

HMS *Colossus*, an Experimental Site Stabilization

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HMS Colossus, a 74-gun warship, sank in the Isles of Scilly in 1798. The stern half of this vessel became exposed on the seabed some time around 2001. The timbers of the wreck were in excellent condition when first exposed but quickly began to deteriorate, mainly due to attack by wood-boring organisms. In 2003 English Heritage commissioned a two-year stabilization trial project on the site. These trials were aimed at determining the most effective method of protecting the exposed timbers of the wreck. Three different methods of protection were trialled, all of which had been used previously elsewhere. One of these methods, a Terram 4000 mat, was clearly the most effective on this site. In 2008, a small area of the wreck was covered with a Terram 4000 mat to determine the long-term efficacy of this means of site stabilization. Prior to installation the area to be covered was recorded in detail, along with an adjacent area as a control, to facilitate future comparison of the condition of the ship's timbers. This work, too, was commissioned by English Heritage (Camidge 2008).

KEYWORDS maritime heritage, marine heritage conservation, site stabilization, historic warship

Introduction

The ship

HMS Colossus was a *Courageux* class 74-gun warship built in 1787 at Gravesend and wrecked off Samson in the Isles of Scilly in 1798. The *Courageux* class ships were built from the lines of the French vessel *Courageux* captured by *HMS Bellona* in 1761 (Lavery 1983, 99). *Colossus* was one of four ships of this class built (*Carnatic* 1783, *Colossus* 1787, *Leviathan* 1790, and *Minotaur* 1793). The 74-gun ships were one of the most successful types of the period. They were typically about 51 m (170 ft) in length with a crew of over 600. During her relatively short working life (eleven years) *Colossus* saw action at Toulon, Groix, Cape St Vincent, and Cadiz. She also took part in the capture of two enemy ships in 1793. She had nine different captains during

her career. *Colossus* had a complete refit, which took six months, in 1796 (Camidge 2005).

In December 1798 *Colossus* was on her way home to England with a remarkable cargo including eight crates of Greek antiquities, wounded sailors from Nelson's victory at the battle of the Nile, and the body of a dead admiral. What she did not have on board was one of her spare bower anchors, which had been given to Nelson's ship *Vanguard* in Naples. This would prove to be disastrous. 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.

The site

The wreck of HMS *Colossus* lies in 15 m of water to the south of the island of Samson in the Isles of Scilly on a flat seabed consisting of light grey coarse sand. 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.

Salvage work took place on *Colossus* from the time of her loss until the early part of the last century. Work included Braithwaite and Tonkin 1803–1806, the Dean Brothers in the 1830s (Wessex Archaeology 2003) and possibly Western Marine Salvage in the early part of the last century. Roland Morris, a marine salvor, began searching for the wreck of *Colossus* in 1967 using a small team of divers. In August 1974 they located material relating to *Colossus*. A large quantity of pottery, remains of Sir William Hamilton's second collection of antiquities, was recovered and deposited in the British Museum — some of which is now on public display (Jenkins & Sloan 1996). Once Morris's team had finished their work, the site was de-designated in 1984.

Areas of exposed timber and iron guns were discovered by divers in 2001 (Figure 1). This material was over 300 m to the east of the area worked by Morris and turned out to be the stern half of *Colossus*. One of the most striking features of this part of the wreck is the row of 18 lb Armstrong pattern guns standing upright with their muzzles buried in the sand, still within the surviving gun ports of the hull. The discovery of these guns and a large carved human figure — part of one of the quarter pieces from the stern of the vessel — led to the redesignation of the site in 2001. The quarter piece was recovered in 2002 and was conserved at the Mary Rose Trust. It is now on display at Valhalla on Tresco in the Isles of Scilly.

What also makes this site so different from the many others in Scilly is the extent and remarkable preservation of the timber. When first uncovered, the timber appears perfect with fine surface detail visible. This was particularly apparent on the stern carving where much intricate detail was preserved intact (Camidge 2002, 21). It was clear that this timber had not been exposed on the seabed for the last two hundred years. Indeed, by May 2002 it was apparent that timber which had appeared perfect when first seen in 2001 was now decayed and gribbled. Furthermore, it was also clear that more of the wreck was emerging from the seabed as time went on.



FIGURE 1 Exposed remains of the stern of HMS *Colossus*, as drawn in 2003.

The inevitable conclusion was that the wreck had been preserved because it was buried in the seabed sediment. Unknown natural forces are now causing the sand to disappear from over the wreck. It is clear neither why this is occurring, nor whether it is a cyclic phenomenon or a more long-term trend. Observation of the site since June 2001 has shown a steady diminution of the sediment levels over the wreck.

The stabilization trials

In 2003, a two-year site stabilization trial was commissioned by English Heritage, to determine the most effective method of slowing down the deterioration of the exposed timbers on the seabed (Camidge *et al.* 2005). Complete stabilization of a site is probably not possible; the stabilization trials were intended to identify viable methods of slowing down the rate of decay.

Aims

The broad aim of the stabilization trial was to determine a method of protecting the timbers of HMS *Colossus* that were exposed on the seabed. These exposed timbers have deteriorated considerably 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 a number of different protection strategies, in the conditions prevailing on this site.

Most stabilization techniques depend on covering or reburying the site to offer protection from physical and biological damage. Examples of this include the Monte

Cristi 'pipe wreck' where a seventeenth-century merchantman was reburied using tarpaulins and a 1 m thick layer of sand and coral (Hall 2006), and on the wreck of the *Solway* which sank in South Australia in 1837 where sandbags were used to protect exposed timbers (Coroneos, 2006). Unsuccessful attempts at site stabilization were also taken into account, notably on the wreck of the *William Salthouse* where 0.4 m high fences were placed over the wreck (1985) which caused unexpected scouring, and where the mass dumping of hundreds of tons of sand from a sand dredger was also attempted but was not considered successful (Staniforth 2006, 52–54).

The different techniques used in this trial have all been used elsewhere with some success. Terram has been used during excavation of the *Mary Rose* (Jones & May 2006, 7), on the Monitoring of Shipwreck Sites (MoSS) project (Palma 2005) and on the Swash Channel wreck (Palma & Parham 2009). Synthetic mesh covering, consisting of polypropylene mesh secured over the site to encourage sediment accumulation, has been used in a number of cases — including the MoSS project, Sri Lanka and in the Netherlands by Martjin Manders (Cederland 2003, 65, Manders 2006, 58). Finally, a number of anti-scour systems are commercially available; these usually consist of floating fronds or artificial weed beds. One such system is that produced by Seabed Scour Systems Ltd of Yarmouth. A similar, custom-made system was used on the wreck of the *William Salthouse* (Harvey 1996, Staniforth 2006).

Methods

The stabilization trials were conducted over a two-year period between May 2003 and May 2005. Three different protection methods were employed in the trial. The area of the trial was some distance from the surviving timbers, about 25 m to the south of the wreck. Each trial area consisted of a rectangle 5×2.5 m, spaced evenly across the prevailing east–west tidal flow 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 (Figure 2). A control area, V₀, was also marked out but no protection was installed in the control area. There were good reasons for conducting the trials away from the structure of the wreck. First, it was necessary 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 stabilization systems. Secondly, had the frond matting performed as claimed, it would, if deployed on the wreck, have buried our existing primary control points and rendered ongoing survey impossible.

The effects of the different stabilization methods were determined using sample timber blocks ($0.20 \times 0.075 \times 0.025$ m) 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 and physical parameters were recorded beneath the geotextile mats (adjacent to the timber sample blocks) using a sub-sea data logger. Timber sample blocks were recovered at intervals of three, six, twelve, and twenty-four months. Measurements using the sub-sea datalogger were taken every hour for approximately three months under each of the geotextile mats in turn.

