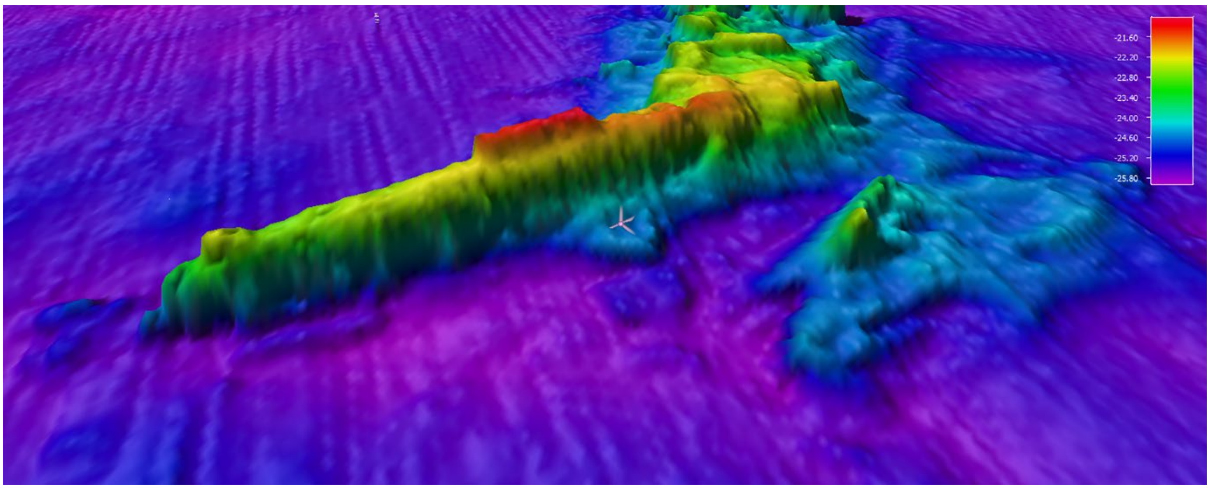
Historic England’s First World War Submarine Wreck Project

Approaches to Wreck Investigation - Appendix



Summary

This document is a downloadable appendix for *Historic England's First World War Submarine Wreck Project: Approaches to Wreck Investigation*. It has been prepared by Wessex Archaeology to provide additional case studies and other information relevant to how future investigations of First World War submarine wreck in English Territorial Waters might be approached. It is based largely on lessons learnt during fieldwork carried out to support Historic England's project.

The recommendations and opinions offered in this appendix and in the main document are not formal advice or guidance issued by Historic England. Users are free to apply them as they see fit.

This document was written by Graham Scott, with contributions by Andrea Hamel and content derived from reports written by other colleagues, including Paolo Croce. It also incorporates material provided by avocational and other submarine wreck investigators with whom Wessex Archaeology has worked.

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Front cover

Multibeam image of the wreck of UB-107, off Flamborough Head

Contents

Introduction

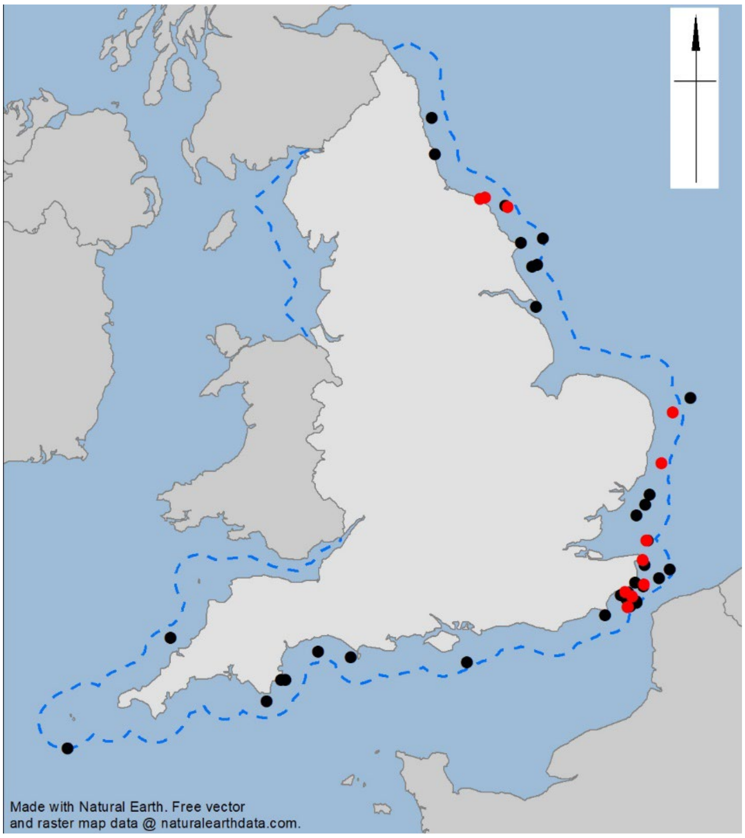
This document has been produced by Wessex Archaeology as a downloadable appendix for *Historic England's First World War Submarine Wreck Project: Approaches to Wreck Investigation*. It contains further information, case studies and discussion of the lessons learnt during fieldwork for Historic England's *First World War Submarine Wrecks Project*. It is not intended to be read as a separate document.

Strategic Assessment

The Strategic Assessment carried out for the Historic England First World War Submarine Wrecks Project (Cotswold Archaeology 2014) identified 47 submarine wrecks from the First World War in English Territorial Waters (ETW). Eleven of these were assessed as being of special interest because of their confirmed identity and rarity:

- U-8
- UB-12
- UB-17
- UB-30
- UB-55
- UB-75
- UB-109
- UC-6
- UC-46
- UC-70
- D5 (British)

The other 36 submarines were as follows: U-11, U-37, U-48, UB-4, UB-29, UB-31, UB-33, UB-38, UB-41, UB-56, UB-58, UB-65, UB-72, UB-74, UB-78, UB-81, UB-107, UB-113, UB-115, UC-2, UC-11, UC-19, UC-21, UC-26, UC-32, UC-39, UC-47, UC-49, UC-50, UC-51, UC-64, UC-72, UC-75 and UC-77 (all German); C29 and E6 (British). Subsequent investigations by avocational divers proved that the wreck originally thought to be UB-113 was in fact the important wreck of the British submarine D1. For practical and other reasons, wrecks from both lists were subsequently investigated.



