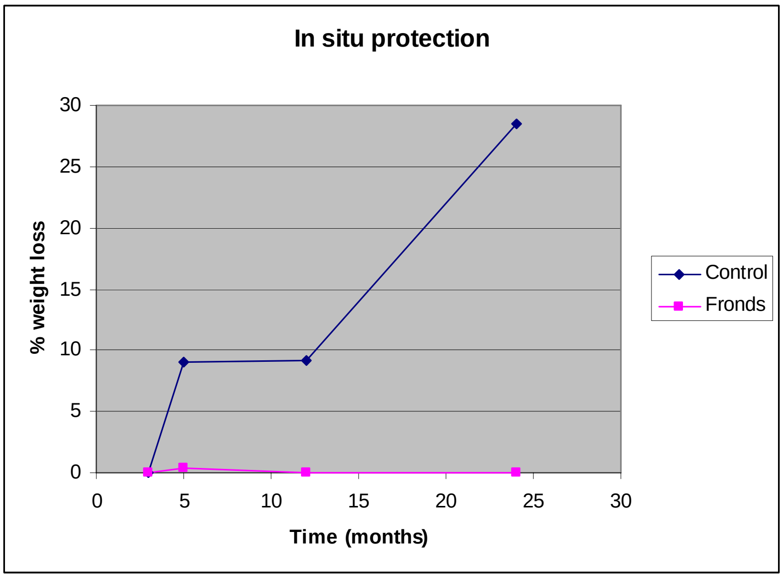


Fig 54 % weight loss of Oak comparing Fronds with the Control sample

Exposure (months)	Control % weight loss	Terram-4000 % weight loss	Mesh % weight loss	Fronds % weight loss
3	0	0	0	0
5	9	4	0	0
12	13	4.5	14	0
24	28.8	0	1	3

Fig 55 Pine samples % weight loss

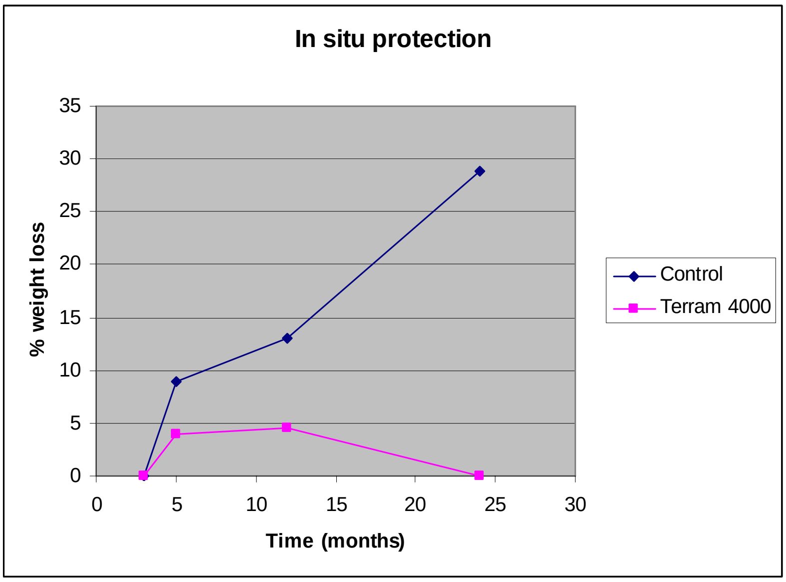


Fig 56 % weight loss of Pine comparing Terram 4000 (V1) with the Control sample (V0)

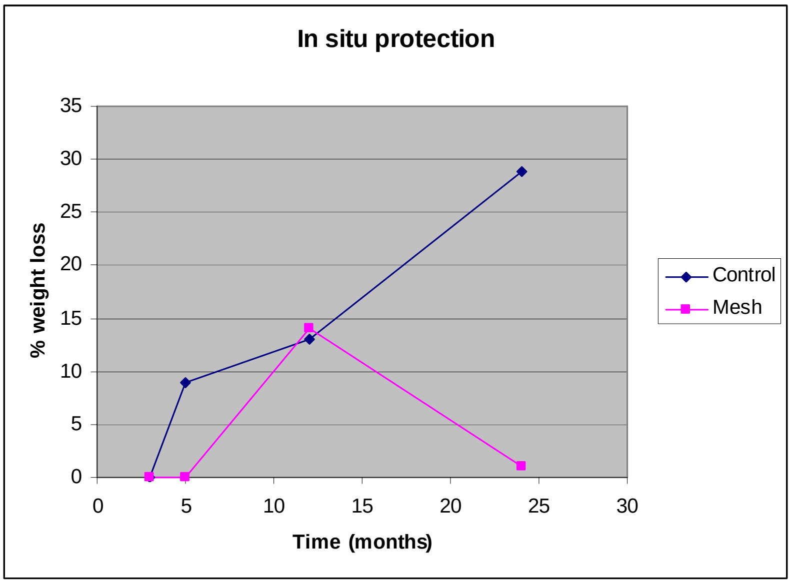


Fig 57 % weight loss of Pine comparing Mesh (V2) with the Control sample (V0)

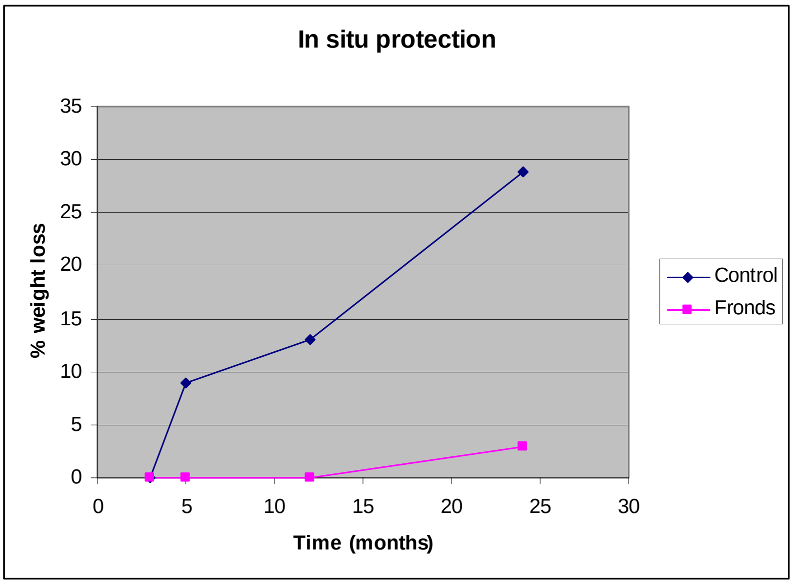


Fig 58 % weight loss of Pine comparing Fronds (V3) with the Control sample (V0)

Inorganic contaminants

Spot X-ray microanalysis was performed on exposed and protected oak and pine samples in a JEOL scanning electron microscope at an accelerating voltage of 15kV, accumulating spectra over a live time of 100s. Fig 59 provides information on elements present within the various wood samples. Similar elements were observed for both oak and pine samples. Differences did occur, however, pine samples had low levels of magnesium and iron.

Further analysis of the sulphur compounds present by XANES indicated large amounts of sulphate present and smaller levels of reduced sulphur (mostly sulfides in oak and iron sulfides in pine. In marine archaeological timbers the presence of sulphur and iron compounds can result in acid production and over long period of time destroy the artefact.

Sample	Wood species	SEM-XRM
O5 – control (V0)	Oak	Na, Si, P, S, Cl, Ca
O9 - Terram 4000 (V1)	Oak	Na, Si, P, S, Cl, Ca
O13 – mesh (V2)	Oak	Na, Si, P, S, Cl, Ca
O17 – frond (V3)	Oak	Na, Si, P, S, Cl, Ca
P4 – control (V0)	Pine	Na,Mg, Si, P, S, Cl, Ca, Fe
P9 – Terram 4000 (V1)	Pine	Na, Mg,Si, P, S, Cl, Ca, Fe
P13 –mesh (V2)	Pine	Na,Mg, Si, P, S, Cl, Ca, Fe
P17-frond (V3)	Pine	Na, Mg,Si, P, S, Cl, Ca, Fe

Fig 59 SEM-XRM analysis of wood (24 month exposure)

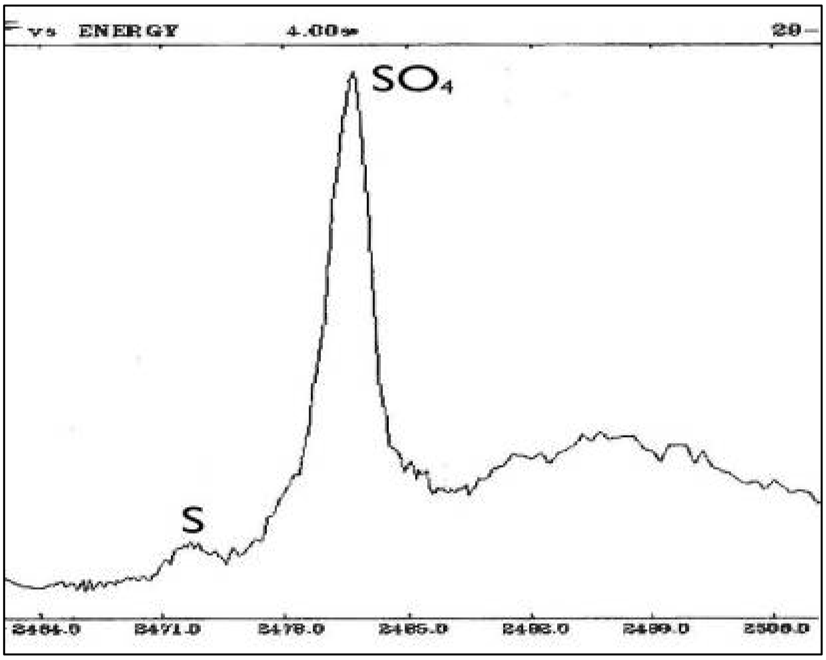


Fig 60 K-edge XANES spectrum of oak sample protected by Terram 4000.

Wood chemistry

Examination of figs 62 and 63 reveal changes to a peak at 1740 (red spectra, oak and pine). The marked decrease in the intensity of this peak indicates extensive degradation of the hemicellulose fraction has occurred. This is to be expected as hemicellulose is soluble in water. No changes to cellulose and lignin were noted after exposure at the site (3 to 24 months).

	Hemicellulose	Holocellulose	Lignin
Absorption bands (cm^{-1})	1740, 1220	1370,1160,896	1510,1330,1260

Fig 61 Diagnostic bands from FT-IR spectra of oak and pine

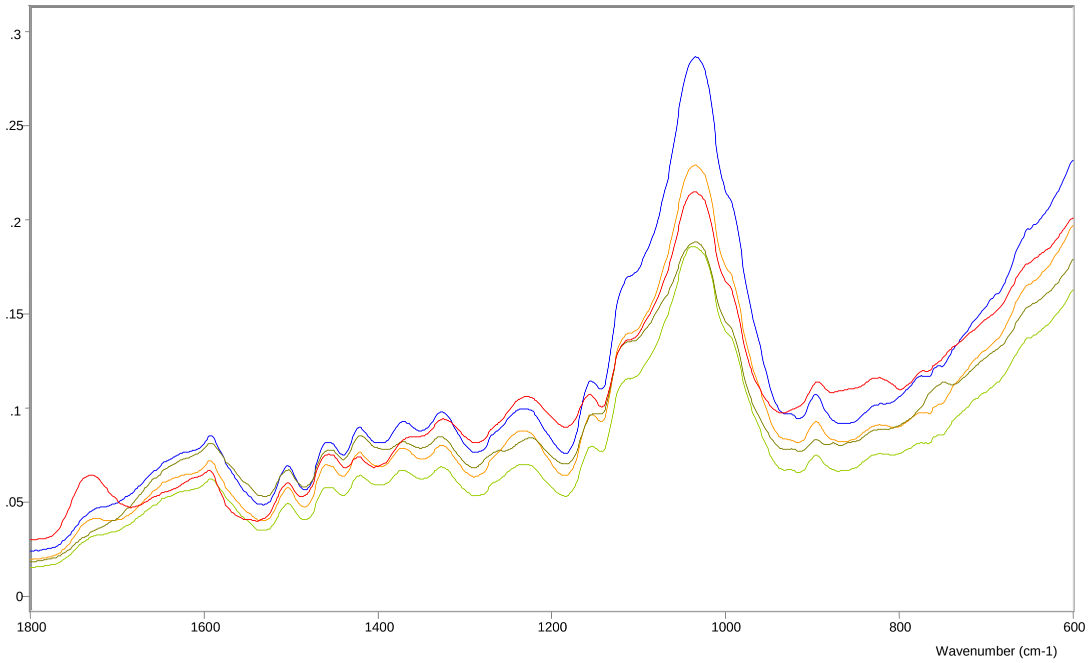


Fig 62 FT-IR spectra of oak samples (24 month exposure0
Fresh oak – red
Oak 5 – control –dark green
Oak 9 – Terram 4000- green
Oak 13 – Netting (mesh)- orange
Oak 17 – Frond Matt-blue

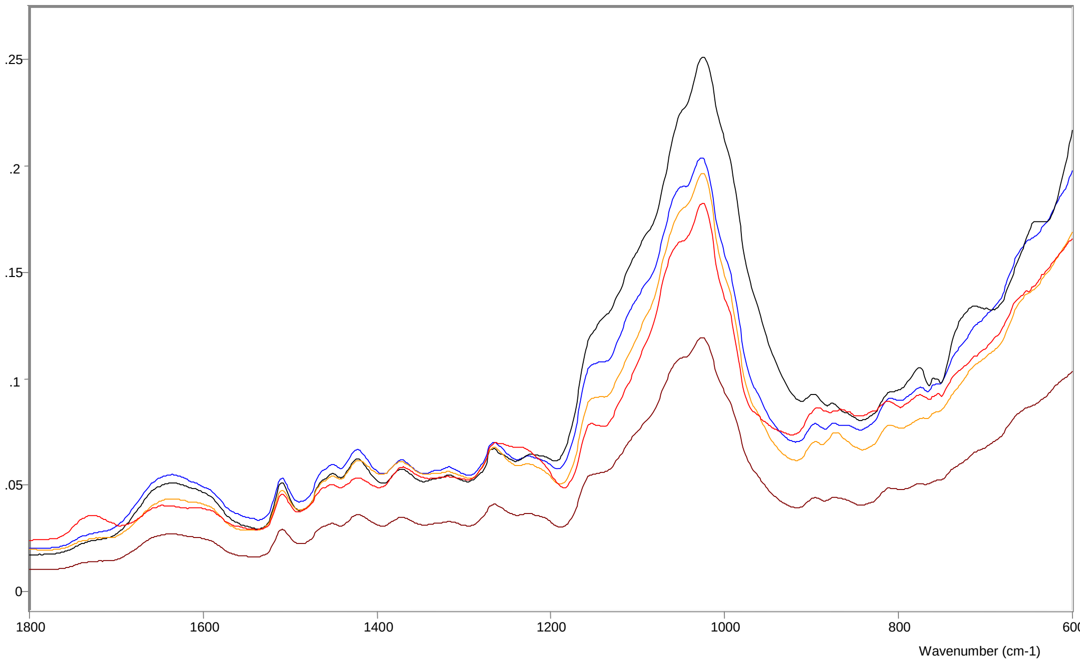


Fig 63 FT-IR spectra of pine samples (24 month exposure)
Fresh – red- fresh pine
Pine 4 – control-brown
Pine 9 – terram 4000-orange
Pine 13 – netting-black
Pine 17 – frond mat-blue

Conclusions

In conclusion, the results of this on-site *in-situ* protection study indicate that the exposed hull remains of HMS Colossus will be attacked by wood boring animals such as *Teredo* and *Limnoria* sp. The rate of degradation would be accelerated dramatically without significant coverage of natural sediment or the safeguarding of exposed wreck timbers by Terram 4000.