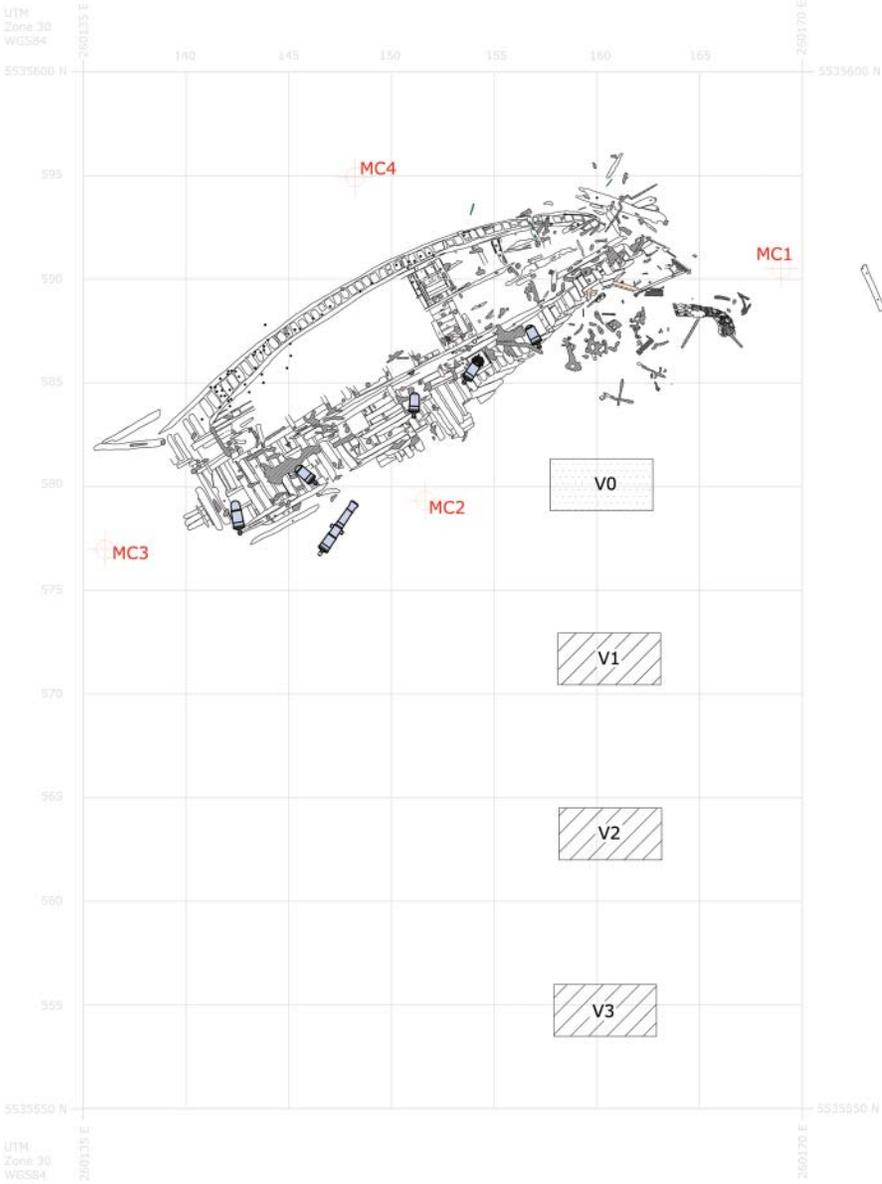


FIGURE 2 Location of the stabilization trial areas relative to the exposed wreckage.

Terram 4000 (V1)

Terram 4000 is a thermally bonded non-woven geotextile composed of polypropylene (70%) and polyethylene (30%). The Terram mat, 5 × 2.5 m, was laid on the seabed and weighted down using continuous lines of sandbags around the edges. 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 0.75 × 0.45 m and constructed of

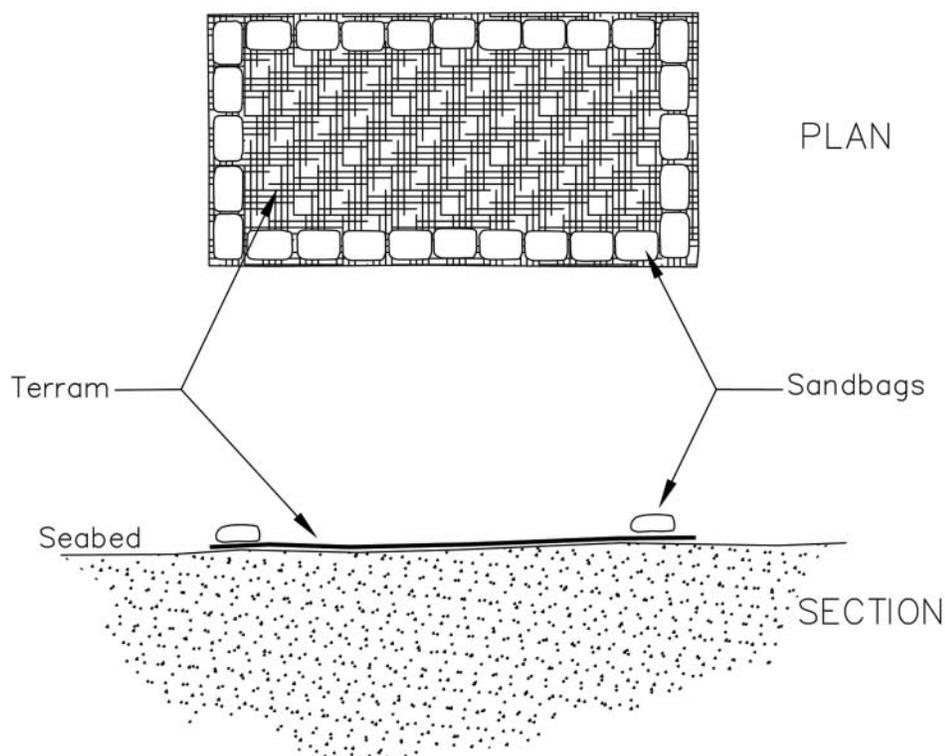


FIGURE 3 The Terram 4000 mat installed in trial area V1.

white laminated polypropylene. Each bag was pre-filled with 25 kg of coarse builders' sand and closed using a polypropylene tie. Thirty of these sandbags were used to secure this mat, a total weight of approximately 750 kg (Figure 3).

Synthetic mesh (V2)

This method has been used by Martijn Manders on a number of sites including the BZN 10 and *Darsser Cog* sites. A fine polypropylene scaffolding or shading net with a density or shading of approximately 50% to 60% was used (Cederland 2004, 65). 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' (Cederland 2003, 19).

This system was successful when deployed on the MoSS project. For the *Colossus* stabilization trial the mesh was deployed in exactly the same manner except that sandbags were used to anchor the mat instead of iron chain. Martijn Manders apparently also used sandbags to anchor the mesh on the *Avondster* wreck in Sri Lanka (Manders 2006, 58–60). A polypropylene mesh with 4 mm square aperture size was deployed in a mat 5 × 2.5 m. This was held in position by securely enclosing a continuous line of 0.75 × 0.45 m sandbags along the short (2.5 m) sides of the mat

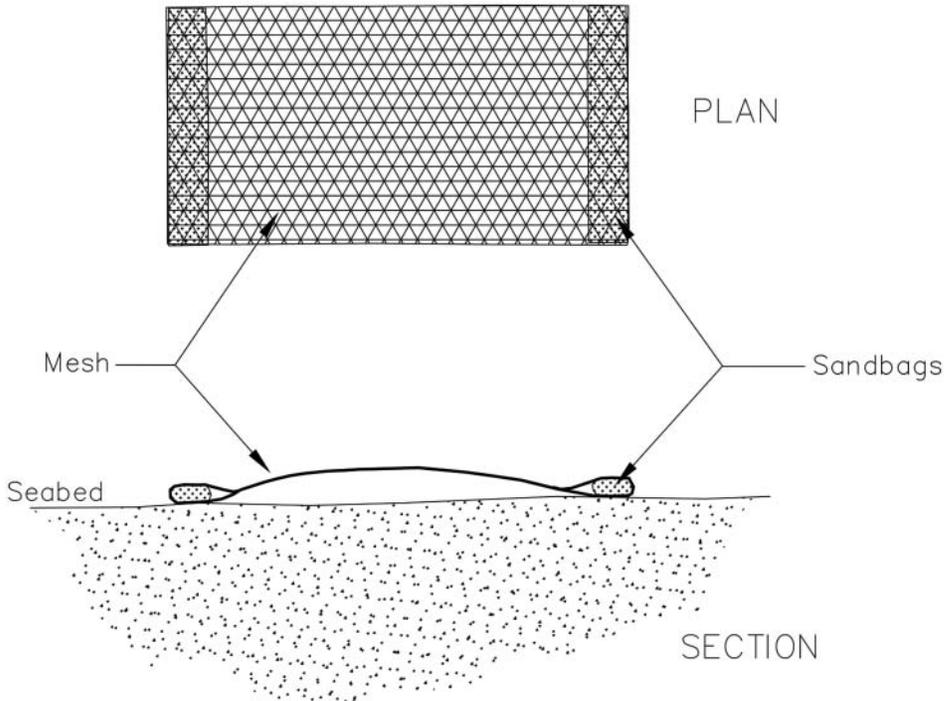


FIGURE 4 The synthetic mesh mat installed in trial area V2.

(14 bags) — this amounted to a total weight of 350 kg anchoring the mat. Cable ties were used to fasten the mesh around the sandbags. The centre of the mat was allowed to float approximately 0.50 m above the seabed (Figure 4). 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.

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.

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 synthetic 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 × 2.5 m and cost in the region of £500 each (2003). Seabed Scour Systems generously donated one of these frond matting systems for the stabilization trial.

The mats are usually anchored to the seabed using a system of intrusive iron fastenings *c.* 1 m 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 a double layer of sandbags was used, laid over the edges of the mats (Figure 5). Approximately seventy sandbags were used to anchor this mat, containing a total weight of 1750 kg of sand.

Deployment was slightly more involved than with either of the other two systems used in this trial. Installation was nonetheless straightforward and was accomplished without any significant problems.

Timber 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 (Figure 6). The blocks in the control area (V₀) were secured to the seabed so that each pair was at least 0.75 m apart.