First World War submarine wrecks identified by the Strategic Assessment (Cotswold Archaeology 2014). Those recommended as being of special interest are in red. The seaward limit of ETW is a blue dashed line.

Safety and submarine wrecks

Although submarine wrecks are relatively easy to navigate, they can still be hazardous places for divers. The underwater work that this advice is based on was carried out safely and in accordance with UK law and guidance, often in difficult circumstances with poor visibility and strong currents. Those using this advice must however undertake their own enquiries and satisfy themselves that anything they propose to do is safe and complies with the law, is within the capabilities of their training and experience and that all involved are competent to carry it out.

Professional archaeologists working with volunteers to investigate submarine wrecks should also remember that they and their employers will, as a minimum, have responsibilities for those volunteers under the UK's Health and Safety at Work Act. Those responsibilities cannot be waived by either the professionals or the volunteers.

The table below lists three of the common hazards associated with submarine wreck investigations that were considered during the project. However, it should be kept in mind that other hazards exist.

Becoming trapped inside a submarine wreck	Entering a submarine through a hatch or a hole in the pressure hull is a hazardous activity. Access into and within the pressure hull is very tight and there are many fixtures and fittings all around that can snag diver equipment in ways can be very hard to unentangle. There is often a layer of fine sand or silt and any movement can very quickly reduce visibility to virtually nothing, disorientating a diver and making it harder to unsnag equipment and find the way out. If a diver gets into difficulty within a submarine, it may be extremely difficult to rescue them. Furthermore, moving around within a submarine has the potential to disturb human remains and damage artefacts that are delicate or weakened by corrosion. It is therefore strongly recommended that you do not go inside submarine wrecks.
UXO hazards	Unexploded ordnance (UXO) and pyrotechnics including mines, torpedoes, deck gun and small arms ammunition and other hazards are often present within and around submarine wrecks. For example, mines are reported to survive in the tubes of what is believed to be the UC-6. Despite their age, much of this material remains viable and could cause a catastrophic accident if disturbed. It is therefore strongly recommended that you keep clear of UXO when diving on a submarine and be familiar with what to expect and what it looks like before you start the dive.
Mono- or multifilament fishing nets snagged on wrecks	If a diver were to become entangled in a fishing net snagged on the wreck, this could be a very dangerous situation. In addition, it could be very dangerous to rescue an entangled diver. It is therefore strongly recommended that you keep clear of fishing nets or lines.

Submarine/Submersible classification of British & German First World War submarines

There were two schools of thought involved in early submarine development leading up to the First World War. The first advocated what might be called a 'submersible', a torpedo boat that was able to submerge to carry out an attack but which was designed primarily for operations on the surface, emphasising sea keeping, surface speed and habitability. The second school of thought was for what might be called a 'true submarine', a torpedo boat designed primarily for submerged operation. Both types had different design characteristics and both served in the war. The table below lists British submarine classes and German submarines by these categories.

Torpedo boats fitting the definition of a submarine during the First World War were of single-hull construction. Optimisation for underwater operation meant that they had good submerged speed and manoeuvrability. They had a small 'reserve buoyancy', the difference in displacement between the vessel when submerged and when on the surface. This meant that they could submerge quickly. However, it also meant that very little of the hull was above the surface of the sea when the vessel was surfaced and they tended to have limited surface speed and seaworthiness, as well as poor stability along their longitudinal (bow to stern) axis. In turn, this meant that they tended to roll more, making things more uncomfortable for the crew. Furthermore, the ballast and other tanks had to be accommodated within the pressure hull. This caused the space inside these vessels for the crew and other equipment to be very limited, unless the diameter of the hull was increased. As a result, submarines of this type tended to be very small, which greatly limited their range, so they tended to be designed for harbour or coastal defence.

Submersibles by contrast had their ballast and fuel tanks placed outside the pressure hull, either within 'saddle tanks' either side of the pressure hull or a true 'double hull'. The increased space, achieved without increasing the diameter of the pressure hull, allowed much more fuel to be carried than the true submarine-type. It also allowed more space for other equipment and increased habitability for the crew.

With hull form optimized for surface operation and a greater reserve buoyancy, the submersible type had better sea-keeping qualities and greater surface speed. All of this gave them a much greater range than could be achieved by the submarine-type, making them suitable for much longer patrols and some for oceanic operations. However, their greater reserve buoyancy meant that they were relatively slow to dive.

Not all of these 'diving boats' were double-hulled or had saddle tanks. For example, the small German UB I type was designed with the seaworthy lines of a submersible.

Type		**British**	**German**
'Submarine'		A, B, C, H and R-class	UB I (but see above); UC I
'Submersible'	Saddle tank	D, E and L-class	UB II
	Double hull	F, G. J, K, M, S, V and W-class; Nautilus and Swordfish	All U-type; UC II and III; UB III

(There is no agreed standard classification list and therefore this table represents the opinion of Wessex Archaeology.)

Main submarine systems

The main systems that a submarine is commonly broken down into are listed in the table below. The list is not intended to be exhaustive and you may wish to add, subtract or devise your own list of systems.

<table>
<tr><th>System</th><th>Sub-system</th><th>Description or comments</th></tr>
<tr><td rowspan="6">Propulsion system</td><td>Diesel main engines</td><td rowspan="4">A diesel electric submarine has one (centreline) or two (either side) shafts. Each is connected to a propeller. At the other end of each shaft is a diesel engine connected to the shaft by crankshaft and connecting rods. The engine may have a supercharger and will have fuel injection, lubricating oil and (seawater) coolant circulating systems. Aft of this, an electric motor is normally built around the shaft, which acts as an armature. Both engine and motor are clutched, to enable them to be disconnected from the shaft.