Therefore, a synergistic maritime archaeological and conservation management plan must be devised to significantly reduce the continued deterioration of this historic shipwreck site.

Recommendations

Based on the results presented in this study, Terram 4000 should be used to protect exposed wreck timbers against microbes and wood boring animals.

Dr Mark Jones

Data logging results

The data logger was installed at each of the trial areas in turn. In each case the redox, dissolved oxygen and pH sensors were installed under the trial mats. The depth and temperature sensors were contained within the body of the data logger which was 2-3m away on the seabed. The table below lists the duration and dates for each deployment of the Waterwatch 2685 data logger.

TRIAL AREA	DATE IN	DATE OUT	DURATION (DAYS)
V1 Terram	29.III.2004	28.VI.2004	91.00
V2 Mesh	20.VIII.2003	20.X.2003	61.00
V3 Fronds	19.V.2003	18.VIII.2003	91.00

Fig 64 Table showing dates and duration for each of the three data logger deployments.

Readings were taken once every hour throughout each deployment. This resulted in over two thousand readings for each of the parameters being monitored in the 91 day deployments. This data has been presented graphically in the form of charts for each of the test areas V1 – V3. The raw data is available on the CD version of this report.

Test Area V1 (Terram mat) March – June 2004

This data is for the 91 day period between 29th March and 28th June 2004. It should be noted that the Terram mat had been in place on the seabed since May 2003. Thus the Terram had been in position on the seabed for approximately ten months when the data logger sensors were placed under the mat.

Dissolved oxygen [fig 66.1 & 66.2]

The measurements for dissolved oxygen were output from the data logger as percentage and as milligrams per litre; charts are shown for both below.
The first reading recorded for the dissolved oxygen was 4.8% (0.54mg/l). This very low initial reading is probably because conditions under the mat had become anoxic in the ten months it had been in place on the seabed. Installation of the oxygen, redox and pH probes must have allowed some oxygenation of the area under the mat where the probes were placed. This reading fell steadily and dropped below 1% after only ten hours. Within five days, the levels had dropped further to 0.3% (0.03mg/l). By the end of the 91 day deployment of the data logger, the dissolved oxygen had fallen to 0.2% (0.02mg/l). Reference to the chart of the dissolved oxygen levels shows the fairly rapid fall to very low levels which were maintained for the remainder of the 91 day deployment. This demonstrates the anoxic conditions prevailing under the Terram mat.

Redox potential [fig 66.3]

The first recorded reading for the redox probe was -42 mV. Reference to fig 28 below shows this to be classed as a reducing environment. After ten hours the redox level had fallen to -173mV. The levels continued to fall (with several transient upward spikes) for the next five days, by which time the redox level had fallen to below -500mV. With the exception of a few small transient spikes the level remained below -500mV for the remainder of the deployment. These readings accord well with the very low dissolved oxygen levels recorded, and suggest a very strongly reducing environment under the terram mat.

Oxidising	+700 to +400 mV
Moderately reducing	+400 to +100 mV
Reducing	+100 to -100 mV
Strongly reducing	-100 to -300 mV

Fig 65 Table of the range of oxidising to reducing environments in terms of their redox potential[17]

pH [fig 66.4]
The chart of rather erratic pH values engenders the suspicion that the pH probe was not functioning properly during this deployment. Particularly suspicious are the starting value of zero, (which persisted for the first five hours of the deployment) and the fourteen days at zero (between 9th and 25th April). Similarly doubtful are the values recorded between 25th April to 25th May, which oscillate between 1.9 and 7.4. The pH values recorded towards the end of this deployment (after about 10th June) show credible pH values for a marine sediment but in view of the preceding values should be viewed with caution.

I invited David Precious of Eauxsys Ltd to comment on this data set in general and the pH values in particular and his comments are recorded in appendix V. Despite David's comments I feel we must treat these pH values as doubtful. The sensor may have become unstable or fouled in some way. Interestingly, the MoSS project team also encountered problems with the pH readings using their Waterwatch 2680 systems.

Temperature [fig 66.5]
The recorded temperatures varied from 9.51˚C at deployment to 13.09˚C at retrieval. With relatively small fluctuations the temperature gradually rises throughout the monitoring period – as would be expected from March to June. The recorded sea surface temperatures at the Sevenstones Lightship shown in fig 22 show that the temperature range recorded by the data logger is credible.

Depth [fig 66.6]
The chart of the depth data clearly shows the rise and fall of the tide as well as the spring and neap tidal cycles. The maximum and minimum recorded depths during this deployment were 16.22m and 10.4m respectively. It should be born in mind that the pressure (depth) sensor was located in the body of the datalogger and thus some 0.20m above the seabed.

Battery
At deployment the battery level was 10.8v and at recovery 10.2v.

[17] David Gregory *Monitoring Wooden Shipwrecks* in *Monitoring, Safeguarding and Visualising North-European Shipwreck Sites* (Final Report).

V1 (Terram)

Fig 66.1

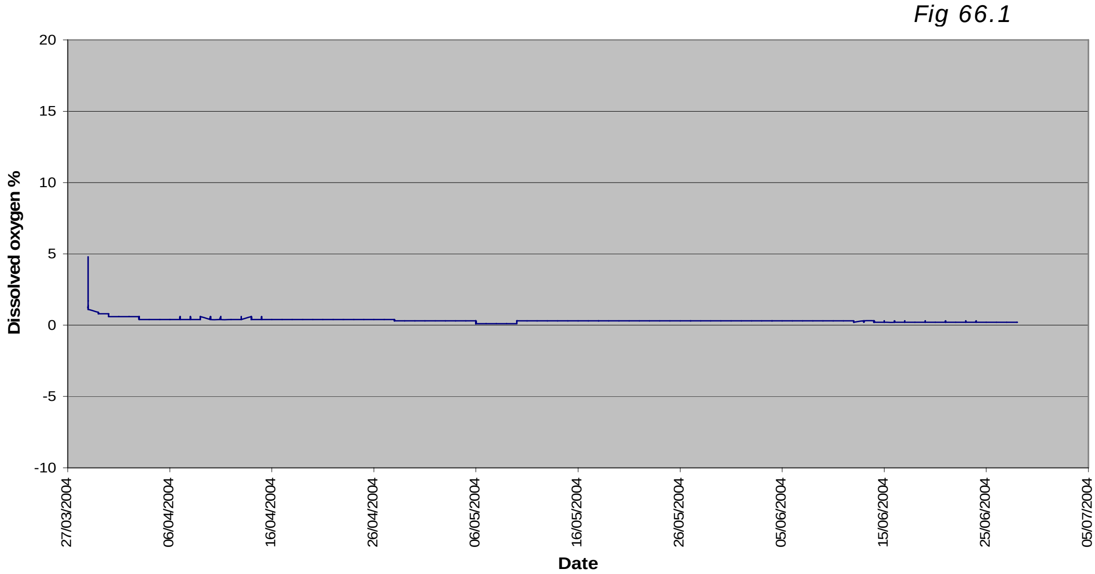


Fig 66.2

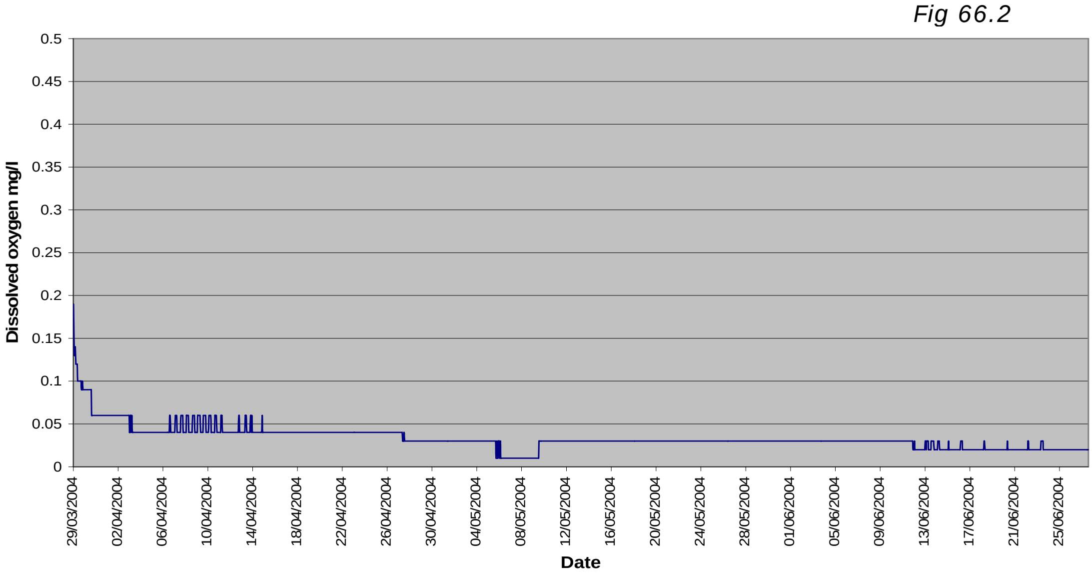


Fig 66.3

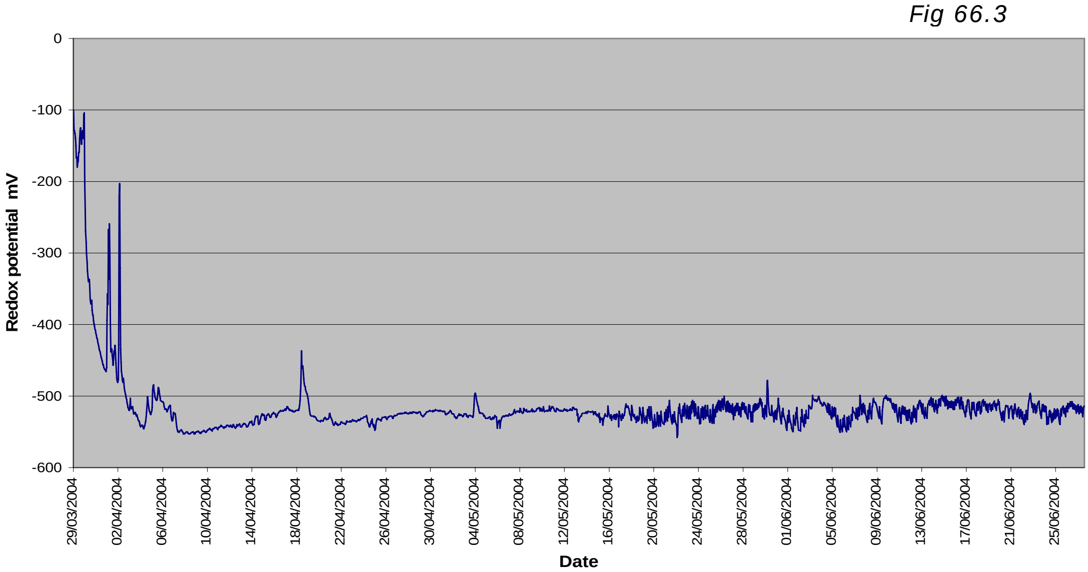


Fig 66.4

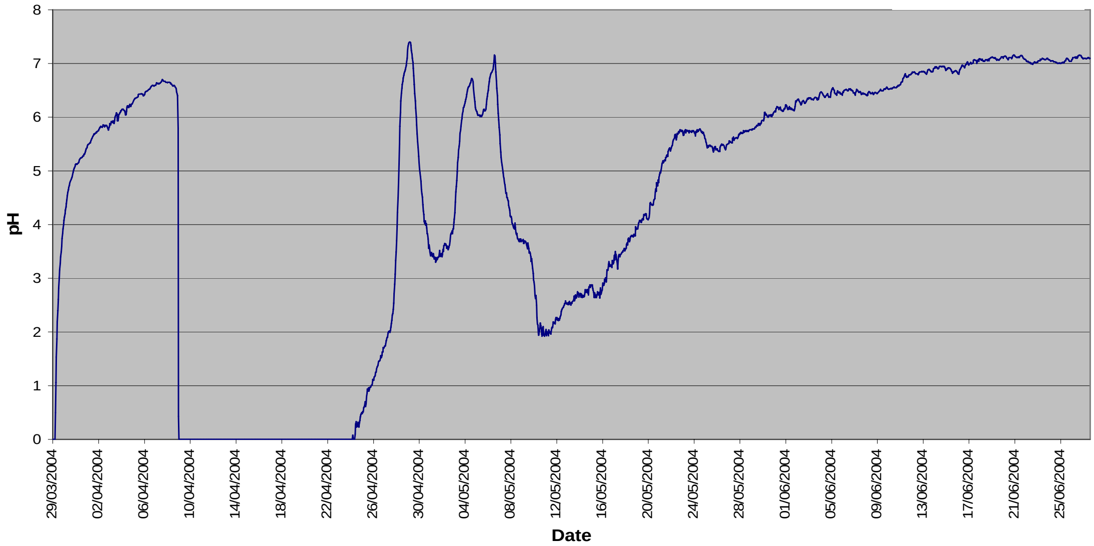


Fig 66.5

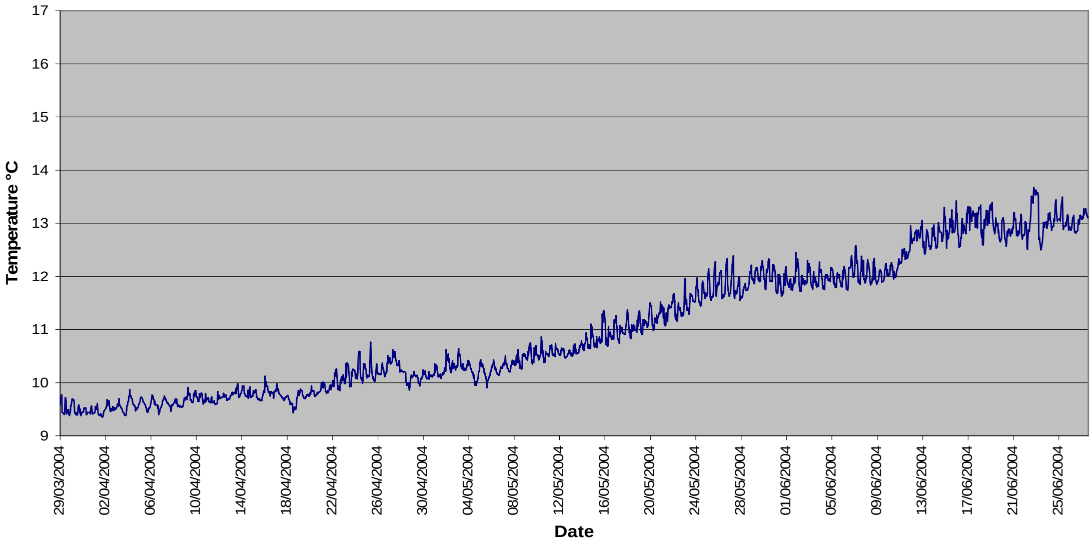
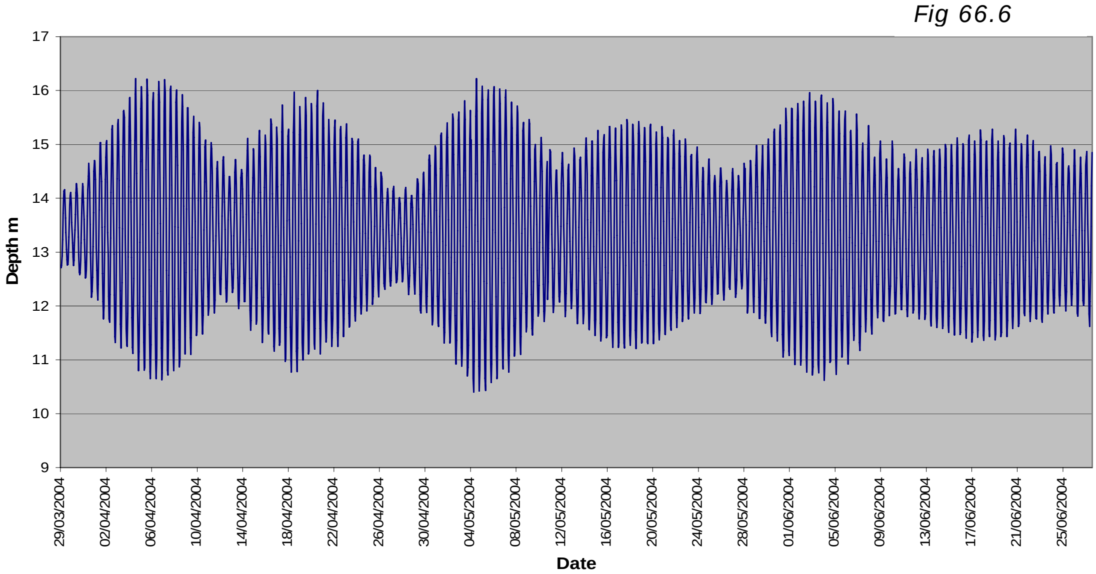