The timber sample blocks from all three trial areas and the control area were retrieved after three, six, twelve, and twenty-four months on the seabed. At retrieval

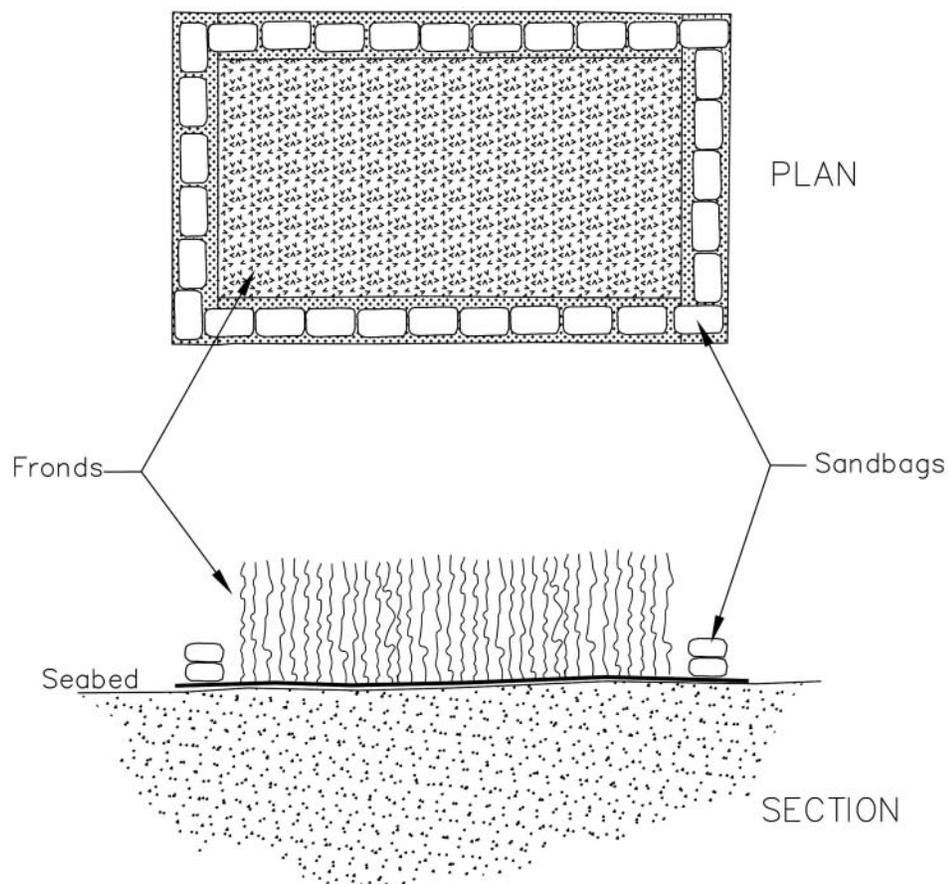


FIGURE 5 The floating frond mat installed in trial area V₃.

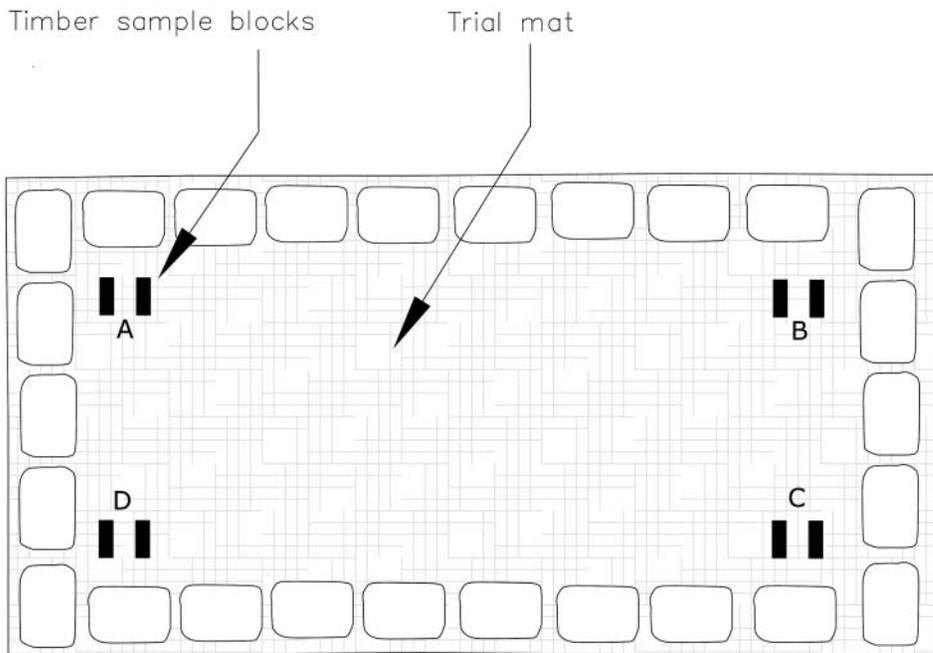


FIGURE 6 Positioning of the timber sample blocks in each trial area.

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.

FIGURE 7 Rating system for attack by teredinids and other wood-boring organisms (BS EN 275:1992).

they were wrapped in damp cloth (seawater), sealed in plastic containers and shipped in a chill box by twenty-four-hour courier service to Dr Mark Jones at the Mary Rose Trust for analysis. Attack by wood-borers was assessed visually and by x-radiography, and the level of attack classified according to the rating system laid out in BS EN 275:1992 (Palma 2005, 328).

Wood-boring organisms removed from the timber sample blocks showed that *Teredo* and *limnoria* were the two wood-borers active on this site. Bacterial

and fungal activity in the sample blocks was assessed using scanning electron microscopy.

Stabilization trial results

Sediment accumulation/entrapment

The sediment levels in each of the trial areas were monitored throughout the trial. All the trial protection methods performed better than the control area. The Terram mat (V1) outperformed the other methods in terms of sediment depth. This was probably because the Terram mat was colonized within three months of deployment by a growth of fine seaweed. This probably acted to slow down water flow over the mat, encouraging sediment suspended in the water column to be deposited on it, where it was trapped by the surrounding sandbags.

The mesh mat (V2) became torn and tangled within the first three months of deployment. A new mesh mat was installed over the top of the torn mat. But at the next inspection the mat was found to be fouled by large kelp fronds which probably hampered its performance. This situation was repeated at each subsequent inspection of the mat. The large amounts of loose kelp passing over this site probably make this type of protection unsuitable for this particular site.

The floating frond mat (V3) performed reasonably well at first, but the performance declined as the trial proceeded. The fronds became colonized by kelp growth, which tended to tangle the fronds and caused them to sink to the mat rather than floating. Moreover, the sediment levels over this mat were very variable; the measurements shown in Figure 8 for this mat (V3) were a mean of four readings.

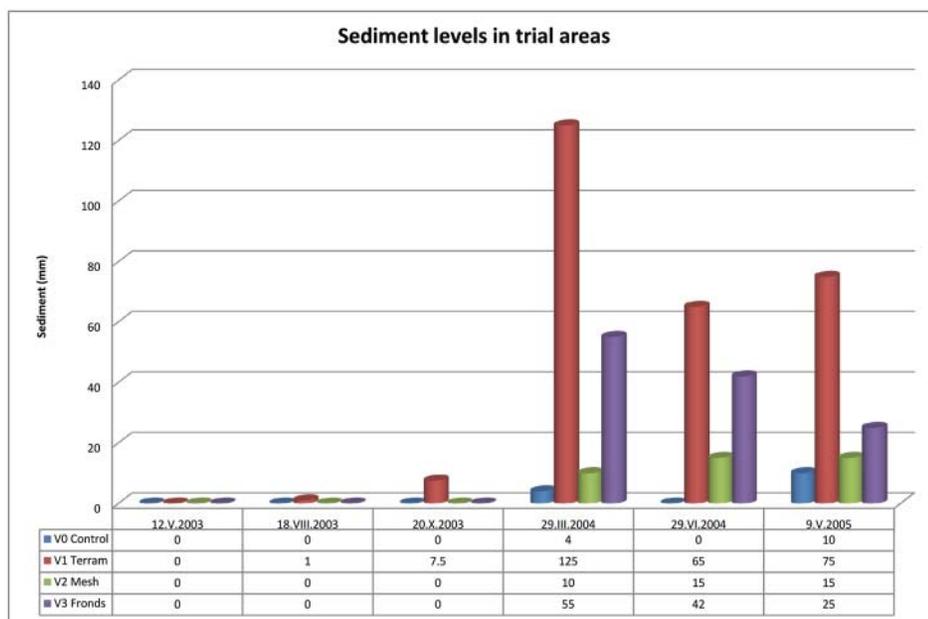


FIGURE 8 Sediment levels recorded in the trial areas — positive values indicate a sediment accumulation, negative values indicate sediment diminution.

It was clear from the trials that in terms of sediment accumulation the Terram mat (V₁) was the most effective. Furthermore, it was the only system on trial which did not have maintenance issues by the end of the trial.

Attack by wood-boring organisms

The greatest level of attack was observed in the control samples (V₀) which were left unprotected on the surface of the seabed. Figures 9 and 10 show that after five months' exposure slight attack was evident, increasing to moderate attack by twelve months and failure by twenty-four months. For definition of the attack levels, see Figure 7. These results confirm observations on the exposed timber of the wreck itself, namely that — after twelve months' exposure — attack by wood-boring organisms is readily apparent. The sample blocks retrieved from under the Terram mat (V₁) showed no signs of attack by wood-borers even after twenty-four months' exposure. This was clearly the most successful method trialled in terms of protection from attack by wood-borers. The blocks from the mesh mat (V₂) showed signs of moderate attack after twelve months' exposure. The samples blocks recovered after twenty-four months of exposure fared slightly better, only exhibiting slight attack. These blocks probably became buried by sediment sooner than those retrieved after twelve months. The timber blocks from the floating frond mat (V₃) showed slight attack after twelve and twenty-four months. This demonstrates that some protection was afforded by the floating frond mat, but that it was not completely effective.

The clear conclusion from this part of the trials is that on this site the Terram mat (V₁) is the most effective method, of those tried, for protecting timber from attack by woodboring organisms (Figure 11).

Fungal and bacterial attack

All sample blocks were examined by scanning electron microscopy to determine levels of attack by fungal and bacterial organisms. Fungal activity of all samples was found to be very low.

Pine: Bacteria

Colonization by erosion bacteria was evident after a three-month exposure period of control samples (unprotected). By twelve months the bacteria had penetrated 3 mm into the pine sample. The decay pattern (Figure 12) shows extensive damage to the cellular structure. By twenty-four months, the S₂ layer of the secondary wall has been severely degraded in the outer 5–6 mm layers. The best-preserved cell wall layer is the middle lamella.

Of the physical barriers used to protect the pine samples at the *Colossus* wreck site, Terram 4000 (Figure 6) prevented bacterial and fungal decay. Although bacteria had colonized 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 mat showed initial signs of bacterial decay in the outer surface layers. This suggests that pine samples protected by Terram 4000 very quickly became anaerobic, preventing aerobic decay by bacteria.