Aft of the motor the shaft passes through a thrust block. This transmits the thrust of the propeller to the submarine hull, enabling it to move through the water. The shaft is modular and the longest section is the tail shaft, which connects the thrust block to the propeller. Inside the pressure hull the shaft passes through a guide tube called the stern tube and penetrates the hull through a waterproof stern gland. Outside of the hull, the end of the shafts of a two-shafted submarine is normally supported by a bracket attached to the submarine hull.</td></tr>
<tr><td>Main electric motors</td></tr>
<tr><td>Shafts</td></tr>
<tr><td>Associated components</td></tr>
<tr><td>Exhaust system</td><td>This is designed to vent exhaust gases produced by the diesel engines to atmosphere.</td></tr>
<tr><td>Diesel fuel oil and compensating systems</td><td>This consists of fuel tanks, normally external if the boat is a submersible type, a fuel distribution system to move the fuel to the engines and a strainer or centrifuge to remove impurities and water. As fuel is consumed the weight of the submarine is reduced. To compensate for this, seawater is added to the tanks using the engine coolant circulating system.</td></tr>
</table>

System	Sub-system	Description or comments
	Batteries and electrical distribution system	The batteries power the main motors and provide power for lighting and other electrical equipment. Batteries are vulnerable to damage from seawater ingress and are therefore positioned below the deck in compartments within the pressure hull. The power is normally distributed to the motors via a main switchboard and to auxiliary equipment and lights via ring mains.
Tank blowing and venting system		This system consists of main ballast tank valves. When open they allow air to escape and seawater in, decreasing buoyancy. When closed, they allow air to be pumped in, expelling water and increasing buoyancy. The valves are located outside of the pressure hull, but their controls are inside. The ballast tanks can be filled with air using either low- or high-pressure air 'blowing' systems. The LP system normally drew its air from inside the boat and was therefore operated when on the surface in order to give a submarine maximum buoyancy on the surface.
HP air system		The HP air system depended upon storing high pressure air in cylinders. It was circulated around a ring main. The cylinders would be replenished using a HP compressor.
Hydraulic (telemotor) system		A hydraulic control system was used to operate valves, levers, hydroplanes, rudder and other external equipment that was beyond the physical capabilities of the crew. A typical telemotor system was comprised of one or more accumulators to store oil under pressure, HP air cylinders to air-load the accumulators and both powered and hand pumps
Auxiliary machinery and equipment		A wide variety of auxiliary machinery might be onboard a submarine, including: ballast pump; trim pump and system; distilling plant; air conditioning plant; refrigerating system; auxiliary air purification systems; freshwater system; domestic systems, including heads; and the oily bilge system.
Weapons systems	Torpedoes	Most submarines carried a deck gun for surface attack and defence, as well as a torpedo armament for surface or submerged attack.
	Guns	
	Mines	

System	Sub-system	Description or comments
	Ammunition storage and loading	A particular feature of First World War submarine design was the external torpedo tube, which enabled torpedoes to be carried without having to allocate space inside the pressure hull, but which could not be reloaded at sea. Minelayers normally substituted mines for a large part of their torpedo armament and their tactical deployment was usually very different. A submarine captain would prefer to use the deck gun if he was not worried about being attacked himself, as a submarine could carry far more shells than torpedoes. Torpedoes and mines required a lot of space for ammunition handling and storage.
Steering gear and control systems	Hydroplane gear	Hydroplanes act like horizontal rudders and enable the boat to rise or dive. They are normally arranged in pairs forward and aft and are controlled hydraulically. In early designs the forward hydroplanes might be amidships. Hydroplanes will have pipework and rams associated with the hydraulic system.
	Rudders	Rudders allowed the submarine to turn. Smaller and earlier submarines tended to have a single balanced rudder, larger and later might have two. Rudders would normally be mounted aft of the propellors and operated by a hydraulic system. Some early submarines had a second rudder mounted on the same shaft on top of the submarine.
Sensors	Periscopes	Periscopes provided the submarine crew with visual surveillance whilst submerged. A submarine would usually have two periscopes operated from the control room or sometimes the conning tower. These had different purposes. One was for long range search and was usually larger. The second was used for attack. As torpedo attacks needed to be made at short range, the attack periscope would be smaller and less conspicuous. Raising and lowering the periscopes was normally by wire hoist. Where the periscopes emerged from the hull they tended to be strengthened by sheaths.

Case Study – using Watson & Gale system to summarise the character of the UC-70 submarine wreck

Watson and Gale provided a simple table in their article 'Site Evaluation for Marine Sites and Monuments (Watson and Gale 1990) which can be used to describe historic shipwreck sites. It has the advantage of consistency and simplicity, but it was not devised for submarines or other modern shipwrecks with very substantial unburied structure and is effectively just a description of the site.

Case Study – Using Watson & Gale to summarise the character of the UC-70 submarine wreck
The results of the project's investigation of the UC-70 wreck were summarised briefly using the Watson & Gale system as follows.

Area and distribution of surviving ship structure	Main body of the wreck is approximately 40 m by 6 m and 3-4 m high from the seabed. The wreck is located with bow facing south-east, in an upright position with a slight list to port. Much of the structure of the wreck is intact. The bow is missing at the bulkhead immediately after the mine tubes. Lots of debris pertaining to the bow was located on the seabed. This includes a large web-frame and part of the forward hydroplane; the mushroom anchor is still in situ.
Character of the ship structure	UC-70 is a First World War minelayer submarine of the UC II class.
Depth and character of stratigraphy	Shallow deposits containing archaeological material may survive within the pressure hull.
Volume and quality of artefactual evidence	The site was partly salvaged but it is still in good condition. There is evidence of plate thinning and corrosion along the pressure hull. The site contains human skeletal remains.
Apparent date of the ship's construction and/or loss	Launched on 7 August 1916. Sunk on 28 August 1918.
Apparent function	The UC II class was intended for carrying out submarine warfare against Allied shipping.
Apparent origin	Blohm & Voss for the Kaiserliche Deutsche Marine (German Imperial Navy).