Fig 66.6



Test Area V2 (mesh mat) August – Oct 2003

This data is for the 61 day period between 20th August and 20th October 2003. The mesh had been in position on the seabed for approximately three months when the data logger sensors were placed under the mat. The sensors were positioned 0.50m north of timber sample blocks V2-D. The three probes (dissolved oxygen, redox and pH) were positioned 0.10m apart on the seabed and secured in position by sandbag placed over the body of each probe (about 0.20m clear of the sensors). When the sensors were recovered at the end of the deployment the dissolved oxygen and redox probes had become covered by a few millimetres of sediment. The pH probe was still completely exposed on the seabed.

Dissolved oxygen [fig 67.1 & 67.2]

The measurements for dissolved oxygen were output from the data logger as percentage and as milligrams per litre; charts are shown for both below. The first reading recorded for the dissolved oxygen was 105.2% (10.75mg/l)[18]. This rose over the next four days to around 150% (15mg/l) and then slowly fell to around 100% (10mg/l) by 1st September. The nature of the readings changes on 21st September when the values begin to oscillate between 100 and 200% (10 – 20mg/l). This may indicate a change in conditions or a malfunction of the sensor[19]. If this is the point at which the sensor became covered with sediment then the dissolved oxygen levels recorded seem unlikely unless the sediment interfered with the operation of the DO sensor in some way. Apart from the readings after 21st September, the levels of dissolved oxygen seem slightly high but perhaps not incompatible with those expected in open water. The possibility of a probe malfunction for dissolved oxygen on this deployment cannot be discounted.

Redox potential [fig 67.3]

The first recorded reading for the redox probe was +126 mV then fell to +73 mV within three hours. The values then fluctuate gradually between +50 and +90 mV until 23rd September. After the 23rd September the recorded redox values oscillate and fall to between -100 and -700mV for the rest of the deployment. This represents a change from a reducing environment to a strongly reducing environment (see fig 15) and may represent the point at which the sensor was covered by sediment. The date of this change roughly coincides with the change in the nature of the recorded dissolved oxygen noted above. However, it is difficult to reconcile the high dissolved oxygen levels with the change to a strongly reducing environment. The possibility that the sediment partially covering the DO and redox probes has caused a malfunction cannot be discounted.

pH [fig 67.4]

The first reading recorded was 10.08 and the last 10.07. The recorded pH did not change greatly during the deployment; the maximum and minimum values being 10.11 and 9.62 respectively. These values seem unreasonably alkali and

[18] Dissolved oxygen ‘percentages’ can apparently exceed 200%

[19] No high wave readings were recorded at the Sevenstones Lightship during this period so the possibility of a storm causing these odd readings is unlikely (see fig 20)

are improbabe for open seawater. The pH probe was checked in tap water post deployment and gave a reasonable value (7.9). The sensor may have become unstable or fouled in some way.

Temperature [fig 67.5]

The recorded temperatures varied from 14.45˚C at deployment to 12.13˚C at retrieval. With minor fluctuations, the temperature fell steadily throughout the monitoring period – entirely reasonable for August to October. Reference to the recorded sea surface temperatures at the Sevenstones Lightship[20] shown in fig 22 shows that the temperature range recorded by the data logger is credible.

Depth [fig 67.6]

The chart of the depth data clearly shows the rise and fall of the tide as well as the spring and neap tidal cycles. The maximum and minimum recorded depths during this deployment were 15.86m and 10.05m respectively. It should be borne in mind that the pressure (depth) sensor was located in the body of the data logger and thus some 0.20m above the seabed.

Battery

At deployment the battery level was 10.9v and at recovery 10.3v.

[20] Bearing in mind that the Sevenstones data is for the sea surface and that from Colossus is on the seabed.

V2 (mesh)

Fig 67.1

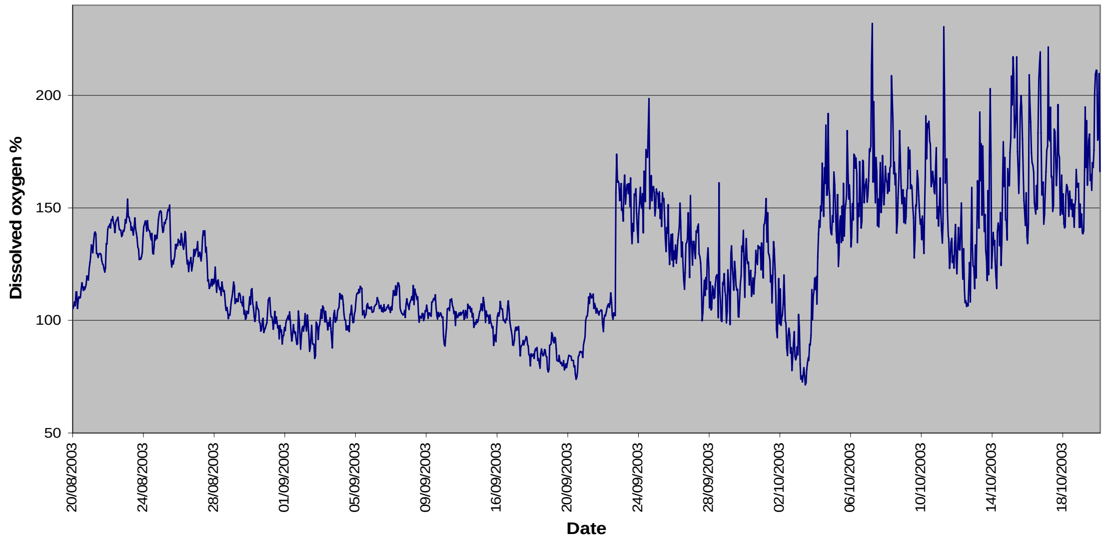


Fig 67.2

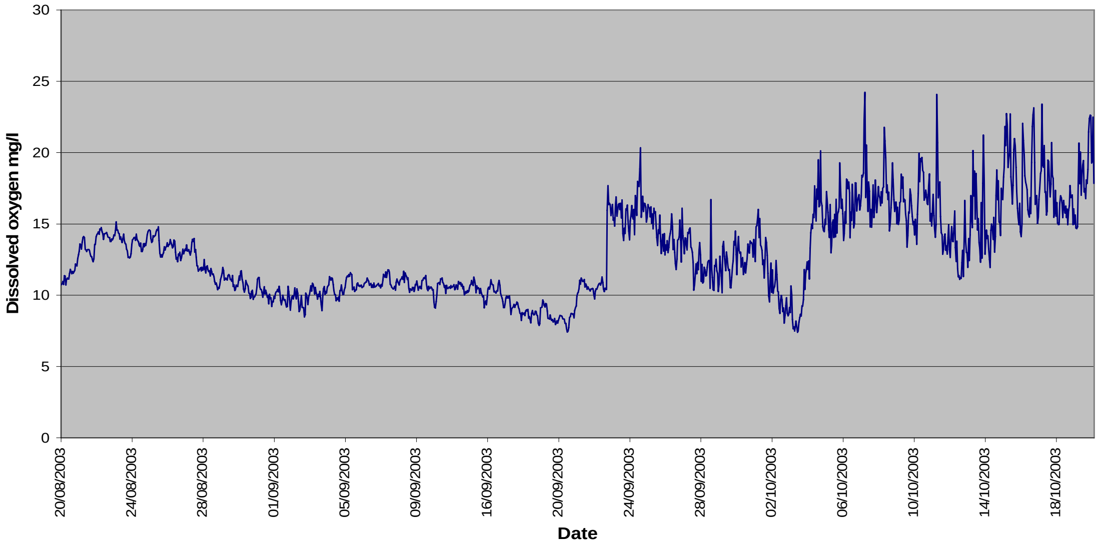


Fig 67.3

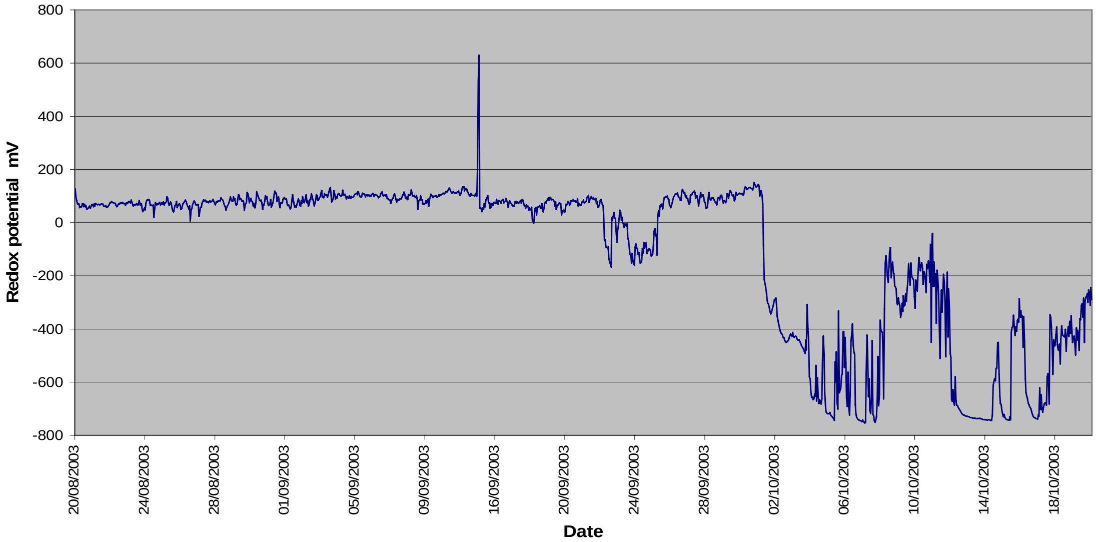


Fig 67.4

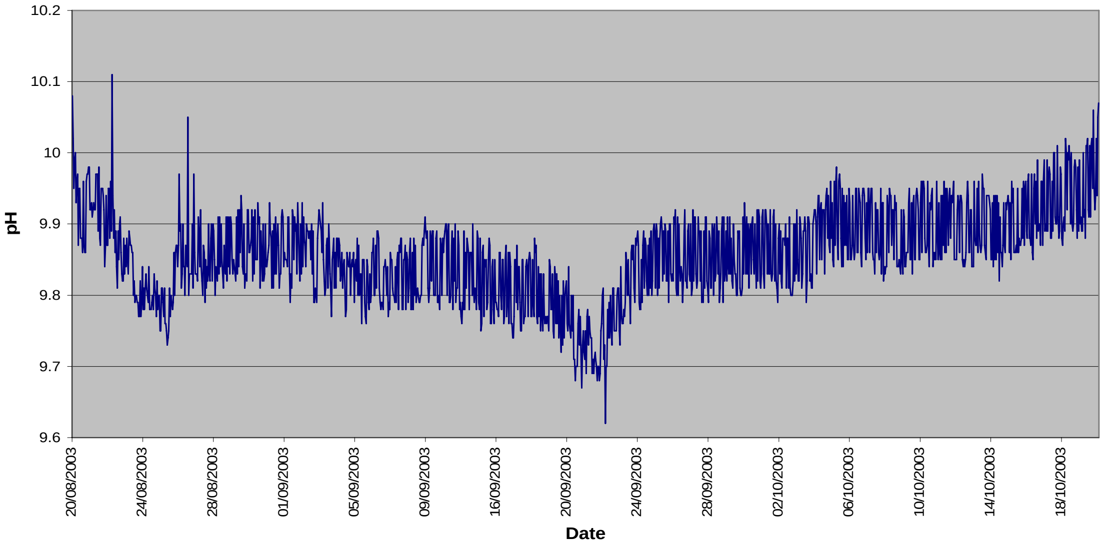


Fig 67.5

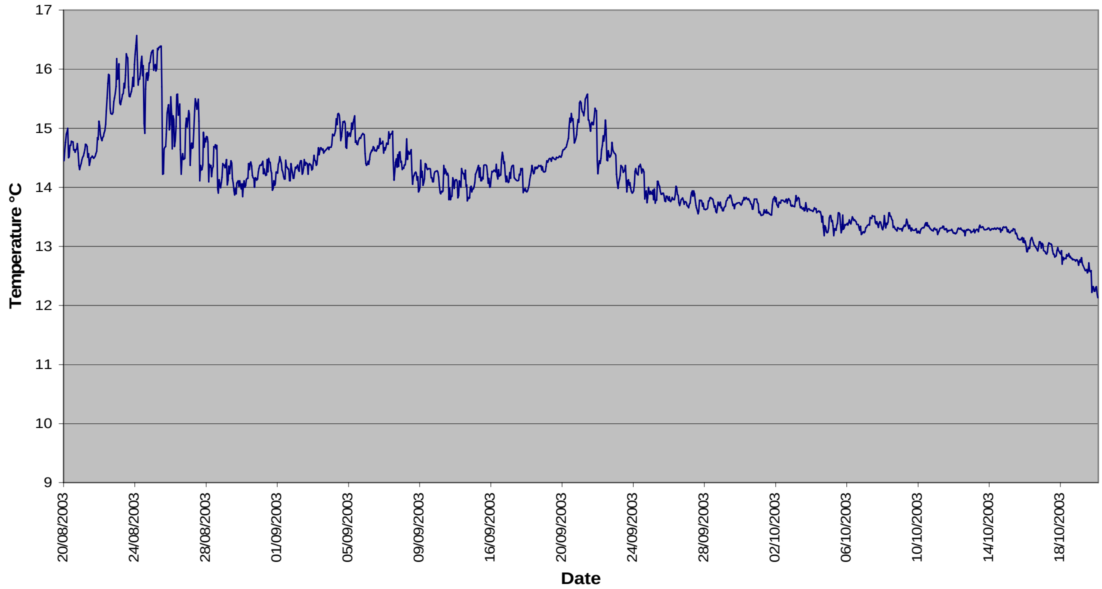
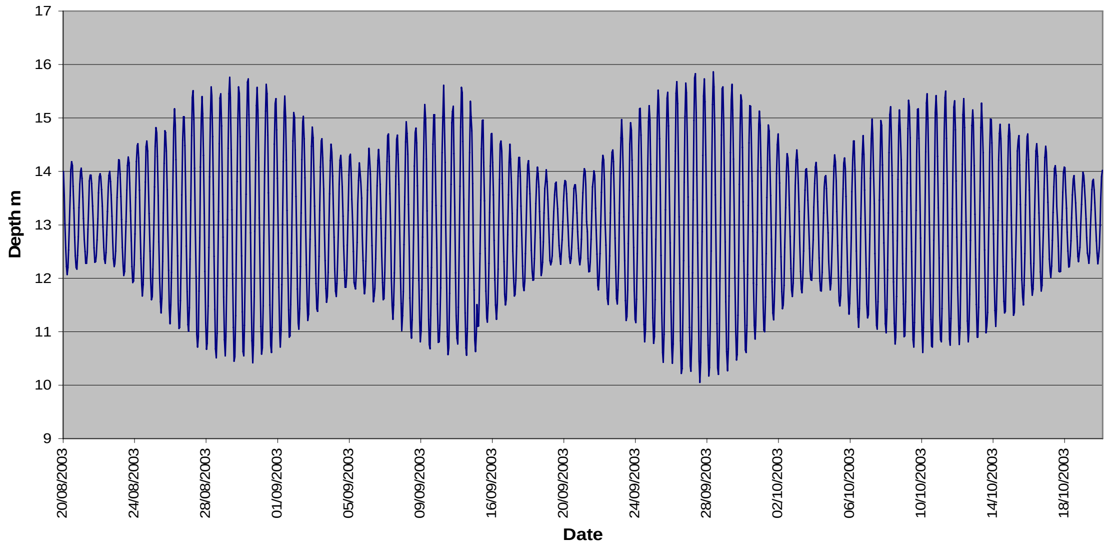