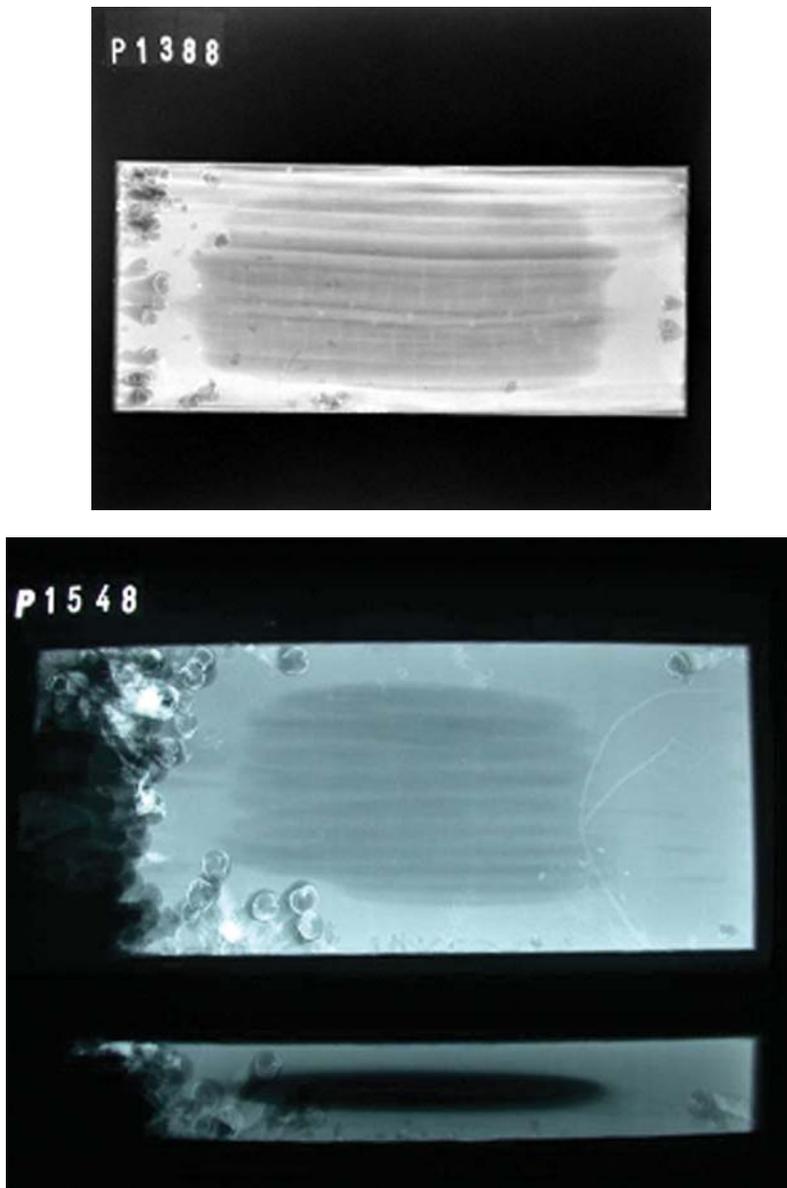


FIGURE 9 X-radiographs of pine sample blocks after five, twelve, and twenty-four months' exposure on the seabed (control V₀).

Oak: Bacterial activity

Bacterial activity was found on oak wood samples exposed at the wreck site of HMS *Colossus*. Colonization by bacteria was evident after three months' exposure and these organisms were associated with pit membrane degradation of unprotected oak samples. After twenty-four months' exposure (Figure 13), severe degradation of the outer surface by bacterial activity had occurred. By this period, decay was most

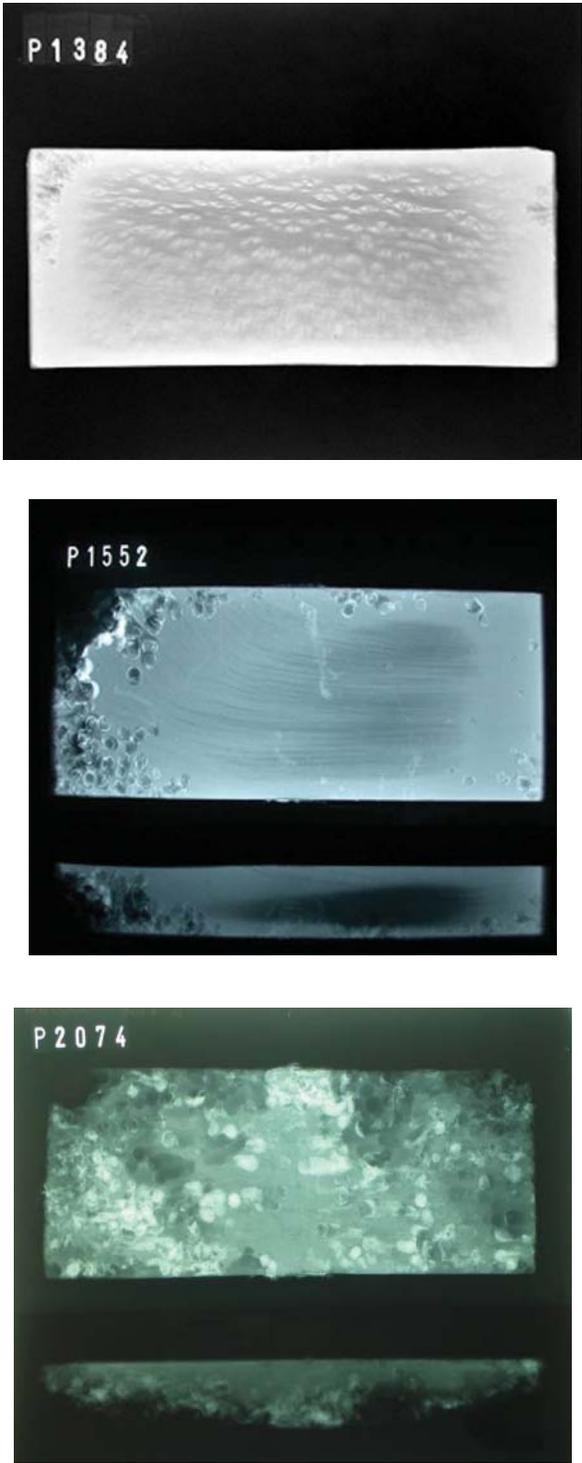


FIGURE 10 X-radiographs of oak sample blocks after five, twelve, and twenty-four months' exposure on the seabed (control Vo).

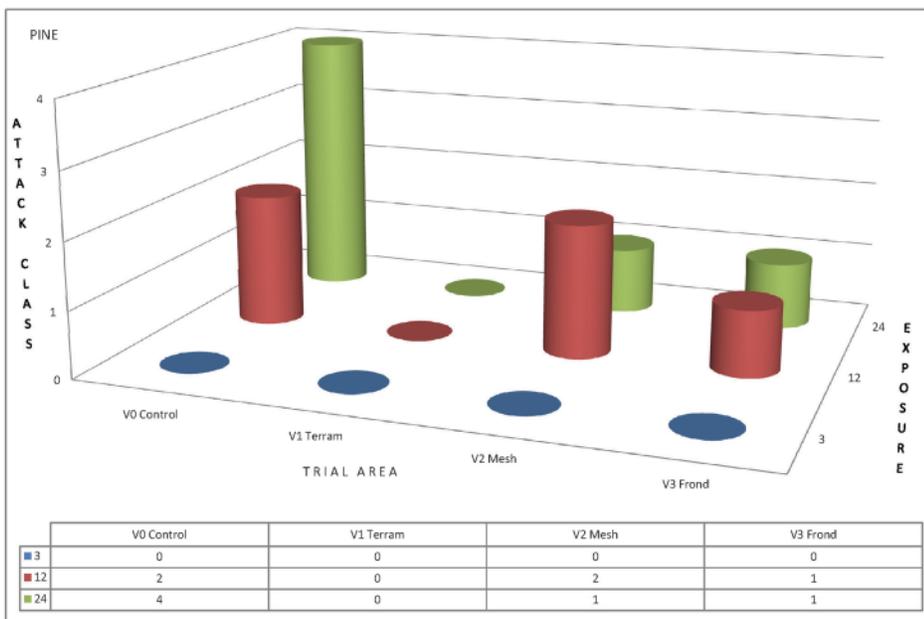
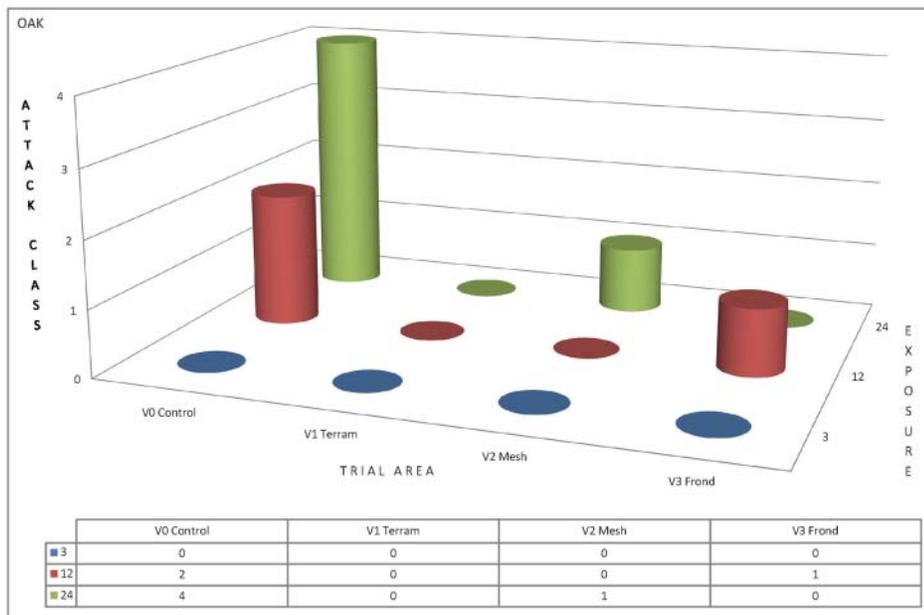


FIGURE 11 Chart showing level of attack of oak and pine sample blocks by wood-boring organisms — for explanation of attack class, see Figure 7.