Case Study – using BULSI to synthesise historical and archaeological evidence

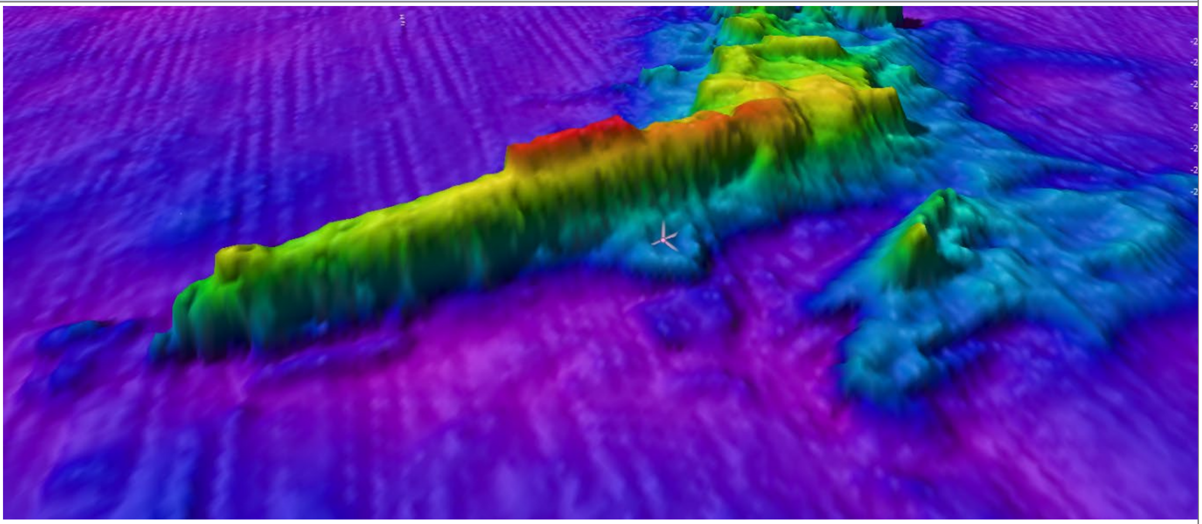
BULSI is a system designed by Wessex Archaeology (see Wessex Archaeology 2006b) to produce a 'biography' of a shipwreck and was routinely used by the project. It takes a 'narrative' approach, combining the archaeological and historical evidence available into the following categories. It does not rely on the compiler having dived the wreck, so it is a good way of sorting existing information before a fieldwork project begins:

- **Build** – this category presents all of the evidence related to how the submarine was built and its design. For example, the evidence for the internal layout of the submarine will be explained here, from plans and descriptions and diver observations and video. It will also include evidence about the builders and shipyard and events during the building of the submarine.
- **Use** – this category presents the evidence for the working history of the submarine, from when it was commissioned up to its last voyage. It includes the archaeological evidence for modifications to the submarine, for example the fitting of a new gun or a change of propellers. Information about who used it, where it was based and used, vessels that it sank and who crewed it is included here.
- **Loss** – this category deals with how the submarine came to sink and become a wreck. It includes the archaeological evidence for the damage that caused it to sink and the evidence for what the submarine looked like immediately after it came to rest on the seabed. Evidence about the casualties and survivors and any vessels involved in the sinking can be added.
- **Survival** – this category describes how the wreck has changed since the submarine sank and what is left of it now (its condition). This section will include a detailed description of the wreck as it is today, or as recently as the evidence allows. The description can be obtained from existing data, such as dive guides, online videos and Historic England Research Records, to which data from the compiler's own investigations can be added.
- **Investigation** – this category describes how the submarine has been investigated in the widest possible sense, so it includes hydrographic survey, salvage, recreational diver visits and archaeological work. Diving investigations immediately after loss, usually by the famous Royal Navy 'tin opener' divers to recover code books, etc. would be described either here or under Loss.

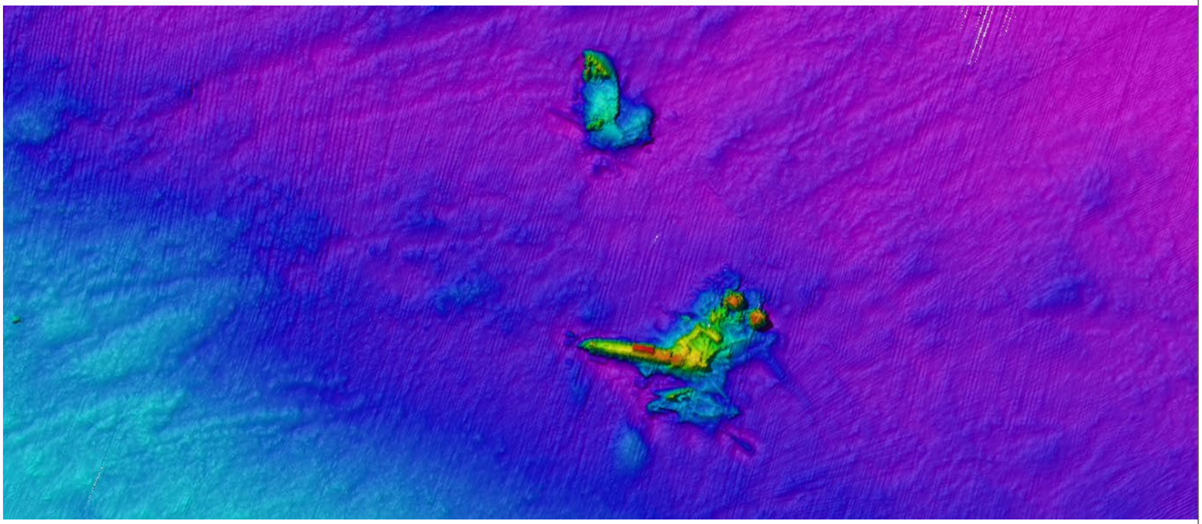
BULSI was applied to most of the submarine wrecks investigated for Historic England during the project. It proved to be a good way of summarising and synthesising archaeological and historical data and the narrative approach also makes it useful approach for 'popular' presentation. Case Study 2 provides an example.