Fig 67.6



Test Area V3 (frond mat) May – August 2003

This data is for the 91 day period between 19th May and 18th August 2003. The mat had been in position on the seabed for 24 hours when the sensors were placed under the mat. They were positioned 0.50m south of sample blocks V3-A. The three probes (dissolved oxygen, redox and pH) were positioned 0.10m apart on the seabed and secured in position by the overlying mat.

Dissolved oxygen [fig 68.1 & 68.2]

The values for dissolved oxygen were output from the data logger as percentage and as milligrams per litre; charts are shown for both below. The first reading recorded for the dissolved oxygen was 97.1% (10.69mg/l). This rose over the next six hours to 105.2% (11.52mg/l) and then remained around 100% (11mg/l) for the next two days. The recorded level then fell steadily to reach 1% (0.1mg/l) by the 25th May. The level then fell further to between 0.2% (0.02mg/l) and zero for the remainder of the deployment. These readings indicate that conditions under this mat quickly became anoxic and then remained stable.

Redox potential [fig 68.3]

The first recorded reading for the redox probe was +234 mV. The recorded levels then fell steadily to -400 mV by 22nd May. The values then remained between -400 and -500 mV until 11th July, after when the values become less stable. They oscillate between -477 and +345 mV until 11th August when they again stabilise at around -500 mV until the end of the deployment. This indicates that conditions became strongly reducing within three days, apart from the period of ‘instability’ between 11th of July and 11th of August. This period of instability may represent a malfunction of the redox probe.

pH [fig 68.4]

The first recorded pH value was 6.47. This rose within six hours to 7.74. The values then remained essentially between7.5 and 8 until 2nd August when they started to fall slightly. By the 6th August they had reached 7.45 after which they oscillated between 7.1 and 7.5 until the end of the deployment.

Temperature [fig 68.5]

The recorded temperatures varied from 11.03˚C at deployment to 13.79˚C at retrieval. The maximum and minimum recorded temperature for this deployment were 13.79˚C and 11.03˚C respectively. Reference to the recorded sea surface temperatures at the Sevenstones Lightship shown in fig 22 shows that the temperature range recorded by the datalogger is credible.

Depth [fig 68.6]

The chart of the depth data clearly shows the rise and fall of the tide as well as the spring and neap tidal cycles. The maximum and minimum recorded depths during this deployment were 15.67m and 9.77m respectively. It should be born in mind that the pressure (depth) sensor was located in the body of the datalogger and thus some 0.20m above the seabed.

Battery

At deployment the battery level was 10.7v and at recovery 10.3v.

V3 (fronds)

Fig 68.1

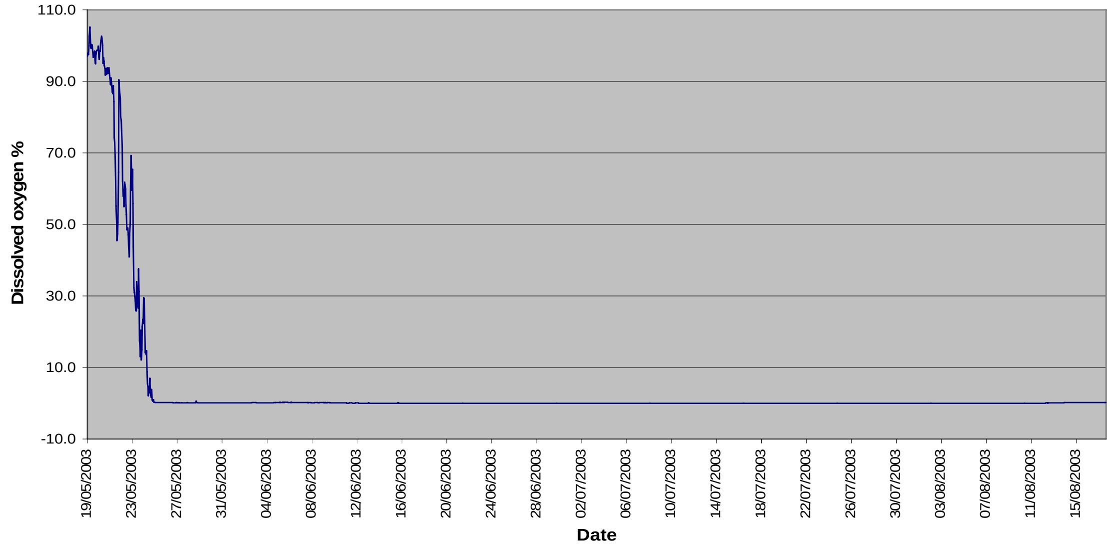


Fig 68.2

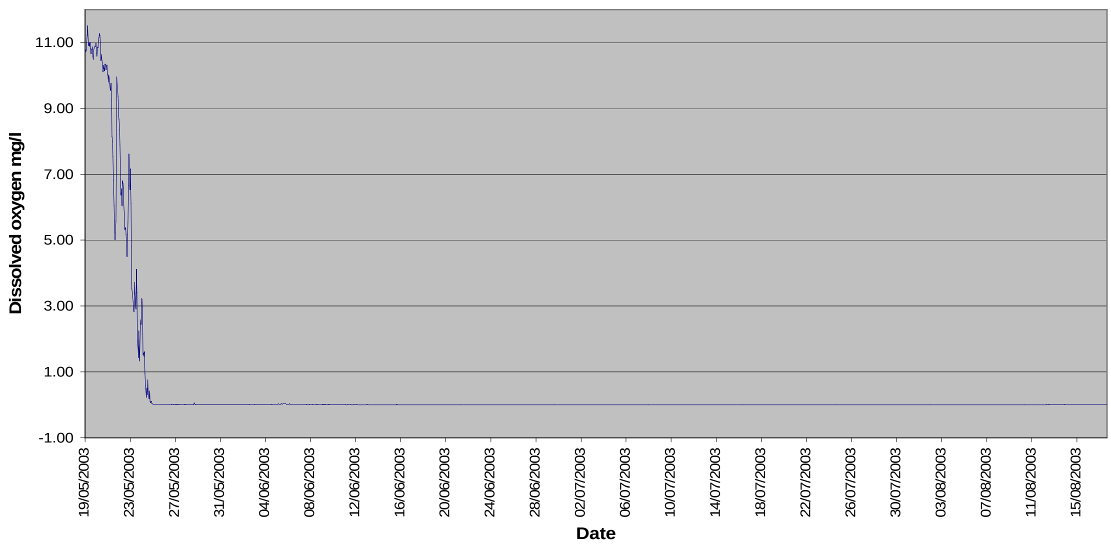


Fig 68.3

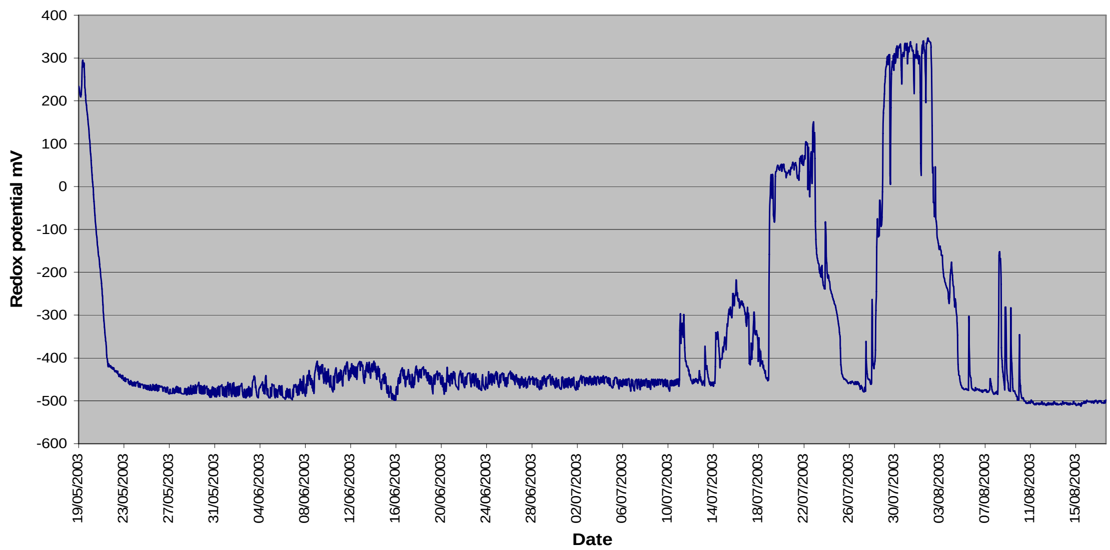


Fig 68.4

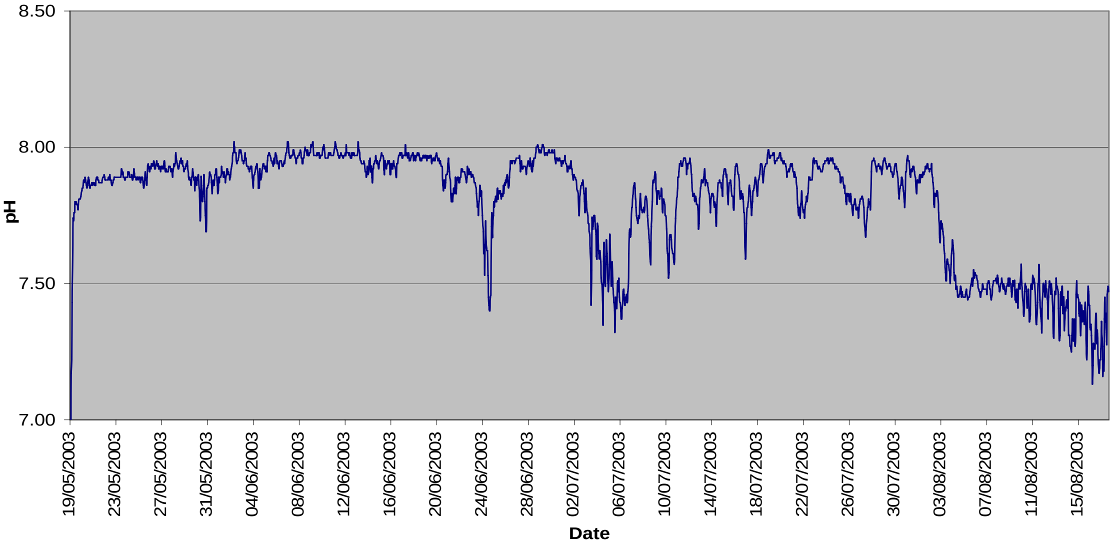


Fig 68.5

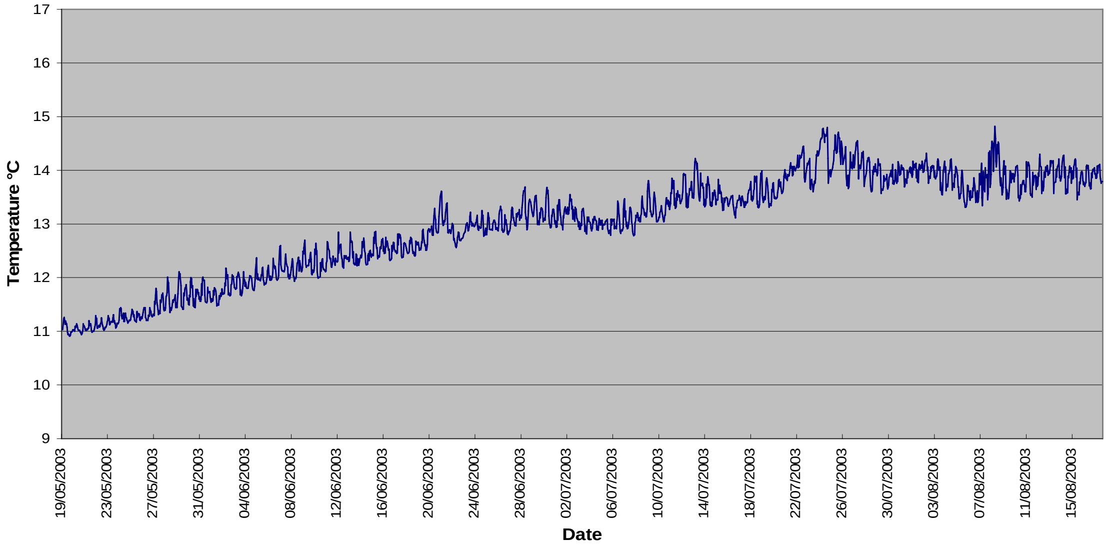
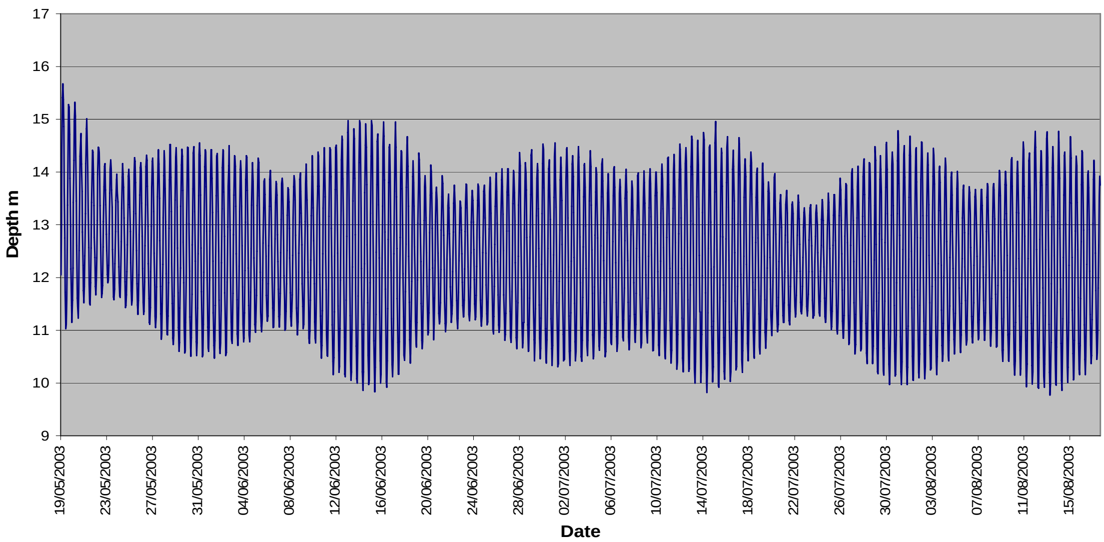
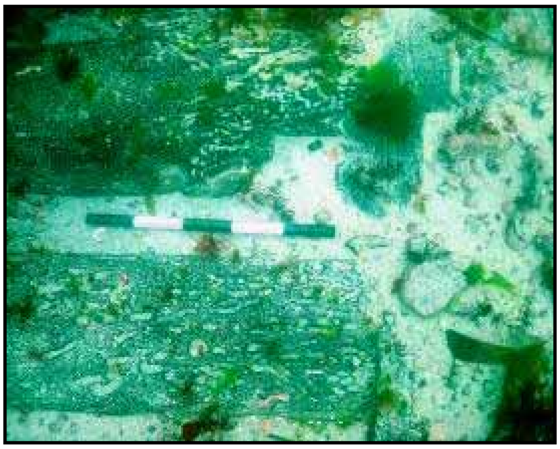


Fig 68.6



Interpreting the data

The most obvious damage to the exposed timber of the wreck is by gribble. The effects of wood boring organisms on the timber are apparent after about six months of exposure. The frame timbers shown here were photographed after one year exposed on the seabed. The timber sample blocks used in this trial also showed deterioration due to attack by wood-borers.