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 three barrier systems was extremely low. Although bacteria were occasionally found in the vessels of oak samples exposed for periods of three to twenty-four months, no decay

patterns were observed. This indicated that wood samples had become exposed very quickly to an anaerobic environment, preventing the erosion by bacterial and marine soft rot activity.

Data logger

A data logger was used 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 2685 sub-sea data logger custom made by EauxSys Ltd of Camelford (Figure 14). 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 project (Cederland 2003, 41).

The system comprises a measuring and data-logging system housed in a cylindrical waterproof housing. In this version the pH, redox and dissolved oxygen sensors are supplied on 5 m long flying leads to allow positioning into the sediment around the site. The temperature and depth sensors were located on the main body of the instrument. The data logger has an internal battery pack sufficient for up to three months'

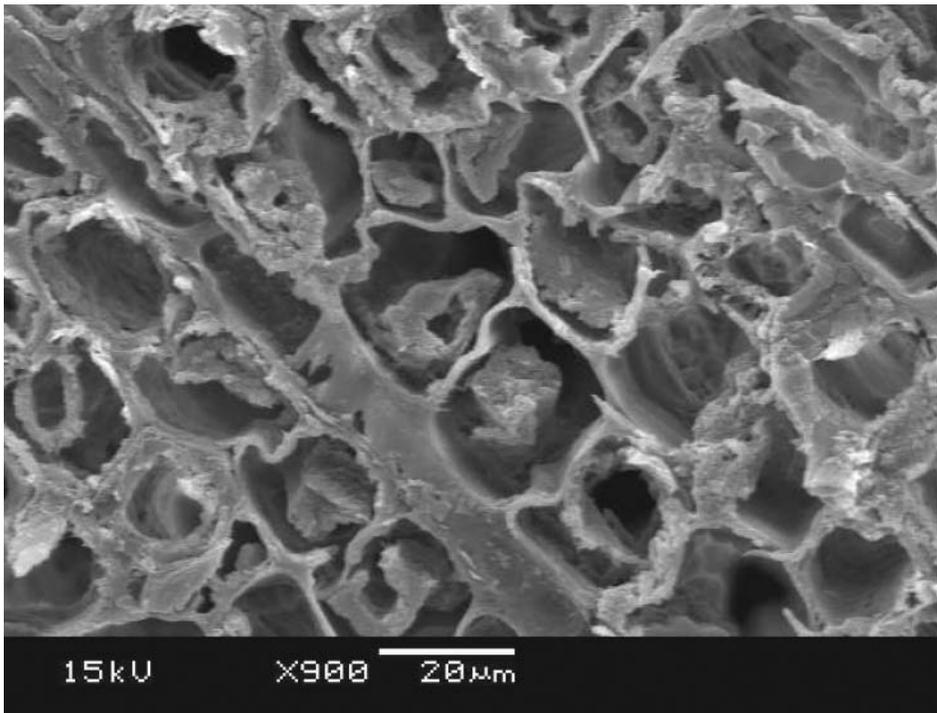


FIGURE 12 SEM of pine sample (control twenty-four-month exposure) showing erosion to secondary wall layers.

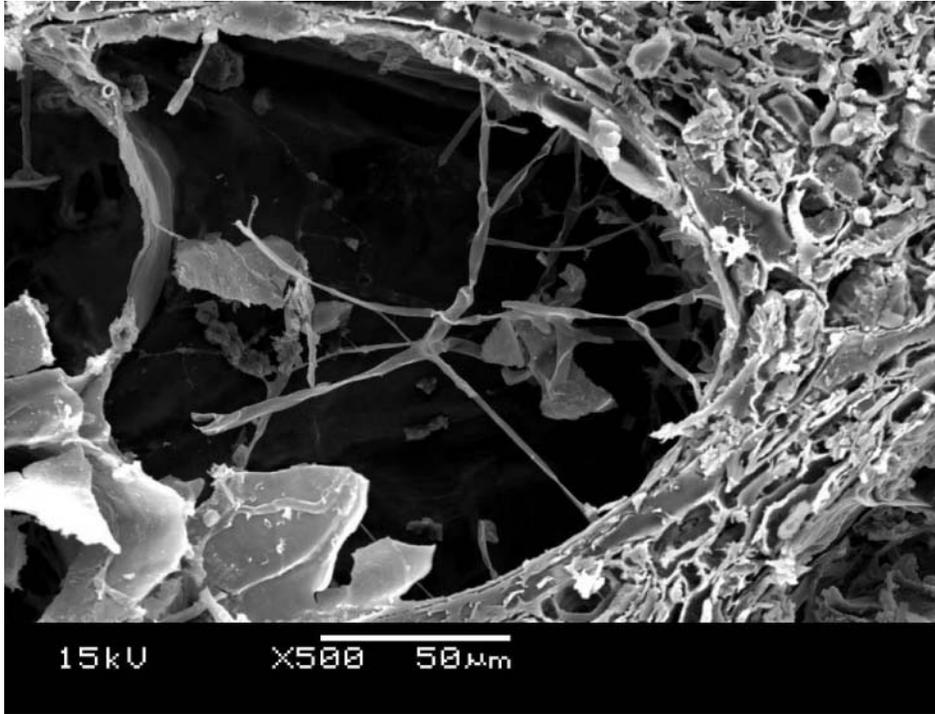


FIGURE 13 SEM of oak sample (control twenty-four-month exposure) Bacterial erosion of secondary wall layers very advanced. Fungal hyphae present in vessel.

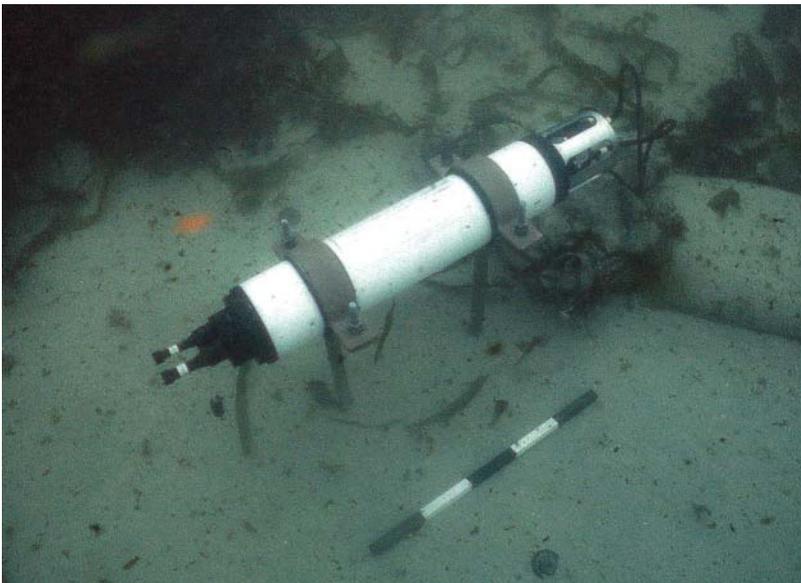


FIGURE 14 The Waterwatch 2685 data logger.

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 minimize 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.

To facilitate data retrieval, the instrument is recovered from the seabed and connected to a computer running TimeTag software. This software also allows the settings and calibration of the instrument to be adjusted. In order to secure the data logger to the seabed, a steel stand was constructed with a 15 mm thick base plate — which resulted in the stand weighing over 60 kg. The data logger was insulated from the steel of the stand with 12 mm thick neoprene strips.

The Waterwatch data loggers used on the MoSS project suffered from extensive fouling of the sensors which affected the measurements obtained (Cederland 2003, 42). 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. 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 on site in Scilly using the calibration standard solutions and calibration manual supplied by the manufacturer.

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 2–3 m away on the seabed. The table below lists the duration and dates for each deployment of the Waterwatch 2685 data logger.

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 ninety-one-day deployments.

Results from the data logger

There is not space here to discuss in detail all the data collected from the data logger (Figure 15). For a full discussion of this, see Camidge *et al.* (2005, 68). A brief discussion of the data collected for dissolved oxygen under each of the protection methods trialled follows.

Data logger deployment		
Trial Area	Deployment dates	Duration (days)
V ₁ Terram 4000	29.03.04 – 28.06.04	91
V ₂ Mesh	20.08.03 – 20.10.03	61
V ₃ Fronds	19.05.03 – 18.08.03	91

FIGURE 15 Table of data logger deployments.

Terram (V1)

This data is for the ninety-one-day period between 29 March and 28 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.

The first reading recorded for the dissolved oxygen was 0.54 mg/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 0.1 mg/l after only ten hours. Within five days, the levels had dropped further to 0.03 mg/l. By the end of the ninety-one-day deployment of the data logger, the dissolved oxygen had fallen to 0.02 mg/l. Reference to the chart of the dissolved oxygen levels (Figure 16) shows the fairly rapid fall to very low levels which were maintained for the remainder of the ninety-one-day deployment. This demonstrates the anoxic conditions prevailing under the Terram mat.