Case study – using BULSI to describe UB-107
In 2016 Wessex Archaeology investigated the wreck of UB-107, off Flamborough Head, for Historic England, to determine what was left of it and whether it was sufficiently important to merit designation (Wessex Archaeology 2016c). The wreck had been flagged up as being of potential significance. After fieldwork and research, to which divers who had visited the wreck contributed, the following BULSI description of the wreck was produced. It is long, but a good example of how archaeological and historical evidence can be brought together to produce a 'biography'. The process of understanding the wreck was complicated by the fact that it appears to lie partly under the wreck of a ship, although the multibeam geophysical survey data obtained from the UKHO helped sort that out to some extent and resolved any uncertainty as to how the wrecks lay on the seabed. The report that this BULSI is taken from (Wessex Archaeology 2016c) also included a separate site description, so only the main points are included in the BULSI. The Divernet webpage on the wreck is no longer available, a warning to those who might see the web as a permanent place to archive useful information about submarine wrecks.

Case study – using BULSI to describe UB-107



Multibeam image showing the submarine on the seabed, with the remains of the ship to the right and top. Unfortunately, the submarine appears to have been damaged in the 1980s when salvors used explosives to remove the non-ferrous torpedo tubes (see 'Survival' and 'Investigation'). Similar salvage work on the UC-70 off Whitby led to the disturbance of the remains of a crew member.



A much wider 'plan' view, north up. The ship split in two and part of it lies to the north. The investigation failed to reach a definite conclusion about whether presence of the ship, the SS Malvina, was co-incidental (see 'Loss'). This image demonstrates just how valuable marine geophysical data can be in providing accurate mapping of wreck sites and the surrounding seabed.

Build

UB-107 was one of a batch of 15 type UB III coastal torpedo attack boats built by Blohm & Voss of Hamburg under Contract Q. It was ordered as hull number 313 on 23 September 1916, launched 21 July 1917 and commissioned 16 February 1918.

UB III submarines were a response to a requirement that the Germans had identified for a medium-sized, torpedo-armed submarine that was capable of operating both anywhere around the UK and in the Mediterranean. The existing UB II coastal boats were too restricted in range and armament, so the Germans instead modified the successful UC II class by replacing that type's minelaying

Case study – using BULSI to describe UB-107

chutes with a torpedo compartment and adding a more powerful engine and additional bunkerage (Rössler 2001: 56-7).

The UB III class had the following technical specifications. No evidence has been found to suggest that the UB-107 was not typical of the class:

Displacement, surfaced	516 tons
Displacement, submerged	651 tons
Length, overall	55.3 m (40.1 m pressure hull)
Beam	5.8 m (3.9 m pressure hull)
Draught	3.7 / 3.68 m
Height	8.25 m
Engines	2 x 550 hp MAN-Vulcan diesels
Electric motors	2 x 394 hp Mafei
Shafts/Propellers	2 / 2 x bronze
Fuel capacity	35 + 36 tons
Batteries	AFA lead acid accumulators
Speed, surfaced	13.6 / 13.3 knots
Speed, submerged	8 / 7.5 knots
Range, surfaced	8,500 nautical miles at 6 knots / 7,460 nautical miles at 13 knots / 9,040 nautical miles at 6 knots
Range, submerged	55 nautical miles at 4 knots / 55 nautical miles at 4 knots
Armament	4 x bow and 1 x stern 50.04 cm (19.7 inch) torpedo tubes; 22 pdr Krupp deck gun
Torpedoes carried	10 x 50 cm
Ammunition	160 rounds
Diving	c. 75 / 50 m
Design complement	34 (inc. 3 officers)

General arrangement British plans of the UB-103-117 batch exist within the Admiralty U-boat history sheets (The National Archives (TNA) ADM 137/3900). No German plans specific to the UB-

Case study – using BULSI to describe UB-107
103-117 batch have been traced. What are believed to be (or based upon) contemporary deck plans of an earlier type UB III batch, UB-75-79, exist (Deutsches U-Boot Museum). Another set of type UB III plans and frame lines for the UB III class are shown in Rössler (2001: 56). A significant number of photographs of UB III boats survive, including the salvaged submarine UB-110 (Q115149) of a slipway launch of an unnamed type UB III boat at Blohm & Voss survives (Rössler 2001: 58). The British interrogation report refers to a special report being written on the technical details of UB-109, another UB III class boat (ADM 137/3874). This report has not been traced. However, following the Armistice, the surrendered UB-88, another type UB III boat, was given to the US Navy. *Use* UB-107 undertook its first war patrol under Kapitänleutnant Hans Howaldt off the East coast after leaving Germany on 2 May. On 16 May, after sinking two ships, it arrived at Zeebrugge and was assigned to Flandern II Flotilla based at Bruges, Flanders. Between 6 June and 11 July the boat undertook two further war patrols under Kapitänleutnant Eberhard von Prittwitz und Gaffron on the East coast, sinking eight vessels.[1] The British intelligence record of its activities during this period survives (TNA ADM 137/3917). The career of the UB-107 was typical of a late war coastal U-boat in that it was fairly short. By the time of its loss, Allied defensive improvements and attrition of both U-boats and experienced crews meant that Germany's attempt to end the war by a submarine blockade of Britain and France was effectively over. *Loss* UB-107 left Zeebrugge on 26 July 1918 for a war patrol off the English east coast with 37 men under von Prittwitz und Gaffron. The boat subsequently failed to return and must therefore have sunk. Just before midnight on 27 July, two ships in the same convoy, the *Chloris* and *John Rettig*, were torpedoed and sunk approximately 17 miles S by E of Flamborough Head. UB-107 is the only submarine believed to have been patrolling in that area at the time (Grant 2003: 77). It is therefore likely that UB107 sank these two ships. The reason why UB-107 sank is unclear and there is no proof, documentary or archaeological, that it was involved in the sinking of the *Malvina*. All that can be said with certainty is that the *Malvina* sank on 2nd August and that the two wrecks are in physical contact with each other. The archaeological evidence for damage capable of sinking the submarine appears to be limited to the substantial hole in the pressure hull forward of the position of the deck gun. The damage to the stern and perhaps also to the bow, is more likely to be linked to salvage activities. Overall, the archaeological evidence is inconclusive. It is possible that the submarine struck a loose British or German mine whilst travelling on the surface and that the point of impact was the position of this hole. Loose mines were quite common after heavy weather and the Flamborough sector of the war channel had been closed the day