Colossus frame timbers showing the effects of wood-boring organisms.

The table below show the conditions under which these organisms can grow and survive. We cannot easily change the temperature or salinity on the seabed but the trials have demonstrated that we can change the dissolved oxygen by using geotextile mats. Both organisms require a dissolved oxygen level of above 1mg/l. The dissolved oxygen levels achieved under both geotextile mats (V1 and V3) were well below this at 0.02mg/l. This is clearly a viable technique of combating attack by these wood boring organisms on the timber of the wreck.

Wood Borer	Temperature	Salinity	Dissolved Oxygen
Teredo	5-30˚C	9-35 PSU	>1mg/l
Limnoria	9-26˚C	15-35 PSU	>1mg/l

Fig 69 General range of values in which teredo and limnoria grow[21]

Reliability of the data

None of the data sets obtained from the Waterwatch data logger were entirely free from anomalies. Problems were apparent with the pH data on two of the deployments (V1 and V2), with the dissolved oxygen on one deployment (V2) and with the redox on two deployments (V2 and V3). No problems were encountered with the temperature and depth data. This accords well with the MoSS projects experiences with this type of data logger.

The problem may be due to hardware malfunction or deployment technique. The similar problems encountered by the MoSS project with their Waterwatch data loggers suggest that hardware may be the problem as they used a completely different technique of deploying the probes. Despite the problems, useful data sets were obtained and the results for the dissolved oxygen and redox levels were of great value. The pH recording seems the most

[21] David Gregory *Monitoring Wooden Shipwrecks* in *Monitoring, Safeguarding and Visualising North-European Shipwreck Sites* (Final Report).

problematic and the value of trying to record this with the Waterwatch system may be questionable.

Sevenstones data

Reproduced below are charts of significant wave height (Hm0) and sea temperatures from the Sevenstones lightship, downloaded from the CEFAS Wavenet web site. These charts cover the period of the stabilisation trials and give some indication of the sea state during the trials. The Sevenstones Lightship is about 26km to the ENE of the site. Conditions are probably not the same at the Sevenstones and the site but some indication of when high energy conditions occur will be given by reference to the Sevenstones data.

V1 (Terram mat) data set March – June 2004

From the Sevenstones wave height charts it will be seen that there were significant wave heights above 5m on nine occasions during the datalogging of V1. Wave heights over 5m were recorded on six occasions between 3rd and 7th of April, the maximum recorded Hm0 being 5.6m. On 19th April the wave heights were above 5m for most of the day and reached a maximum of 7.2m. On the 21st April the height reached 5.8m, and on 5th May 6m. These are the roughest conditions encountered during any of the data logger deployments. No correspondence between these events and any data anomalies is apparent.

V2 (mesh mat) data set August – October 2003

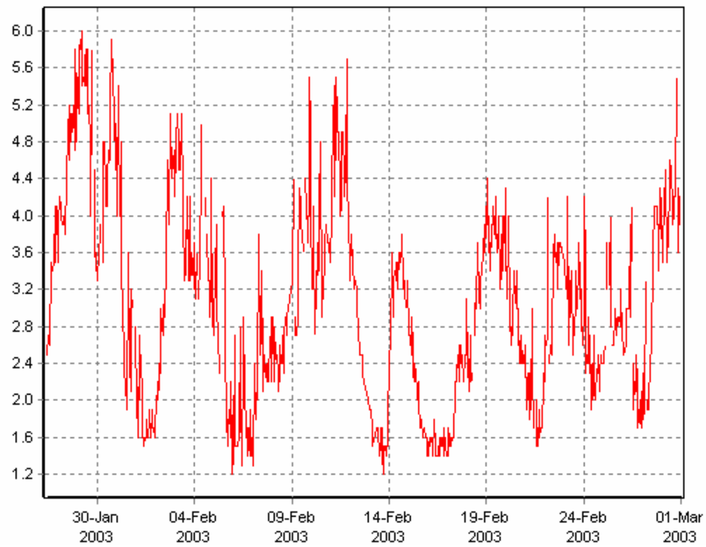
Only one significant wave height over 5m was recorded at the Sevenstones during this deployment. A wave height of 5.8m was recorded on September 10$^{th.}$. Apart from three peaks of 3.2, 3.3 and 3.7m in September the significant wave height was generally below 2m for this deployment.

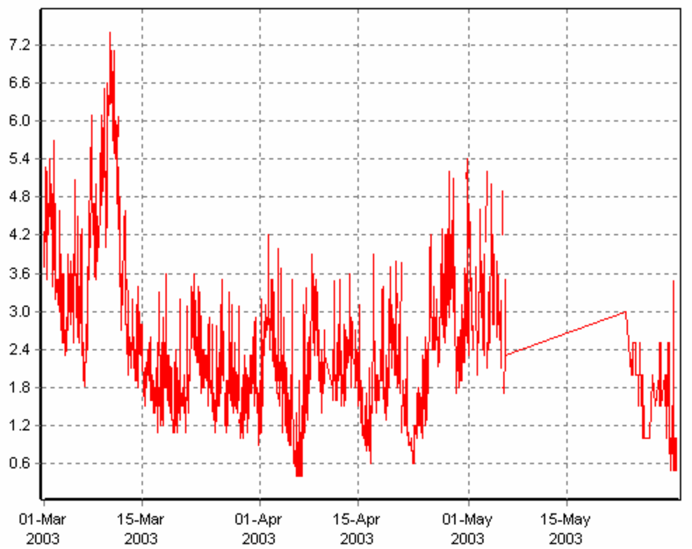
V3 (frond mat) data set May-August 2003

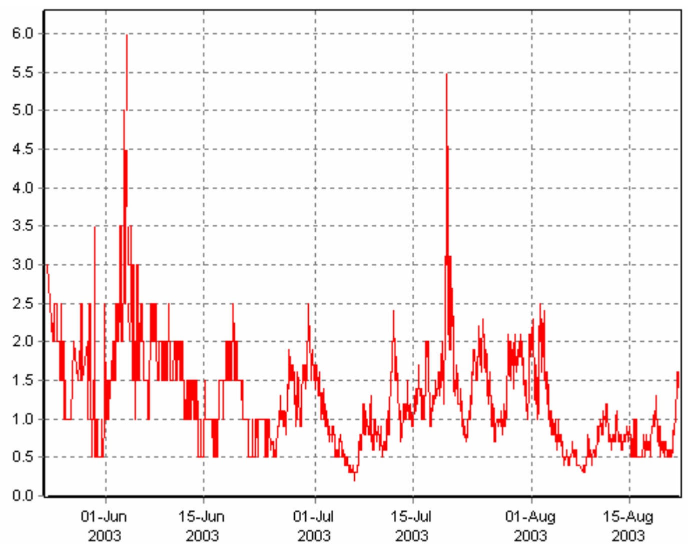
The Sevenstones wave height charts show significant wave heights above 5m on two occasions during the datalogging of V3. These occurred on 5th June (6m) and 20th July (5.5m). Both were of short duration (a few hours only) and apart from these events the significant wave height was below 2.5m for the duration of the datalogger deployment. Neither event seems to have caused any abnormal readings in the V3 data set.

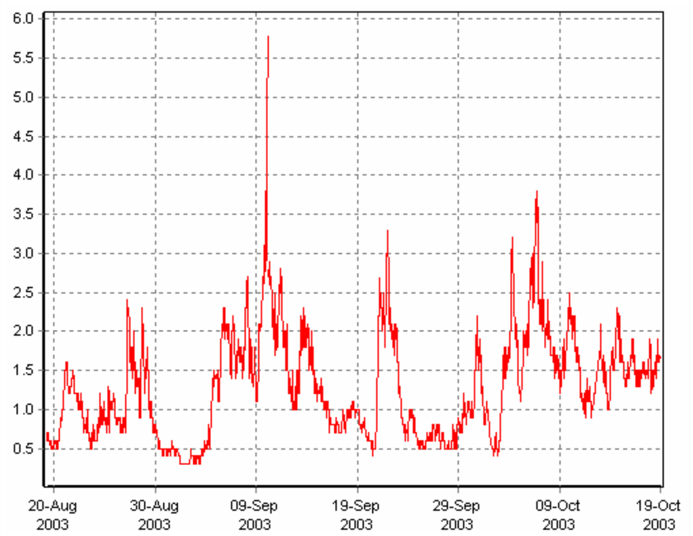
One possible cause for some of the apparent data anomalies noted in the stabilization trial data could be disturbance caused by large waves. However, none of these apparent anomalies corresponds with periods of exceptional wave height recorded at the Sevonstones.

Sevenstones significant wave height (Hm0) charts - 2003









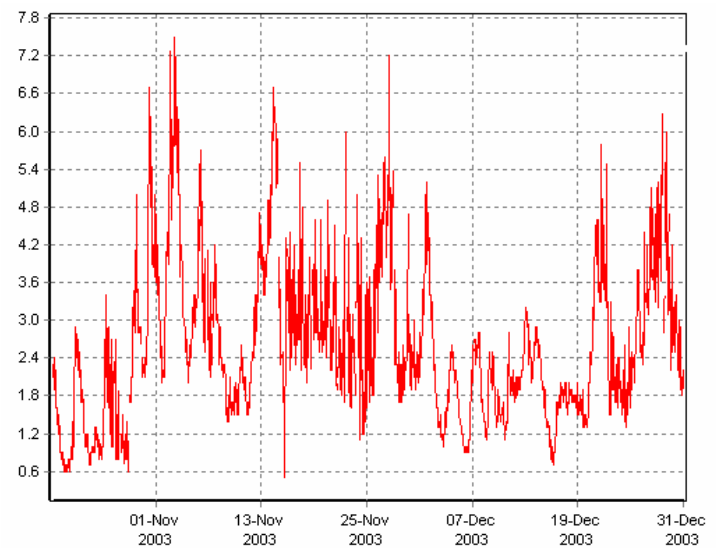
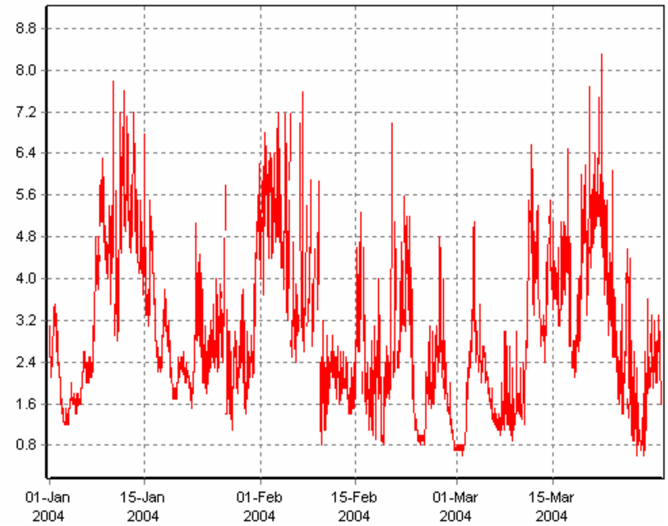
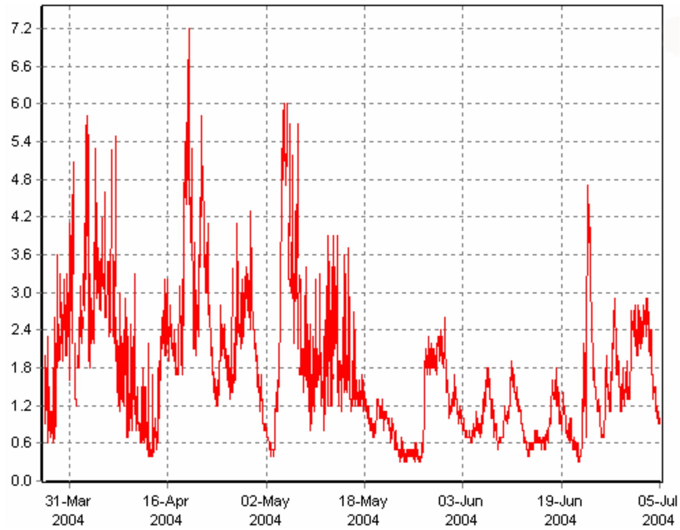


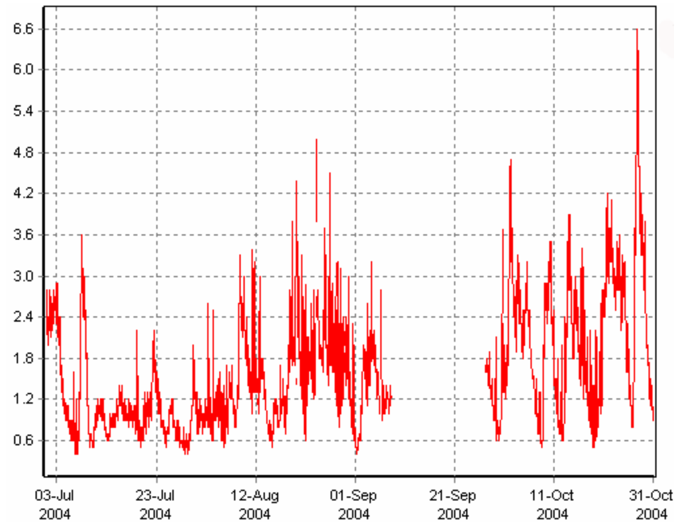
Fig 70
Significant wave height data from the Sevenstones Lightship 2003. The Sevenstones Lightship is operated by the UK Met Office.