Mesh [V2]

This data is for the sixty-one-day period between 20 August and 20 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 0.50 m north of timber sample blocks V2-D (Figure 6). The three probes (dissolved oxygen, redox, and pH) were positioned 0.10 m apart on the seabed and secured in position by a sandbag placed over the body of each probe (about 0.20 m 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.

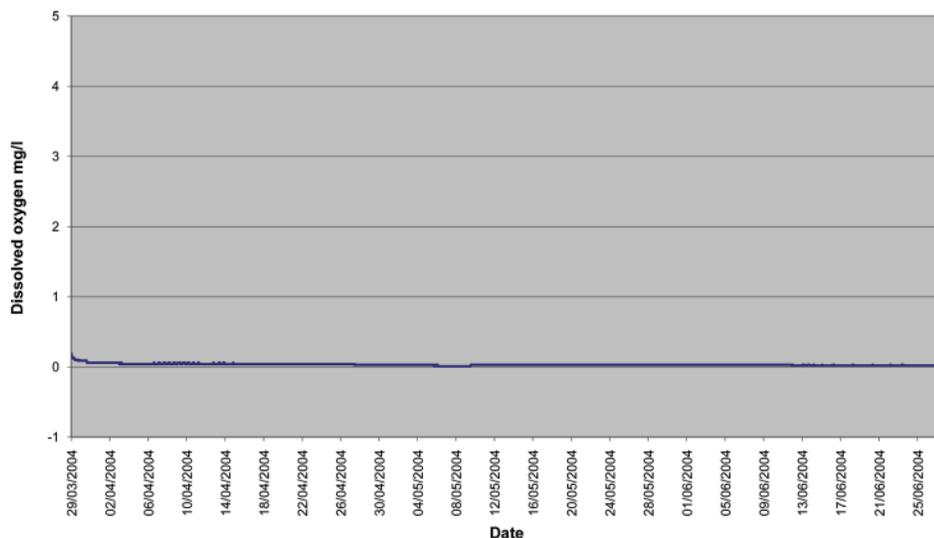


FIGURE 16 Chart showing dissolved oxygen data from Terram test area (V1).

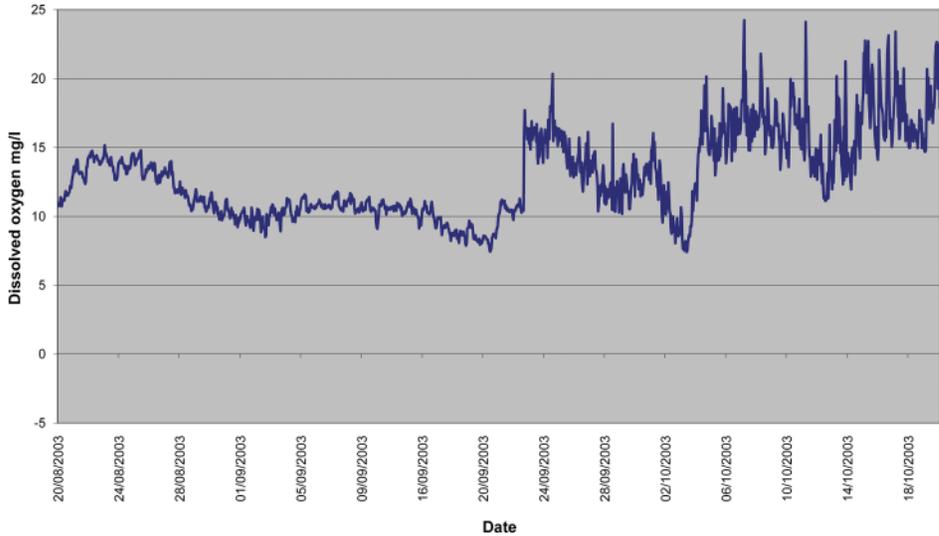


FIGURE 17 Chart showing dissolved oxygen data from mesh test area (V2).

The first reading recorded for the dissolved oxygen was 10.75 mg/l. This rose over the next four days to around 15 mg/l and then slowly fell to around 10 mg/l by 1 September (Figure 17). The nature of the readings changes on 21 September when the values begin to oscillate between 10–20 mg/l. This may indicate a change in conditions or a malfunction of the sensor. 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. Apart from the readings after 21 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.

Fronds (V3)

This data is for the ninety-one-day period between 19 May and 18 August 2003. The mat had been in position on the seabed for twenty-four hours when the sensors were placed under the mat. They were positioned 0.50 m south of sample blocks V3-A (Figure 6). The three probes (dissolved oxygen, redox, and pH) were positioned 0.10 m apart on the seabed and secured in position by the overlying mat.

The first reading recorded for the dissolved oxygen was 10.69 mg/l (Figure 18). This rose over the next six hours to 11.52 mg/l and then remained around 11 mg/l for the next two days. The recorded level then fell steadily to reach 0.1 mg/l by 25 May. The level then fell further to between 0.02 mg/l and zero for the remainder of the deployment. These readings indicate that conditions under this mat quickly became anoxic and then remained stable.

As already discussed above, the most apparent attack of the timbers on site is by wood-boring organisms. Any successful protection method must produce conditions unfavourable to these organisms.

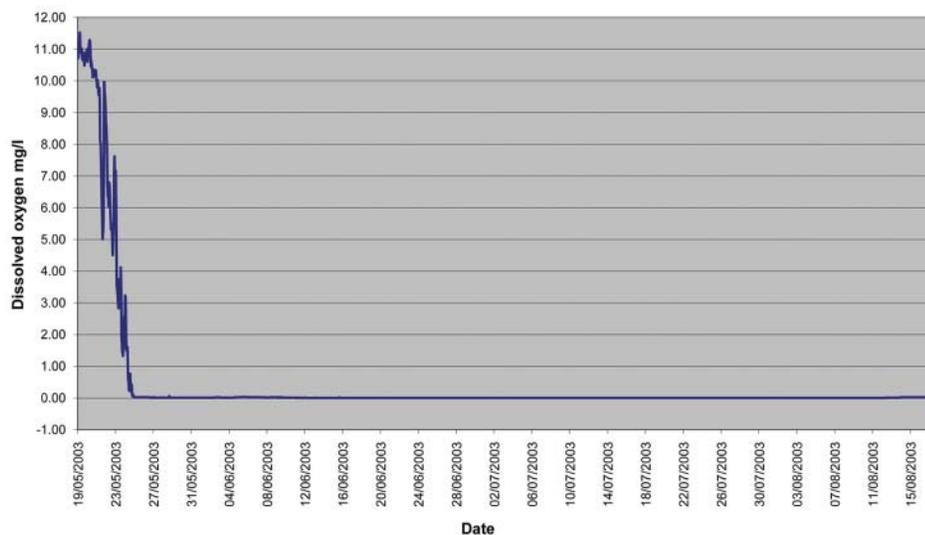


FIGURE 18 Chart showing dissolved oxygen data from frond test area (V₃).

It is not easy to change the temperature or salinity on the seabed, but the trials have demonstrated that the dissolved oxygen levels can be changed by using geotextile mats. Both organisms require a dissolved oxygen level of above 1 mg/l. The dissolved oxygen levels achieved under both geotextile mats (V₁ and V₃) were well below this at 0.02 mg/l. This is clearly a viable technique of combating attack by these wood-boring organisms on the timber of the wreck.

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 project's experiences with this type of data logger. The same data logger was used on the Swash Channel Wreck where similar problems were encountered with data reliability (Paola Palma, pers. comm.).

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 value. The pH recording seems the most problematic and the value of trying to record this with the Waterwatch system may be questionable.

Sediment monitoring

The excellent preservation of the exposed timbers when discovered in 2001 and their subsequent rapid deterioration suggested that sediment levels over the wreck had

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

FIGURE 19 General range of values in which teredo and limnoria grow (after Cederland 2004, 40).

recently diminished. Any attempt to stabilize the site must take into account the sediment levels surrounding the exposed wreckage. Consequently, in 2003 a programme of sediment level monitoring was inaugurated. To achieve this, fourteen sediment monitoring points were established around the site and the seabed levels are recorded on every site visit (Figure 20). 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 since monitoring began. Seabed samples from around the wreck were analysed to establish the nature of these sediments. The sediment exposed on the seabed is light grey coarse sand with broken shell, which extends to *c.* 0.25 m below the seabed. This overlies a layer of fine white compact sand or silt, extending from *c.* 0.25–0.40 m below the seabed.

Note how the levels are generally lower at the beginning of the year and higher at the end of the year. This suggests that the sediment is removed from the site during the winter months and slowly returns throughout the calmer summer months. However, the overall trend is towards a net loss of sediment over the site (Figure 21).