[1] Ships hit by UB 107 - German and Austrian U-boat Successes during WWI - uboat.net

Case study – using BULSI to describe UB-107

before the *Malvina* sank because of this hazard (Young & Armstrong 2006: 115). A very large explosion at this point could also explain why the deck gun is missing, possibly blown from its mounting. However, it is not clear that there is evidence of the pressure hull plating or framing being pushed inwards, as would be expected had a moored mine, more than capable of blowing the submarine in two, exploded on contact. This explanation also requires the presence of the *Malvina* to be entirely co-incidental, something which would seem to be somewhat implausible away from a major navigational hazard such as a submerged reef.

Previous investigations aimed at proving that the UB-107's radio masts were deployed and that therefore the submarine was on the surface when it sank or had executed an emergency dive with them up have been unsuccessful. The forward mast has not been identified and the evidence with regard to the aft mast is inconclusive.

The possibility exists that the UB-107 torpedoed the *Malvina* before succumbing to calamity itself. The Home Waters casualty report for the loss of the ship states that at 04:15 a torpedo struck it on the starboard side and that the ship 'buckled' and sank within 3 minutes (TNA ADM 137/4019). The Chief Officer of the ship told the inquiry that he was certain that the ship had been torpedoed, rather than mined, although he did not see it or its track. However, a torpedo was certainly capable of doing the damage necessary to cause a ship of the *Malvina's* relatively small size to split in two.

It is conceivable that the submerged UB-107 failed to keep clear and then struck or was struck by the sinking ship. It is also conceivable that if the UB-107 was on the surface, then von Prittwitz may have felt forced to dive quickly by the approach of the trawler Gaul, which was only half a mile away and picked up survivors (TNA ADM 137/4019). The main problem with this explanation is that not only does it require the UB-107 to approach a sinking ship whilst underwater, an undoubtedly hazardous activity, but also that the submarine is orientated with its bow to the west. It is therefore reasonable to assume that its firing position would have been from the west. However, the ship was northbound and struck on the starboard side. The torpedo must therefore have been fired from the east. This explanation therefore requires the submarine to have been spun round by the impact which sank it or to have carried out a complex manoeuvre after torpedoing the ship. The theory that the submarine accidentally collided with the steamer because it failed to see it in the dark and this detonated a torpedo, sinking both vessels is also problematic because of the orientation of the submarine and the reported position of the explosion.

It is also conceivable that the submerged UB-107 sank as a result of running into the wreck of the *Malvina*, which had previously hit a mine and sunk. However, it is difficult to explain the hole in the pressure hull forward of the gun.

If the UB-107 was involved in and heavily damaged during the action off Scarborough, then it is just about conceivable that it could have been brought or drifted south to Flamborough Head before finally sinking. However, such incidents are not well evidenced elsewhere and the two locations are a considerable distance apart. This explanation therefore appears to be somewhat implausible.

None of the explanations put forward to explain how the UB-107 sank can be convincingly evidenced. Therefore, at the present time there is insufficient evidence to prove how the submarine was lost and whether its loss was connected to the loss of the *Malvina*.

Survival

Case study – using BULSI to describe UB-107
The greater part of the pressure hull of the submarine survives, although it is badly damaged in places and open at the stern. This is likely to be due to the salvage of the stern torpedo tube, which is not present. There is a large, partial circumference hole immediately forward of the gun mount. There is no sign of the crew accommodation below, suggesting heavy internal damage to the submarine at this location, although the cause is unknown. The bow is also reported to be damaged and open. Small holes in the pressure hull observed elsewhere are likely to be the consequence of plate thinning caused by corrosion. Evidence of active corrosion was seen on the edges of the hole forward of the gun mount. The port side saddle tanks survive in part. The submarine is lying on its starboard side at an angle of 45 degrees and the condition of the starboard side saddle tanks were not assessed. The port side propeller was observed to have been salvaged, although the shaft survives. The starboard side propeller was not observed. There is some divergence of opinion amongst divers as to whether it has been salvaged and Bill Woolford believes that it could be buried (pers. comm.). However, salvage seems likely. The deck planking is missing, although the stubs of the deck casing and supports survive in part. Fittings mounted on the outside of the pressure hull such as the exhausts and intakes and valves are largely absent, displaced or damaged. The aft radio mast has fallen onto the seabed. Its mechanism is in situ but damaged. Other debris is lying on the seabed on the starboard side. The conning tower is no longer in situ and has fallen onto the seabed and lies in two halves. It is not known when this occurred. One of the periscopes has been partially salvaged, the fate of the other is unclear, but is at least partially displaced. Hydroplanes and rudders appear to have become detached from the aft section of the submarine. A rudder is lying on the seabed amongst debris. The current condition of the submarine is not untypical of First World War U-boats in UK coastal waters. Although the history of the wreck prior to its discovery in the 1980s is not clear, it would seem that significant damage was probably done shortly after discovery, as valuable non-ferrous metals were removed from the wreck. The mystery concerning how and why the UB-107 sank means that it is not known how many of its crew died within the pressure hull. However, it appears likely that human remains will be present. *Investigation* A wreck had been known to be present on this site since at least 1950 (UKHO H0146/39). It was known by local fishermen, for unknown reasons, as the 'Porter Packet' (Godfrey and Lassey 1988: 130). When the site was dived in 1985 to free lobster pots, the visiting divers discovered that a submarine wreck was present. Further dives resulted in the discovery of the propeller markings that identified the boat (Godfrey & Lassey 1988: 130). In 1986 the discovery was reported to the UKHO by B. Winfield (UKHO H1310/86/20). The wrecks then appear to have been dived by more than one group of divers. The presence of non-ferrous metals drew the attention of Bridlington and Leeds-based 'scrap men' (Gordon Wadsworth, pers. comm.). The Bridlington business is reported to have had a reputation for using