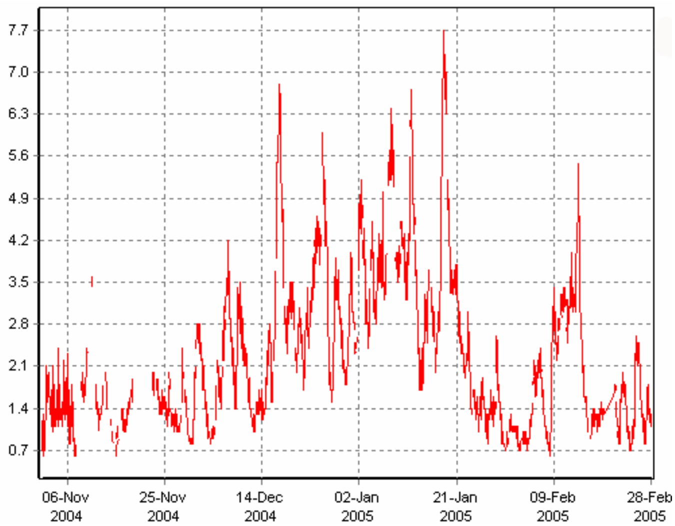
The data was downloaded from the CEFAS Wavenet site at www.cefas.co.uk/wavenet/gagc.asp

Sevenstones significant wave height (Hm0) charts – 2004/5









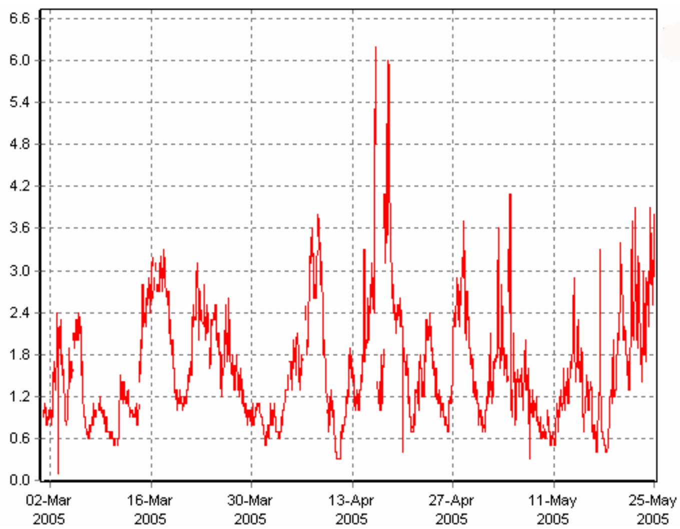


Fig 71
Significant wave height data from the Sevenstones Lightship 2004-5. The Sevenstones Lightship is operated by the UK Met Office.

The data was downloaded from the CEFAS Wavenet site at www.cefas.co.uk/wavenet/gagc.asp

Sevenstones sea temperature charts – 2003/4

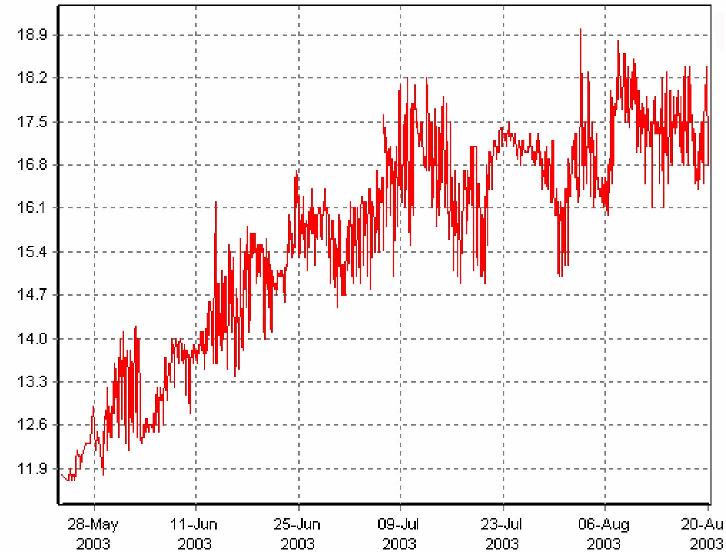
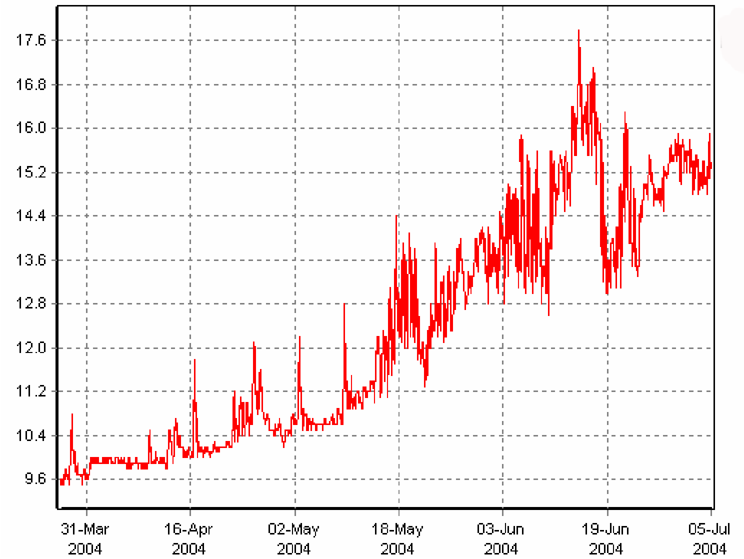


Fig 72
Sea surface temperature data from the Sevenstones Lightship 2003-4. The Sevenstones Lightship is operated by the UK Met Office.

The data was downloaded from the CEFAS Wavenet site at www.cefas.co.uk/wavenet/gagc.asp



Conclusions and recommendations

Sediment monitoring

Monitoring of the sediment levels around the exposed timbers of the wreck has demonstrated that the sediment is subject to mobility. Sediment levels were found to have reduced around the site after the winter storms. These levels then tended to rise again over the more settled summer months. Overall, the sediment levels decreased slightly over the course of the two year monitoring period. It is clear from observations on the site that a fall in seabed level of only a few millimetres will result in more timber being exposed on the seabed. Once the timber is exposed, it tends to stay exposed - possibly due to the action of sediment scouring.

There would be some benefit in continuing to monitor the sediment levels around the site over a longer period. To this end, the timber monitoring pins have been left in place so that sediment level measurements can be taken if required in the future. In addition, it would be prudent to continue to monitor the amount of exposed timber on the seabed and to monitor the condition of the timber which is currently exposed. Particular watch should be kept for further carved timber being exposed at the stern of the wreck.

Measurement of water flow rates over the site would aid interpretation of the sediment level data. A current meter installed on the seabed in the vicinity of the wreck (ideally for a 12 month period) would enable flow rates and storm surges to be accurately quantified. This would allow a more informed interpretation of the seabed level changes already observed. This, however, would not be cheap – consideration would need to be given to the cost effectiveness of collecting such data.

Sediment samples

The sediment samples taken from below the seabed surface clearly show a different composition to those taken from the seabed surface. The surface samples consist of medium sand, while the sub-surface samples exhibit a significant proportion of finer material when compared to the surface samples. One possible interpretation is that this is due to the seabed surface mobility already demonstrated by the sediment monitoring, the finer material having been dispersed during sediment transport in the surface layer.

Copper alloy samples

During the stabilisation trials three samples of copper alloy were taken from the site, in particular to determine the composition of the copper alloy fastening bolts used to fasten the hull timbers. The analysis showed that the copper bolts used in Colossus were composed of almost pure copper, and not an alloy as suggested by Lavery.[22]

[22] *The Arming and Fitting of English Ships of War 1600-1815* Brian Lavery 1987

Data logger

None of the data sets obtained from the Waterwatch data logger were entirely free from anomalies. Problems were apparent with the pH and redox data on two out of the three deployments. No problems were encountered with the temperature and depth data. This accords well with the MoSS project's experiences with this type of data logger.

The problem may be due to hardware malfunction or deployment technique. The similar problems encountered by the MoSS project with their Waterwatch data loggers suggest that hardware may be the problem as they used a completely different technique of deploying the probes. Despite the problems, useful data sets were obtained and the results for the dissolved oxygen and redox levels were of great value. The pH recording seems the most problematic and the value of trying to record this with the Waterwatch system may be questionable.

It has been suggested that it would be advantageous to collect sediment samples and assess their chemical composition to better understand redox and pH results in any future data logging.[23]

Stabilisation

The Terram 4000 mat (V1) and the floating frond mat (V3) performed well in terms of producing conditions favourable to the preservation of timber. They both achieved anoxic conditions (less than 0.02 mg/l of dissolved oxygen) within days. In the case of the floating frond mat (V3), this was not caused by sediment accumulation but probably by the geotextile used as a base for the mat.

Analysis of the timber sample blocks showed that attack by the wood boring organisms *Teredo* and *Linmnoria* were the principal agents of timber deterioration over the two year period of the trial. Although fungal hyphae were observed in the samples no evidence of fungal decay was detected. Bacterial decay was detected in the control samples and, to a lesser extent, in the samples from the mesh (V2) and the frond (V3) mats. No bacterial decay was observed in any of the samples protected by the Terram (V1) mat.

None of the timber sample blocks recovered from the Terram 4000 mat (V1) showed any attack by wood borers even after two years under the mat on the seabed[24]. By contrast, the control blocks (V0) had been seriously damaged after two years, with parts of the blocks entirely missing at recovery. The blocks recovered from the mesh (V2) and frond (V3) mats both showed some attack by wood boring organisms.

[23] Personal correspondence with Ian Panter of EH.
[24] This accords with results obtained elsewhere. It has been shown on the MoSS project (referenced above), and by Pournou who conducted trials on the Zakynthos wreck, that Terram 2000 and 4000 afford protection from wood boring organisms on the seabed.

All the proximity test blocks showed attack by wood boring organisms. The level of attack was slightly higher in the blocks 2m from the wreck than in those 24m from the wreck. However, one of the blocks 14m from the wreck showed the highest level of attack of all. It is apparent that there is no clear relationship between proximity to the wreck and the level of attack by wood boring organisms.

In each case the stabilisation trial mats (V1 – V3) performed better than the control area (V0) in terms of building sediment levels. Although the sediment levels varied, at any given inspection the relative performance of the different trial methods was the same. The Terram 4000 consistently outperformed all other methods, followed by the frond mat (V3), and finally the mesh mat (V2).

The Terram 4000 was found to be the best method of stabilisation (of those tried) in terms of efficacy, cost and ease of deployment. It performed well for two years without any need for maintenance and was the only system which was still in good condition at the end of the trial. On this site this is clearly the most suitable system of those tried, should any stabilisation of the wreck be undertaken.

If any stabilisation is to be installed on the wreck then I would recommend that the eastern end of the wreck is protected with Terram 4000. Specifically, the area to the east of the trial excavation undertaken in 2002 is one obvious candidate. This would protect the stern of the wreck where any remaining carved timber is likely to be situated. This amounts to an area of approximately 65 square metres. Another advantage of protecting this area is that the upstanding guns and extensive timber to the west of Gun 1 would be left on the seabed as an amenity for visiting divers while protecting approximately 25% of the exposed timber under a Terram 4000 mat.

If it is decided that no stabilisation of the exposed timbers is to be undertaken, then consideration should be given to further investigations at the stern. This would establish whether there is more carved timber buried beneath the seabed which - if current trends continue - will become exposed eventually. If any further investigation of the site is contemplated then it will be advantageous to establish to what depth within the seabed sediments archaeological material exists, especially as the seabed waterjet probing undertaken in 2001 indicated a considerable depth of soft sediment around the exposed timber of the wreck.

Whatever approach is adopted, the continuing need to monitor and record the degree of exposure and deterioration of this wreck is obvious.

Kevin Camidge June 2005.

Appendix I – Terram 4000 data sheet

Terram – Thermally Bonded Nonwovens

TERRAM
Geosynthetics
data
P1 Data GB
03 May 2001 • 1 of 2

Product Grades		500	700	900	1000	1300	1500	2000	3000	4000
Mechanical Properties – control										
Wide width strip tensile EN ISO 10319										
- Mean peak strength	kN/m	3.0	6.0	7.5	8.0	10.5	12.5	14.5	18.0	22.0
- Elongation at peak strength	%	35	25	28	28	28	30	30	33	33
CBR puncture resistance EN ISO 12236										
- Mean peak strength	N	525	1050	1350	1500	2000	2250	2750	3250	4300
Trapezoidal tear resistance ASTM D4533										
- Mean peak strength	N	175	225	275	300	425	475	575	700	900
Mechanical Properties - consequential										
Wide width strip tensile EN ISO 10319										
- strength at 5% strain	kN/m	1.3	2.6	3.2	3.4	4.3	4.7	5.5	6.3	7.5
Hydraulic Properties - consequential										
Pore size EN ISO 12956										
- Mean AOS O_{90}	μm	300	180	160	150	130	125	110	100	85
Permeability EN ISO 11058 - VI_{H50}										
- 5cm head	$10^{-3}m.s^{-1}(l/m^2.s)$	150	130	105	100	80	75	65	55	45
Physical Properties - typical										
Mass per unit area EN 965	g/m^2	65	90	115	125	160	180	215	260	335
Roll width	m	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Roll length	m	200	150	150	100	100	100	100	100	50
Roll weight	kg	65	65	85	65	80	90	105	125	80

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Web: www.terram.com

Certificate No: FM 22730

Property Description

Control Properties

Control properties are those properties that are statistically controlled during manufacture of the product. The results quoted are the family means of the appropriate tests derived over periods of time. Other statistical parameters are available on request.

Consequential Properties

Consequential properties are those properties which arise as a consequence of the manufacturing process. Furthermore, the test methods used to evaluate these properties do not have the required level of reproducibility to be used as control tests. The result quoted are the family means of the appropriate tests derived over periods of time.

Typical Properties

Typical properties are family means of the appropriate tests derived over periods of time.

Composition and Environmental Behaviour

Composition

70% polypropylene / 30% polyethylene.

Chemical Resistance

Alkali - Resistant to all naturally occurring soil alkalis.
Acid - Resistant to all naturally occurring soil acids, (i.e. to acids of pH$\geq$ 2).

Biological Resistance

Terram is unaffected by bacteria, fungi, etc. Since it is not a source of nourishment, rats and termites will not eat the product as food.

Reaction to Temperature

The tensile strength of Terram decreases with increase in temperature, but recovers fully when the geotextile is returned to normal ambient temperature.

Exposure to Sunlight

Terram is delivered in coloured polyethylene wrappers to protect it from the harmful effects of ultra-violet rays: it is recommended that it remains wrapped until it is to be used.

In most applications geotextiles are exposed to direct sunlight for only short periods during installation; the degree to which they resist the effects of UV light is, therefore, of no significance.

For projects where prolonged exposure is inevitable Terram Ltd offers special Terram grades with UV resistance to match the requirement. In these grades the UV light resistance is enhanced by appropriate stabilisers in the polymers, so that they retain over 50% of their original strength after exposure to 70,000 Langleys of solar radiation. All other properties are identical to the corresponding standard series Terram presented in the data sheet. Terram products with enhanced UV resistance carry the suffix UV (e.g. Terram 1000 UV).