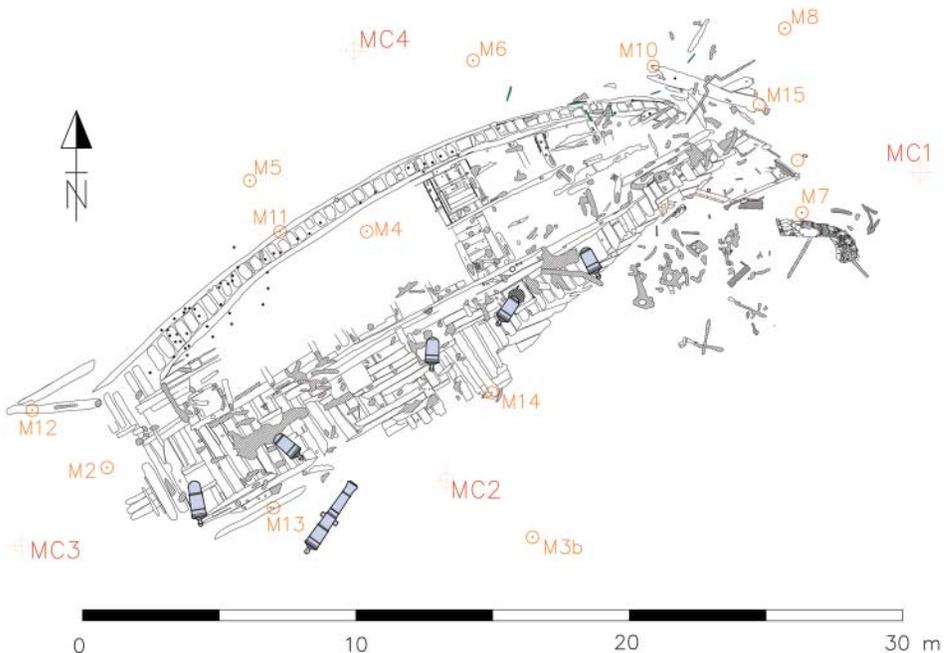


FIGURE 20 Location of the sediment monitoring points around the wreck.

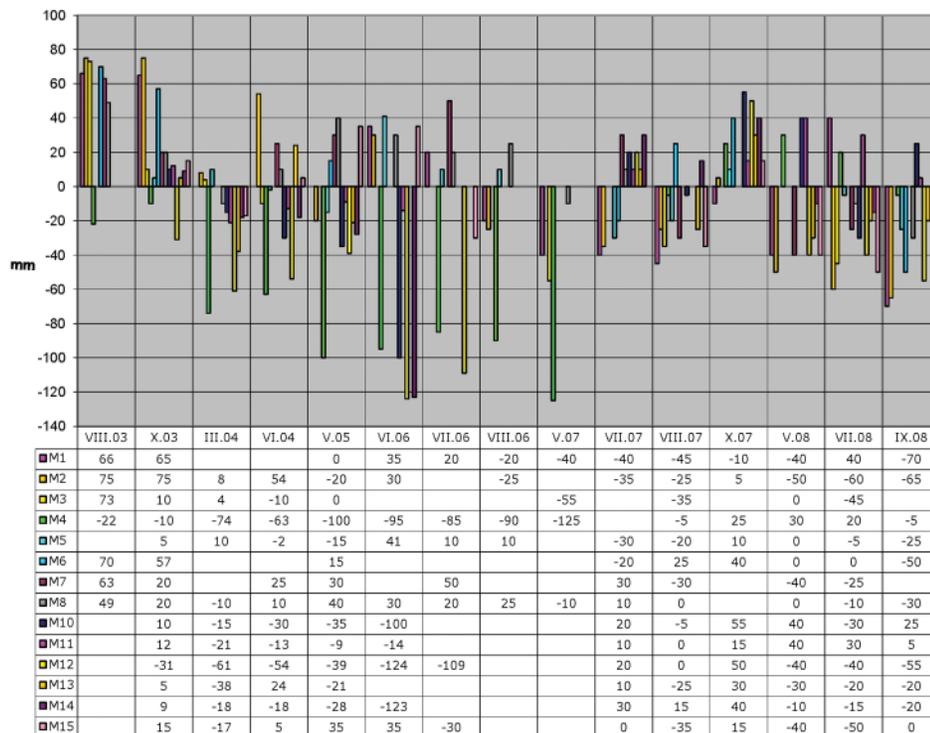


FIGURE 21 Chart showing the sediment level measurements taken between 2003 and 2008 for sediment monitoring points M1 to M15. The depth of sediment shown is relative to the levels recorded in May 2003. Positive values indicate a sediment accumulation, negative values a sediment diminution.

Site stabilization and recording

The stabilization trials carried out on the site from 2003 to 2005 established the efficacy of stabilization using Terram on this site. However, the trials were only conducted over a two-year period and there is a need to understand the longer term effects of stabilization on this site. Accordingly, in 2008 a small area (3.8 × 5.5 m) of Terram 4000 mat held in place with sandbags was installed at the stern of the wreck.

The Terram mat was secured using 60 sandbags, each containing 25–35 kg of clean builders’ sand. Two different types of sandbag were used. Green heavy-duty bags containing approximately 35 kg of sand were used at the eastern and western ends of the mat — the ends subject to the greatest tidal flow. The rest of the sandbags were standard white polypropylene bags containing 25 kg of sand. The sandbags were placed in a continuous line around the edge of the mat. Additional lines of standard sandbags were also placed in the centre of the mat.

Work on the stabilization trials suggests that this mat will quickly become colonized with weed and will accumulate a layer of sediment within a few months. The ultimate longevity of the Terram mat will depend to some extent on future sediment

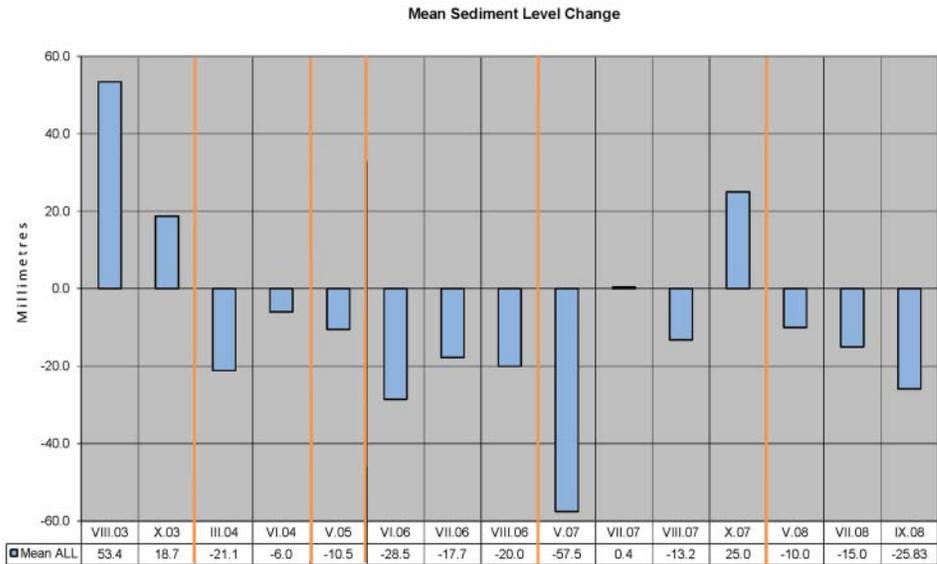


FIGURE 22 Chart showing the mean of the sediment level measurements taken between 2003 and 2008 for sediment monitoring points M1 to M15. The depth of sediment shown is relative to the levels recorded in May 2003. Positive values indicate a sediment accumulation, negative values a sediment diminution.

movements on the site. Indications are that the Terram itself will have a long lifespan. Experience has shown, however, that the sandbags will start to deteriorate within five to ten years. By then, there should be sufficient sediment accumulated on the mat to hold it securely in position (Figure 22). Inspection of the Terram mat made in August 2009 revealed an accumulation of more than 100 mm of sediment over the mat.

The reason for choosing the small area at the stern of the vessel is twofold. First, excavation at the stern of the vessel carried out by the ADU in 2001 demonstrated the high quality of the remains on this part of the wreck. The possibility of further carved material lying buried in this area is considerable. Secondly, this is a visually unappealing part of the wreck, so covering it with Terram will not detract from the appeal of the wreck to visiting divers. Currently the local dive charter boats in Scilly take divers to the wreck using visitor licences issued by DCMS.

To help establish the long-term effects of the stabilization, the protected area was recorded in detail prior to protection. The recording took the form of a detailed planning frame survey at a scale of 1:5 and a digital photo mosaic, one photograph per 1 sq m. A control area where no protection is planned was similarly recorded (Figure 23) to allow future comparison of protected and unprotected areas. Once this work had been completed, the installation of the Terram protection and a small seabed sign explaining the function of the Terram mat were installed (Figure 24).

A number of disadvantages of drawing at 1:5 were noticed. As anticipated, the drawing took slightly longer; in this case the 42 sq m were drawn by four divers in five days. Each draughtsman undertook two one-hour dives per day. This resulted in

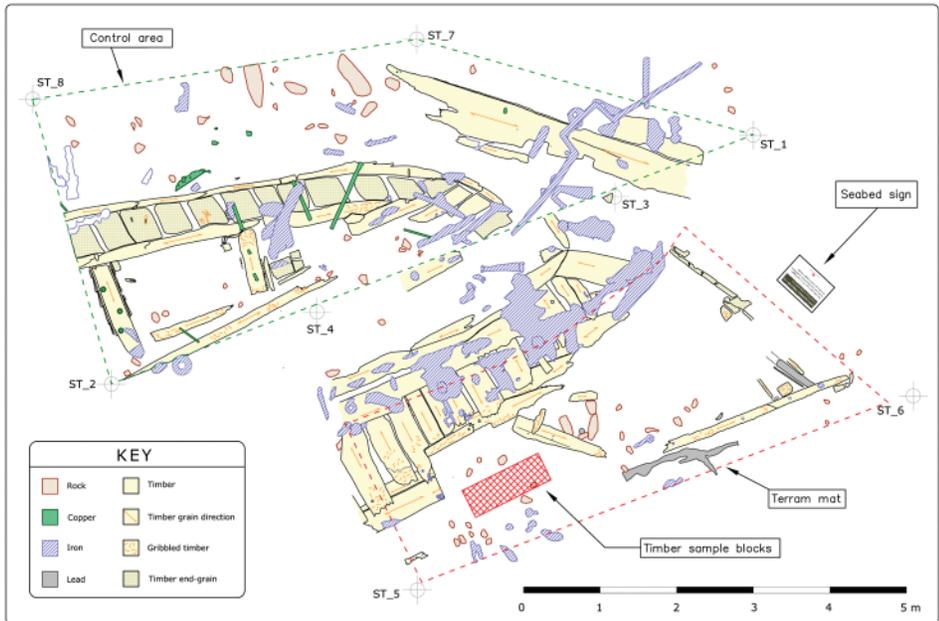


FIGURE 23 Area protected with Terram 4000 and control area.