Case study – using BULSI to describe UB-107
explosives, often in large quantities (Gordon Wadsworth, pers. comm.). Both props and the aft torpedo tube appear to have been removed at this stage and it would appear from the damage to the stern of the submarine that a highly destructive means of removing the latter was used. The aft torpedo tube was reportedly found to contain a torpedo when delivered to a local scrap yard. Rumours then circulated that the tube had been disposed of by throwing it over Bempton Cliffs when news of its recovery reached the police (Gordon Wadsworth, pers. comm.). At some point the base of one of the periscopes was sawn off and recovered. It is currently in Scarborough BSAC club house and was reported under the 2001 Wreck Amnesty (Droit A/3132; image published on Wrecksite.eu). The eyeglass is reported to have been pushed inwards, possibly by an explosive force (Gordon Wadsworth, pers. comm.). In addition, photographs of a brass gimbal bracket dated 1917 and a brass compass cover have been published by Carl Racey. Finds have also been recovered from the Malvina, including a London & Edinburgh Shipping Company plate, a large glazed ceramic jar described as 'earthenware' made in Leith and a number of ceramic ink bottles. To date Wessex Archaeology has been unable to obtain droit data, other than data drawn from the NRHE Monument record. It would be reasonable to assume that other finds, perhaps undeclared, have been recovered from both wrecks. The wrecks are well known to the local diving community. They are featured in regional dive guides and included together as one dive in Divernet's '100 best dives'). The UB-107 has also been the subject of Deep Sea Detectives documentary, which focussed on the circumstances of loss without reaching a firm conclusion. Despite this, the general impression from speaking to local divers is that the site is not very frequently dived, with better preserved submarines further offshore appearing to draw more attention. The wreck has been subject to hydrographic survey on a number of occasions. Data can be accessed through the UKHO INSPIRE web portal. The multibeam swath bathymetry dataset used in this assessment was identified through this portal and represents the most recent high quality data available. Other than this assessment, no survey carried out to archaeological standards or for archaeological purposes has been traced. A sketch plan of the site made available to Wessex Archaeology by Bill Woolford has been published on the Wrecksite.eu website. *Further reading:* Heritage Gateway Hob UID 907963 [Heritage Gateway - Results] Wessex Archaeology, 2016. UB-107, Flamborough Head, East Riding of Yorkshire. Undesignated Site Assessment, Wessex Archaeology Report No.108280.31 Wessex Archaeology, 2006, On the Importance of Shipwrecks, Final Report. Unpublished report, ref. 58591.02.

The location of First World War submarine wrecks in ETW

The First and Second World Wars have resulted in the coastal waters of the UK, particularly off the east and south coasts of England, having the richest submarine archaeology in the world. No other country has a greater concentration of submarine wrecks.

The great majority of First World War submarine loss locations correspond with patrol areas, which in turn correspond with pre-war coastal shipping and wartime convoy routes, which in turn corresponds in England mainly with the South and East coasts between the Scottish border and North Cornwall. The losses are there because that is where the targets were and therefore where the U-boats patrolled. It is also where the main Allied effort to hunt them down was concentrated and therefore where most U-boats were lost. The south-east is also where the Allies built barrages, which forced U-boats whose patrol areas were in the English Channel or the Western Approaches to either risk the barrage crossing or sail around Scotland to reach their patrol areas.

Most of the submarine wrecks in ETW are German, because very few British submarines patrolled in these areas. The main British submarine effort was offensive action outside of ETW and close to U-boat bases along the north-west coasts of Europe. Those German submarines present in ETW, mainly UB II/III and UC II/III boats are also those submarines designed and built to attack enemy shipping in coastal waters around the UK and its western approaches. Very few are the oceanic U-boats designed and built to fight in the North Atlantic and further afield. In that sense submarine wrecks in ETW are more representative of a single, all be it vital campaign, rather than of First World War submarines generally.