Notes

1 The mean tensile strength and tear resistance values quoted are the mean values of either the length or cross directions, whichever is the lower.
2 For a full description of the test procedures quoted please refer to the specific methods of test.
3 Where widths or lengths greater than those supplied on one roll are required, jointing is normally effected by simple overlapping. However, depending upon application, subgrade conditions, material loading, convenience and cost, alternative methods (pegging, sewing, stapling or gluing) may be used. Please refer to the Terram Jointing Methods leaflet for more details.
4 As part of its continual improvement process Terram Ltd reserve the right to change the properties listed on this data sheet without prior notice.

Appendix II – Seabed Scour Control Mat

<u>T12 "Special" ROLLED MAT INSTALLATION PROCEDURE</u> (cont'd)

Seabed Scour Control Systems Limited

SEABED SCOUR CONTROL MAT

TYPE 12 "Special" MAT

MAT INSTALLATION

Drawings

1 T12 "Special" T12HH + 2M – Plan & Side Elevation. Drg. 5451-001

2 T12 "Special" T12HH + 2M – NOTES. Drg 5451-002

Photographs

1. T12 "Special" positioned ready for roll out
2. A Banding Strap marked by a white band
3. Cutting one of the four (4) Banding Straps
4. Inner Edge Membrane Unfolded and Pulled Out
5. Simulated Sand / Gravel Bags laid over the Inner Edge Membrane
6. T12 "Special" rolled out a further 2metres to show Safe Net and Buoy line
7. The Type 12 "Special" (under construction)
8. The Type 12 "Special" fully unrolled (under construction)

Note : These Drgs / Photos are normally Faxed or sent by Post.

SSCS Doc: T12Special-Instl *Page 5*

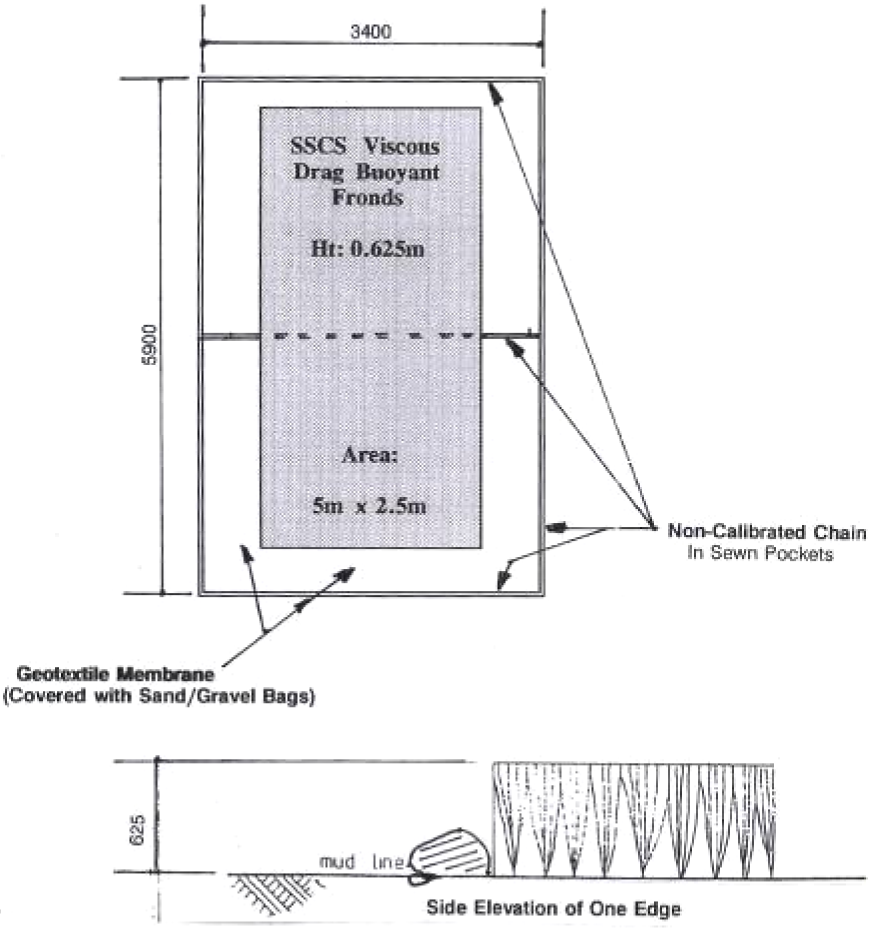
CLIENT English Heritage		SIG	DATE	**Seabed Scour Control Systems Limited**
PROJECT "Colossus" Wreck Stabilisation Trial	DRG'N	[signature]	8/4/03	
	APPV'D	[signature]	8/4/03.	
	REV.			

DRG TITLE **SSCS Type 12 "Special" T12HH + 2M – Scour Protection Mat**
Fronded Area: 5m x 2.5m, Buoyant Fronds: 0.625m Height,
Overall Area inc Membrane: 5.9m x 3.4m.

DRG NO. 5451-001

NOT TO SCALE

See DRG NO. 5451-002 for **NOTES (Page 2).**



REVISIONS

CLIENT English Heritage		SIG	DATE	Seabed Scour Control Systems Limited
	DRG'N	[signature]	8/4/03	
PROJECT "Colossus" Wreck Stabilisation Trial	APPV'D	[signature]	8/4/03	
	REV.			

DRG TITLE **NOTES: SSCS Type 12 "Special" T12HH + 2M ~ Scour Protection Mat**
Fronded Area: 5m x 2.5m, Buoyant Fronds: 0.625m Height,
Overall Area inc Membrane: 5.9m x 3.4m.

DRG NO. 5451-002

See DRG NO. 5451-001 for
PLAN & Side Elevation (Page 1).

NOTES:- "Colossus" Wreck ~ Stabilisation Trial

1. MAT for SCOUR PROTECTION as indicated on this DRAWING by SEABED SCOUR CONTROL SYSTEMS Ltd.

   MINIMUM REQUIREMENT:
   a). SSCS "Special" Type 12HH+2M SCOUR CONTROL MAT. Frond Area: 5.0m x 2.5m, BUOYANT FROND HEIGHT 0.625m; Geotextile Membrane Area: 5.9m x 3.4m.
   Weight in Air: 122kg, Est Weight Submerged: 95kg (includes weight of Non-Calibrated Chain In Sewn Pockets at the edges of the Geotextile Membranes).
   Minimum FROND Tensile Strength 530N for Colossus Site: Average SSCS FROND TENSILE STRENGTH 931N and up to 1181N.
   b). One hundred and twenty (120) Sand/Gravel Bags each weighing approx 25kgs in air must be supplied to cover the edge Membrane to provide all round hold down as NO anchors are to be used (It is advisable for a small "spare" quantity to be available in case bags are broken or misplaced)

2. MAT to be positioned and anchored by DIVERS, preferably two, but 1 competent DIVER should suffice. The Mat is crane deployed by a 2 leg wire rope sling (Slings supplied by SSCS). Detailed Installation Instructions are supplied with the Mat.

3. INSTALLATION. The Membranes **MUST** be covered by Sand/Gravel Bags as they are exposed / uncovered by roll out.

4. The SAFE NET must **NOT** BE REMOVED UNTIL THE INSTALLATION HAS BEEN FULLY COMPLETED.

5. **Additional Stability Post Installation - Frond induced Sedimentation:** For this site on the Type 12 Mat 5m x 2.5m with Half Height fronds (0.625m) the final submerged sediment bank should be in the range:

   – 4.8 tonnes to 5.8 tonnes submerged weight **over** the mat; this hold down is **additional** to the retention provided by the one hundred and twenty 25kg sand/gravel bags and also excludes gently sloping extension of sediment bank down to seabed up to 1.1m away from mat edge.

REVISIONS

1. T12 "Special" positioned ready for roll out

2. A Banding Strap marked by a white band

3. Cutting one of the four (4) Banding Straps

4. Inner Edge Membrane Unfolded and Pulled Out.
With non-calibrated chain sewn into the edge pocket, and
with the Safe Net covering the fronds and the Release Buoy visible.

5. Simulated Sand / Gravel Bags laid over the Inner Edge Membrane

Approx 24 Sand / Gravel bags, laid as in brick laying in layers, over the whole of the Inner Edge Black Membrane (3.4m x 0.45m = 1.53m² ~ 24 bags). They must **NOT** cover the fronded area nor the Rip Cord and Marker Buoy.

6. T12 "Special" rolled out a further 2metres to show Safe Net and Buoy line

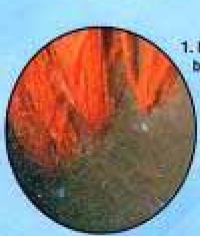
This is a simulated roll out. Subsea this **MUST NOT** be done until **ALL** of the Inner Edge sand / gravel bags are in place.

Appendix III – SSC buoyant frond systems.

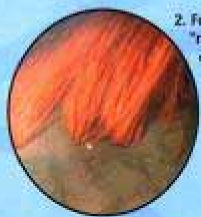
SSCS

"Natural" PROTECTION against Seabed Scour and Erosion ~ Combining the Forces of Nature for a permanent solution

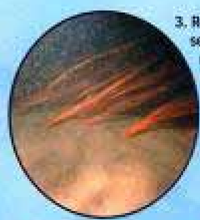
- When conditions that create scour exist underwater the problems associated with such scour can impact on subsea facilities immediately they are installed. That impact can become severe if it is not remedied. Scour can be physically damaging and can impose often unacceptable operating conditions as well as being environmentally detrimental.
- Following intensive Research and Development, Seabed Scour Control Systems Ltd (**SSCS**) created a method of harnessing nature to produce an economic, effective and permanent end to scour and **SSCS** has been providing solutions to the problems associated with scour in the offshore oil and gas industry since 1984.
- The **SSCS** Buoyant Frond Protection Systems have been used to protect all types of subsea installations by all of the major operating companies within the oil and gas sector. Installed both to provide immediate protection for new facilities and for post installation scour rectification works they provide long term maintenance-free protection.
- High Tensile Strength Buoyant Polypropylene Fronds set in parallel lines create Viscous Drag and so reduce the velocity of the current and STOP Scour. This Velocity Reduction leads to particles in suspension being deposited into the fronded area to form a permanent natural and dense sandbank which is also a natural habitat for marine life.



1. Initial sediment build-up covering mattress and the foot of the fronds.

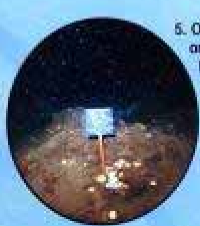


2. Further build-up "mounding" in centre and sloping to mattress edge.



3. Reinforced sediment bank near full development with a few short lengths of fronds still exposed.

4. Diver inspecting sediment bank in fully developed stage with short random fronds showing typical "ripple" pattern appearing on surface



5. One year after installation on a scoured pipeline. Marine life colonies on the final sediment bank which is sustained by natural ebb and flow of currents.

- The **SSCS** Systems and their applications have been approved by: –

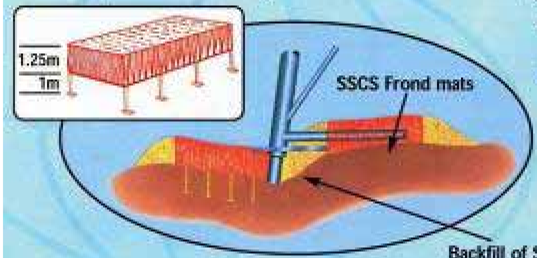
UK Ministry of Agriculture and Fisheries;
UK Department of Transport (Marine Directorate);
US Corps of Engineers;
UK National Rivers Authority (now Environment Agency);
British National Federation of Fisherman's Organisations;
Institute of Hydro-Engineering, Polish Academy of Sciences;
& Hydraulic Engineering Division, Rijkswaterstaat, Netherlands.

SSCS Products are approved as being an environmentally acceptable solution to scour.

- While the application of the **SSCS** Frond Systems has been acknowledged within the offshore industry they are now also being recognised for their efficacy and already proven use with Submarine Cables (Power and Telecommunications) and also with Offshore Wind Farms.

TIME AND TIDE STOPS FOR NOTHING - BUT SSCS SCOUR CONTROL SYSTEMS ARE FOREVER

- **SSCS Buoyant Frond Lines** ~ In all **SSCS** systems the Buoyant Fronds are set in continuous overlapping parallel lines, individual Fronds are 40mm wide UV Stabilised Polypropylene with a High Tensile Strength per strip: 681 to 1181N ~ Adequate Tensile Strength is essential for Viscous Drag systems. Standard Frond length: 1.25 metres. All Fronds are "Fibrillated" in film profile, sewn into base 6 tonne and 1.4 tonne MBS polyester webbing.



- **SSCS Frond Mats** ~ Mats are rolled out on the seabed and have a flexible anchoring system for diver installation - **SSCS** Anchors have a Lloyds and ABS certified retention of 1tonne per anchor. Standard Sizes ~ Type 12: 2.5m x 5.0m; Type 25: 5.0m x 5.0m and Type 30: 7.5m x 5.0m. All with high tensile strength buoyant fronds 1.25m in height.

- **SSCS Fronded Concrete Mattresses** ~ The **SSCS** Fronds are attached to a flexible base of concrete blocks inter-linked by a network of polypropylene ropes - for diver or work class ROV installation. Standard base block heights ~ 150mm,300mm, and 450mm. Block density 2.4t/m³ - density options are available up to 3.6t/m³. Sizes: Moulds are 10m x 3m in plan area. Tapered edge blocks are available for harsh or severe environments.

- **SSCS Anchors** ~ These are increasingly used for seabed retention purposes ranging from anchoring data recorders, GRP gratings, SSIV packages, fastening power and telecomms cables to the seabed and to provide temporary anchor points for subsea installation works, and are widely used by clients for projects where underwater anchoring and retention functions are required. The **SSCS** anchor driven in sand creates a LRQA and ABS certificated retaining force of 1tonne.

- **Consultancy ~ Scour Protection Assessment & Layout Design - SSCS** will execute for any site a full technical assessment and assess scour potential (given site specific environmental data) and, where necessary, provide an efficient, cost effective, permanent and maintenance free scour protection Design for installation.

- **Benefits** ~ "The key benefits in stabilizing and protecting submerged structures and pipelines with **SSCS** are: *Lower cost compared to currently used systems; "One-Off" only Cost - a Permanent Engineering Solution to Scour; Stops Scour immediately on installation; Build up of Permanent Mass Fibre Reinforced Sandbanks; Environmentally Acceptable; Effective in Deep and Shallow Water; Impact Damage Protection from Energy-Absorbing Sand; Load Bearing Solution - Natural agitation of Fronds creates Sand Compaction."*

  Hydraulic Eng. Division, Rijkwaterstaat, Netherlands.

- **SSCS Services and Applications** ~
  - *Base Protection of Subsea Structures*
  - *Protection of Cable / Pipeline Crossings*
  - *Subsea Cables (Power and Telecomms) Scour Protection*
  - *Scour Prevention at Offshore Wind Farms*
  - *Site Assessment & Design Service*
  - *Pipeline Scour Correction and Prevention*
  - *Outfall Scour Protection*

- **SSCS "Specials"** ~
  Designed and built as required.

Mat "Special" for a Subsea Power Cable

Fronded Concrete Mattress "Special" for a Telecomms Cable Crossing a gas Pipeline

Seabed Scour Control Systems Ltd

Harfreys Road, Harfreys Ind. Estate, Great Yarmouth, Norfolk NR31 0LS, UK.

Tel: 44 +(0)1493 443380 --- Fax: 44 (0)1493 443390

Email: info@sscsystems.com --- Website: www.scourcontrol.co.uk

Registered in England No. 2459166

Appendix IV – Sediment analysis – Matthew Canti.