FIGURE 24 The Terram mat in place and the seabed sign.

an average of 1 sq m drawn per hour (including all ancillary tasks such as establishing baselines and positioning planning frames). The actual speed achieved depended very much on how complex the drawing was. Surveying of baselines was undertaken by two separate divers who were not drawing. An unforeseen disadvantage of drawing at this scale was the amount of time it took to digitize the site drawings; about twice as long as it took to make the original drawing. Experience on previous projects has shown that it is essential to do this digitizing as soon as possible to allow anomalies to be resolved on the ground. Past experience has also shown that digitizing 1:10 drawings is considerably quicker.

Comparing the planning frame survey made this year with that previously drawn in 2003 gives a graphic illustration of how the timbers have deteriorated in the intervening five years. Figure 25 shows details from the 2003 and 2008 surveys. Those timbers shown in pink on the 2003 survey no longer survive. Comparison of the two plans also shows many areas where timbers have decayed to a smaller size in the five years separating the two surveys.

Eight timber sample blocks, four oak and four pine, were also installed under the Terram mat to allow direct comparison with the results of the original stabilization trials. No date has been set for evaluation of the long-term effects of this stabilization. The Terram mat will be monitored regularly (at least twice per year) and its condition recorded. It is envisaged that a long-term assessment will be made after ten years on the seabed, unless conditions change significantly in the mean time.

Finds recovered from the original excavation to recover the stern carving in 2001 and 2002 were reburied on the site. The finds were recorded underwater and placed in perforated polythene bags containing sediment recovered from around the artefacts. These objects were buried at a depth of 0.6 m below the seabed. These buried objects could at some future date be studied to assess the efficacy of reburial (Camidge 2002, 40).

Conclusion

Stabilization is really a misnomer. There is probably no such thing as a stable archaeological site (and certainly not of a ship). Site stabilization should perhaps be considered as a slowing of the rate of deterioration. That said, the work on *Colossus* has indicated one method of slowing the deterioration down, in this case by discouraging attack by wood-boring organisms and to some extent by bacteria and fungi. This project has concentrated on the deterioration of the exposed timber elements of the wreck. What has not been addressed is the deterioration of the other elements of the wreck, notably the ironwork of the vessel (of which there is a great deal), and the non-ferrous elements (of which there is somewhat less).

The need for this work was driven mainly by the mobility of the sediment around the wreck, which continues to expose the vessel. Indications are that this is a relatively recent phenomenon. Whether it is a cyclic event or a more long-term trend is not known. If the former, then the site may eventually rebury naturally. Monitoring of sediment levels on the site will continue and may eventually help to answer these questions (Dunkley 2007).

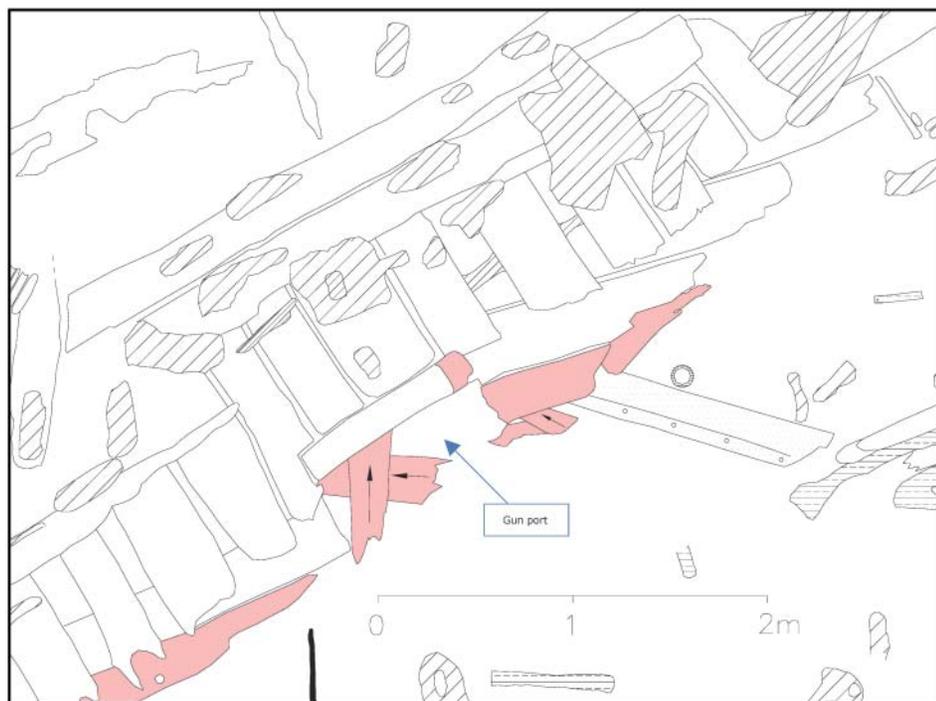
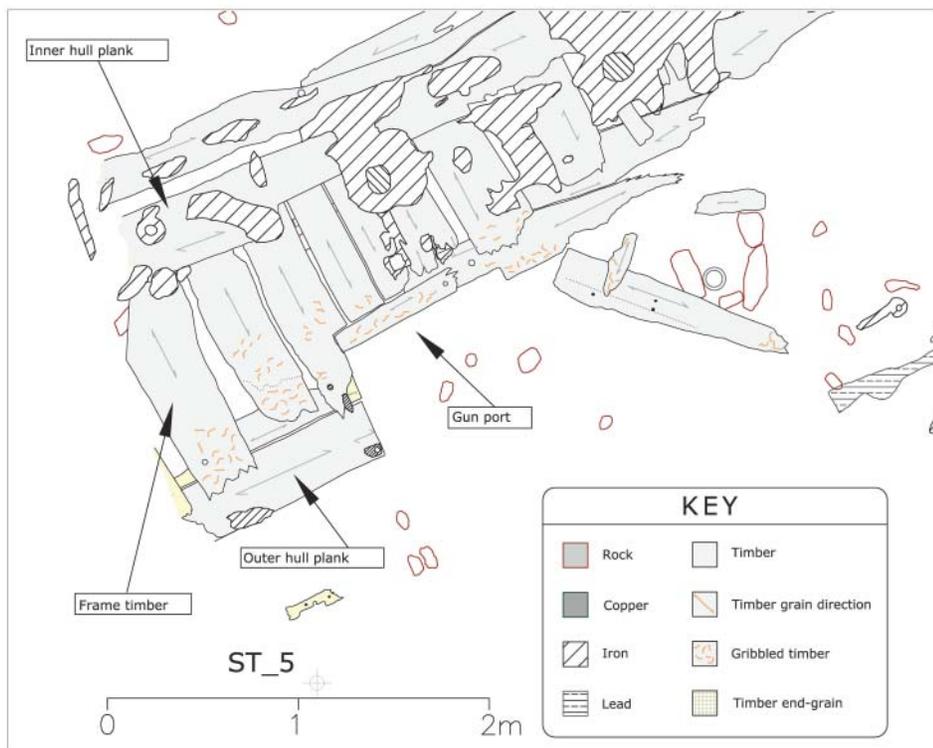


FIGURE 25 Details from surveys made in 2003 and 2008.

Long-term assessment of the efficacy of the small area of ‘stabilization’ installed should help us to determine whether this is a viable solution to site protection problems. While this method of protection is probably viable on other sites (the similar stabilization trials being undertaken on the Swash Channel site by Paola Palma of Bournemouth University may throw more light on this), it should be born in mind that different sites may require different methods of protection. While it is a fairly depressing experience watching the exposed parts of *Colossus* deteriorate, some comfort is gained from the fact that this project has, albeit in a limited way, tried to document the process, trialled methods of slowing it down and installed a long-term trial of the method for future archaeologists to study.

Acknowledgements

The stabilization trials and subsequent stabilization projects were funded by English Heritage. I would like to thank Ian Oxley, Annabel Lawrence, Jesse Ransley, Mark Dunkley, and Alison Hamer of English Heritage for all their assistance with the project. Matthew Canti of English Heritage undertook the sediment analysis. Seabed Scour Systems Ltd donated the floating frond mat for the stabilization trials. Dr Mark Jones of the Mary Rose Trust undertook the analysis of the timber sample blocks for the stabilization trials. Peter Holt of 3H Consulting Ltd donated copies of Site Surveyor and later Site Recorder which were used for the survey and recording of the wreck. Mac Mace and Jo Williams of Scavenger Diving Services undertook the installation of the seabed mats for the stabilization trials and subsequent stabilization. The Cornwall and Isles of Scilly Maritime Archaeology Society dive team — Sharon Austin, Peter Holt, Luke Randall, Bren Rowe, and Janet Witheridge — tirelessly undertook the detailed recording prior to the stabilization. Dr Paola Palma gave much useful advice and assistance. Martijn Manders gave helpful advice concerning the deployment of the mesh mat system used in the stabilization trials.

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Notes on contributor

Kevin Camidge worked in land archaeology as a field officer for the Trust for Lincolnshire Archaeology until 1987, when he retired to Cornwall. He took up diving that year and shortly afterwards became involved in marine archaeology in Cornwall. Kevin is currently the nominated archaeologist for the protected wrecks *Scheidam*, *St Anthony*, *Rill Cove*, *Royal Anne Galley*, and *Colossus*.

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