M.G.Canti, English Heritage, Fort Cumberland, Eastney, UK. PO4 9LD

Introduction

Eight bagged samples from the seabed around the wreck of the Colossus were submitted for analysis. The aim of the work was to establish a baseline description of sediment properties for comparison with samples to be taken during future monitoring of the site preservation.

Figure 1 shows the locations of the samples in relation to the wreck. Most of these samples were surface deposits, but at the north east sampling position, a greater depth of stratigraphy was recorded and sampled as follows:-

0.20 - 0.25 m	Coarse sand and broken shell.	Sample SS6
0.25 – 0.40/0.60 m	Fine white compact sand or silt	Sample SS7
0.40/60 m -	Coarser light grey sand	Sample SS8

Similar stratigraphy was recorded to the south east, and at the centre of the site.

Methods

The main method used for the sediment characterisation was particle size analysis by sieves and a Sedigraph 5100. Samples were disaggregated using water and 0.5% Calgon, tested with both techniques, and full curves produced by the approach outlined in Canti (1991).

In addition, some of the fine sediment residues produced for the Sedigraph tests were dispersed in methyl salicylate and examined under the polarising microscope for mineral identification.

+

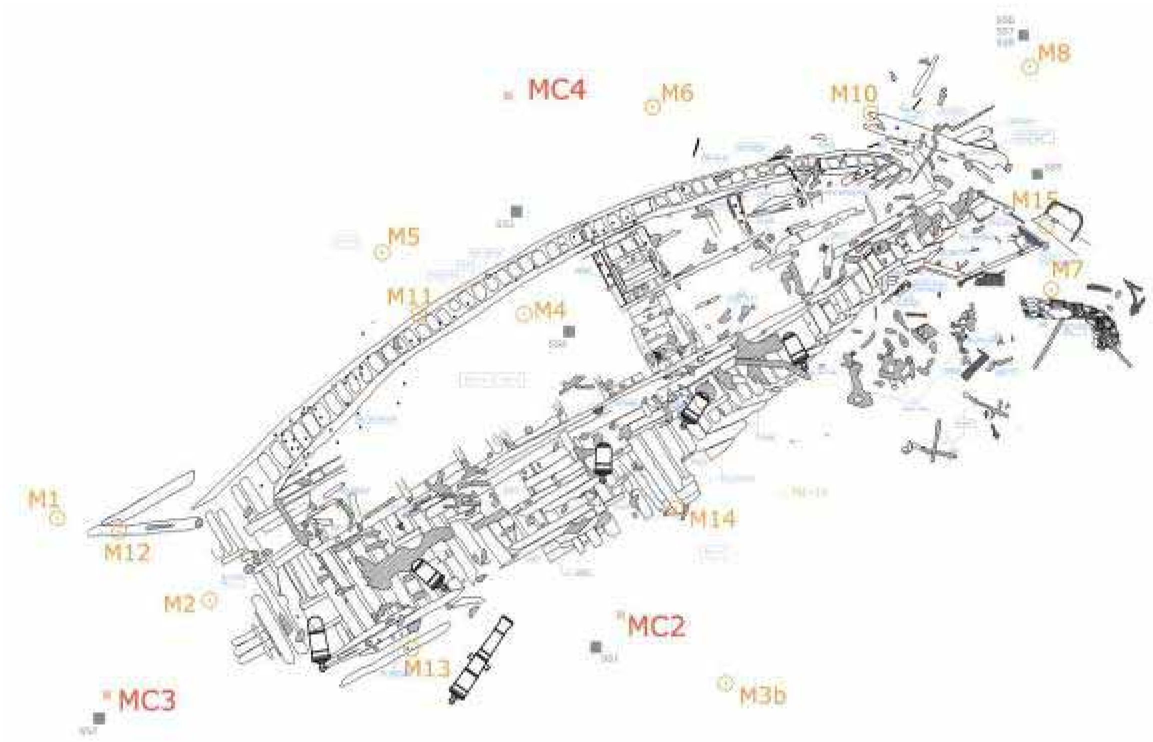


Figure 1. *Wreck plan and location of samples*

Results

Figure 2 shows the particle size results as a series of cumulative curves. These can be most simply interpreted as large proportions of material where the curve is steep and smaller amounts where it is flatter. SS1 to SS6 all show a steep curves around 250-400 µm, therefore having a strong modality in that diameter range (medium sand). SS7 and SS8, on the other hand, show highs in the size range 30 – 100 µm, which is silt and fine sand. Note also that large amounts of coarse stony material are present in SS3 (see 2 – 20 mm) and to a lesser extent SS5 and SS4. The textures of the fine earth (< 2mm) fractions are all sand, except for SS7 and SS8 which are sandy loams.

The large sized fragments were all of a dark igneous rock type. The silt and sand fractions were composed mostly of fine-grained biogenic carbonate material (60%) with a high proportion of heavy minerals (e.g. mica, calcite, tourmaline) and about 20% common quartz.

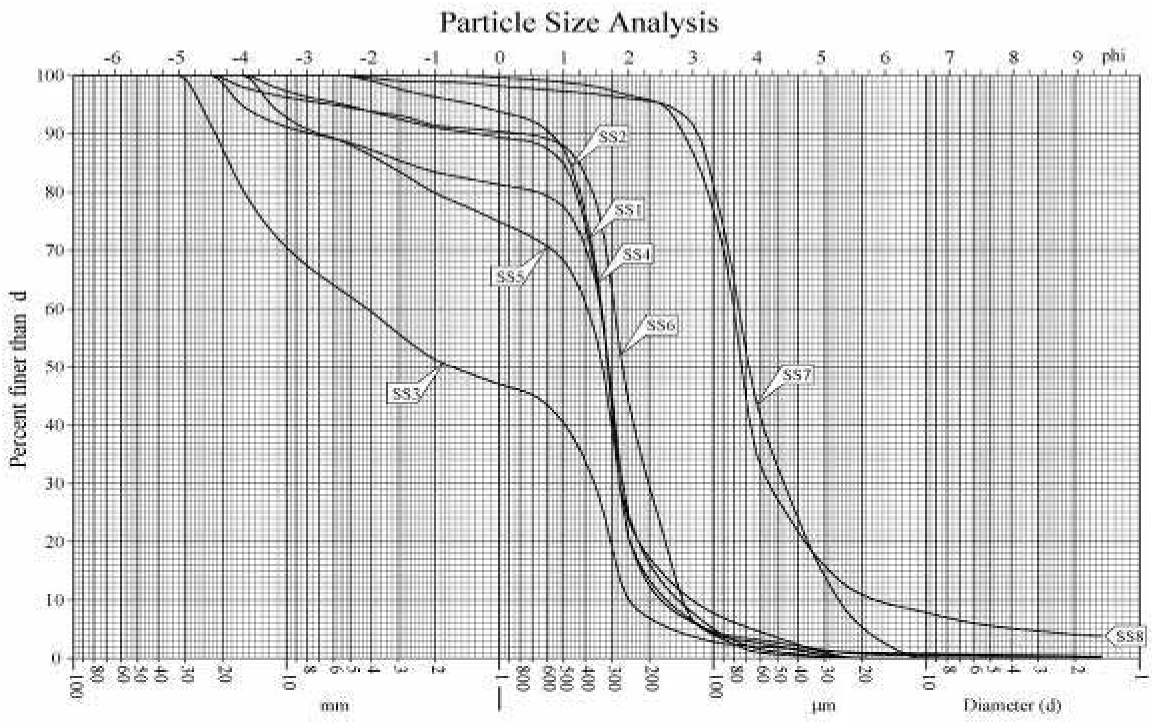


Figure 2. *Particle size analyses of the Colossus seabed samples.*

Sample	Sand	Silt	Clay	Texture
SS1	96.6	3.1	0.3	Sand
SS2	97.4	2.6	0.0	Sand
SS3	96.2	3.1	0.7	Sand
SS4	98.2	1.8	0.0	Sand
SS5	99.0	1.0	0.0	Sand
SS6	94.4	5.6	0.0	Sand
SS7	55.0	42.0	0.0	Sandy loam
SS8	66.6	29.4	4.0	Sandy loam

Table 1. *Textural groupings of the Colossus seabed samples.*

These results confirm the field description of the stratigraphy in all respects except that the ‘fine white compact sand or silt’ of SS7 is the same textural grouping (sandy loam) as the ‘coarser light gray sand’ below (SS8).

References

Canti, M.G. (1991) *Soil particle size analysis: a revised interpretative guide for excavators*, English Heritage Ancient Monuments Laboratory Reports **1/91.**

Appendix V – Observations on the V1 (Terram) data set.

Observing the overall data trend shows predictable trends in most of the responses. The datalogger being located close to the seabed with redox, pH and dissolved oxygen sensors provided with flying leads to allow placement of the measuring sensor below a protective 'matting' placed over the wreck site.

The temperature measurement showed typical seasonal variations. The depth sensor clearly shows the passage of the tides and the longer term cycles of neap and spring tides.

Dissolved oxygen rapidly descends to zero indicating anaerobic conditions below the mat and this is confirmed by the negative redox readings indicating highly reducing conditions beneath the mat. Redox is a measurement of the degree of oxidising or reducing reaction taking place positive readings would indicate oxidation reactions taking place. The redox and dissolved oxygen together clearly confirming the deeply anoxic state of the sub matting material.

The pH readings are less easy to interpret. Very little information is available relating to the measurement of pH in highly anoxic conditions and it is possible that the electrode has been affected in some way resulting in the movement to zero pH which would indicate strongly acidic conditions. It is also possible that in the highly reducing conditions hydrogen sulphide gas has been generated resulting in a very localised strongly acidic medium below the matting. It would be necessary to carry out some additional testing to confirm these effects.

Post deployment calibration would have confirmed the operation of the sensor. Some research of previously published work on pH measurement in fermentation processes my reveal relevant information. In summary, the readings would tend to indicate that the covering material successfully produces anaerobic, reducing conditions on the site below.

The use of a butyl rubber protection sleeve on the logger has dramatically improved resistance to fouling and the data logger has operated for the required periods on the internal batteries.

No major work was carried out on the datalogger during the operating period accept for routine calibration and service.

David Precious

Appendix VI –EauxSys sub-sea data logger check list

Deployment

Day before deployment

1. Set sample interval to 1 hour
2. Check input parameters are within tolerance
3. Charge battery – 16 hours

Immediately before deployment

4. Attach data probes – Ensure they are correctly connected
5. pH
6. Redox
7. DO
8. Remove protective caps from probes (3x)
9. Make sure blanking plugs are in place on data link and charging port

On the seabed

10. Attach data logger to the support frame
11. Place probes into required position (100mm apart)
12. Cover leads with sandbags – ensure leads cannot be snagged – there is a danger they could disconnect the plugs.
13. Switch the data logger on
14. Cover the body of the data logger with black butyl sheet

Retrieval

On the seabed

1. Switch off
2. Remove the butyl sheet
3. Recover probes and attach to the body of the data logger
4. Unbolt the logger from the support
5. Recover to the surface

On the boat

6. Place protective caps over the probe ends (3x)
7. Disconnect the probes
8. Replace probe socket protective plugs

Ashore

9. Download data
10. Log short data series in tap water to check proper operation
11. Recharge
12. Recalibrate
13. Pour a large beer

Appendix VII –Copper alloy analysis – David Dungworth

Introduction

Three copper alloy objects from the wreck site of HMS Colossus were examined and analysed. Small samples were taken from a bolt (SF420) a rove (SF403) and sheet (SF421); in the first two cases with a hack-saw and in the last case using side-cutters. The samples of copper alloy were mounted in resin and polished to a ¼-micron finish. The samples were examined using an optical microscope and a scanning electron microscope. Chemical composition was investigated using an energy dispersive X-ray spectrometer attached to the electron microscope.

Microstructure

All three samples display identical microstructures (see below). The metal is completely homogenous: there are no signs of segregation or coring associated with casting. The lack of coring shows that the metal has been heated after casting. The metal contains well-defined grains or crystals and these frequently contain annealing twins. The annealing twins are the bands visible within the grains. Annealing twins are formed in metals as they are heated during or after forging. The metal also contains numerous non-metallic inclusions which have been distorted by the forging of the metal (see SF403, below).

Chemical Composition

The analysis of the copper alloy samples showed that they are all composed of copper with traces of other elements. The analysis of large volumes of the metal failed to detect any elements other than copper. The analytical technique used has a detection limit for most elements in a copper alloy of 0.1–0.3wt%. The analysis of the non-metallic inclusions showed that these contain lead, arsenic, bismuth and oxygen.

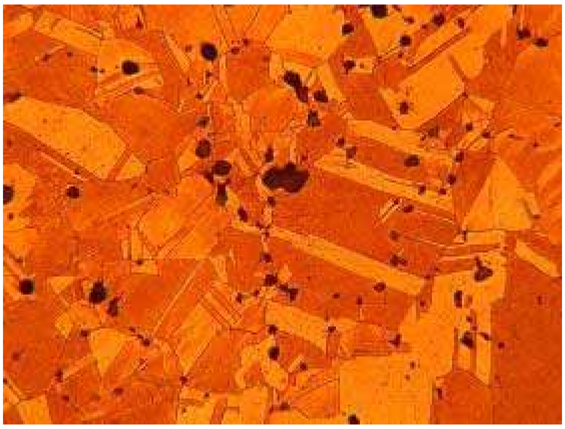
Discussion

The copper alloy fittings from the Colossus were all formed from an impure copper (~99wt% copper). The trace elements present in the copper are typical for English copper of the 18th century (Peter Northover personal communication). The metal components were all made by forging (or rolling) and annealing (heating) or possibly by hot-forging.

David Dungworth, 11th July 2005

Images

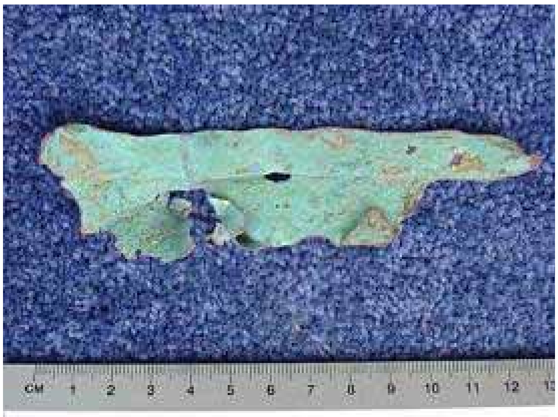
SF 420 Bolt



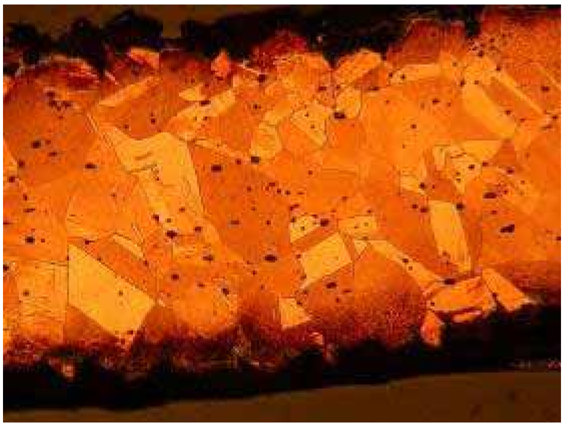
SF 420 (Image is 450microns wide)

SF 403 Rove

SF 403 (Image is 450microns wide)



SF 421 Sheet



SF 421 (Image is 450microns wide)