Inspecting and surveying a submarine wreck – basic approach

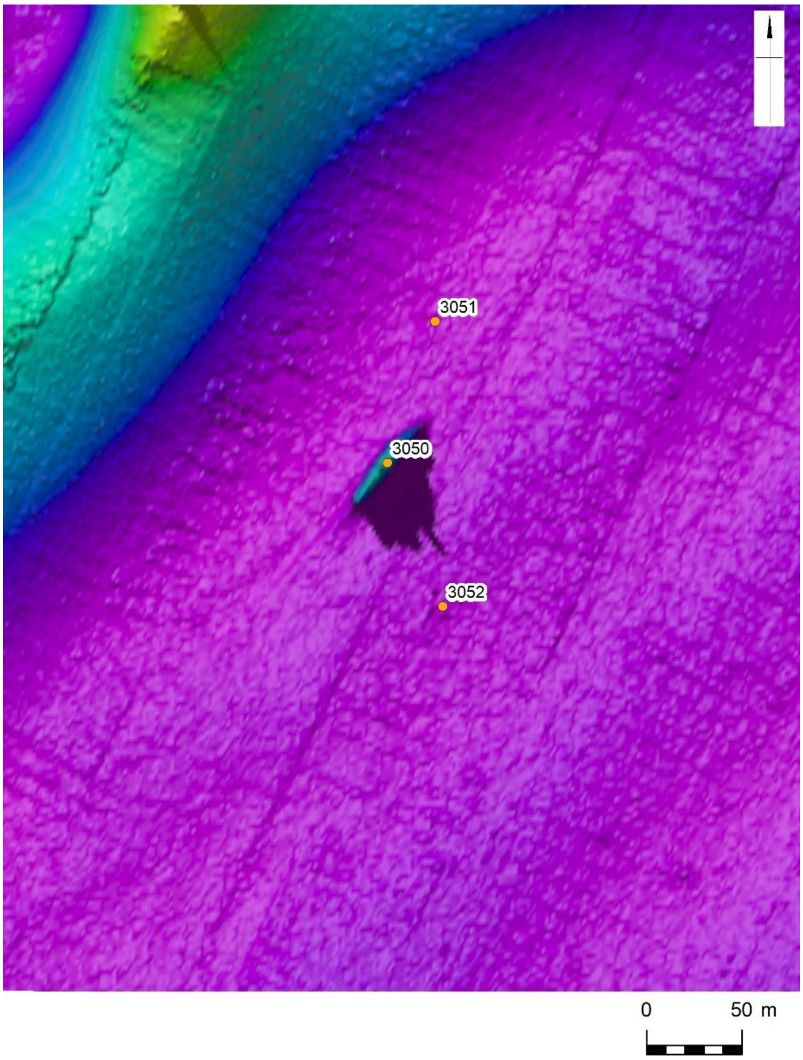
Identification

If the submarine is unidentified, then your approach is likely to be heavily focused on working out what type of submarine it was (and therefore the date range when it is likely to have been lost) and which individual submarine it was. Your approach to the wreck is likely to prioritise looking for and recording key features (see Table 4 below in Section 9.3).

'Full survey' versus 'data gaps'?

The project demonstrated that it is not always necessary to carry out fieldwork to determine the importance of a submarine wreck, the risks it faces and appropriate heritage management decisions if the information already available is good enough. That will require the archaeologist to search for and assess what is already available, a task that is undoubtedly easier if there is a co-operative relationship with whoever may have acquired the data. If existing data is considered to be of good quality, then rather than repeating it, a better approach may simply be to identify and fill in any gaps in the initial survey. The increasing availability of high resolution wreck videos on social media is likely to encourage the 'data gap' approach.

In the case of the D1, this audit of available data determined that there was visual data of the wreck acquired by avocational divers. Their video data was good, so rather than repeat their survey, the project simply examined their video and compared it with plans of the submarine, identifying what was present and what was missing. The avocational investigators lacked geophysical survey data, which would improve understanding of the submarine in its environment. However, geophysical survey can be expensive, so the project looked for data that already existed. The UKHO had MBES data acquired for hydrographic purposes that included the submarine's location, so this was obtained instead of commissioning a new survey.



Multibeam image of the D1, processed from existing hydrographic data held by the UKHO. Analysis of the data indicated that there were two outlying anomalies that could be debris from the submarine (3051 and 3052).

Systems-based approach

The systems-based approach has the potential to be very rewarding. However it was not implemented by the project due to lack of time. It is probably worth considering only if sufficient time is likely to be available to undertake a close visual inspection of much of the submarine exterior and of any interior areas that can be safely accessed. It will also require the investigators to have or develop a high level of knowledge of the design of the submarine.

Geophysics

Geophysical survey data was an essential tool of the project. Submarine wrecks are normally easy to detect because they have a very distinctive shape. The reasons why geophysical data was so important include the following:

- it is an efficient means of searching large areas of seabed if the available position is unreliable;
- it can produce a reliable position, orientation and wreck dimensions and can be used as a basic scaled plan of the wreck;

- if the wreck is in two sections it provides a reliable means of mapping their relative positions;
- it can map debris around the hull and in a wider area very efficiently;
- by providing an initial plan of the wreck, it can help plan and prioritise objectives for subsequent diver or ROV investigation; and
- by mapping the seabed as well as the wreck, geophysical data, particularly multibeam data, can help provide an understanding of the natural processes affecting a wreck such as scouring and erosion.

The project has shown that it is possible to create a description of submarine wrecks by combining geophysical survey data with existing diver video. However, when that video is not of good quality, for example if it is hard to understand where the diver was on the wreck or the footage is of low resolution, or the visibility poor, then an 'eyeball on the seabed' is usually required to create a reliable description of the wreck.

The project has also demonstrated that considerable savings can be made through the use of existing geophysical survey data, particularly MBES data, which is otherwise usually very expensive to acquire. Geophysical datasets for UK waters held by the UKHO can be accessed through the ADMIRALTY Marine Data Portal[2]. The extent to which the average avocational submarine investigator has the software resources, technical knowledge and willingness to exploit this will inevitably vary.

For those who are not being funded or who do not have the technical skills or experience required to carry out a professional standard geophysical survey, the increasing availability of easy to use and relatively cheap vessel-mounted sonar is providing greater opportunities to integrate marine geophysics in their work.

Regardless of the approach, it is of great importance that when reporting geophysical survey results that the methodology used to acquire and process the data should also be reported. Too much reliance is placed on the 'legibility' of images, without an understanding of how the data was acquired and processed.

The following case studies provide examples of the methodology used for acquiring and processing geophysical data, how the results were presented and how they were integrated into the report.

Case Study - UB-109: an example of geophysical survey methodology in a professional context
This case study examines the geophysical survey undertaken for the investigation of UB-109, in order to provide an example of how data can be gathered, processed and interpreted in a professional context. Detailed specifications are provided as an example of how data can be gathered. **Data Sources** Geophysical data over the UB-109 were acquired in 2014, with Wessex Archaeology acquiring the sidescan sonar and magnetometer data, and Swathe Services acquiring the multibeam bathymetry data (Wessex Archaeology 2015b) The geophysical data used for this report were assessed for quality and their suitability for archaeological purposes, and rated using the following criteria:

[2] Access Data (admiralty.co.uk)

Case Study - UB-109: an example of geophysical survey methodology in a professional context

Data Quality	Description
Good	Data which are clear and unaffected by weather conditions or sea state. The dataset is suitable for the interpretation of standing and partially buried metal wrecks and their character and associated debris field. These data also provide the highest chance of identifying wooden wrecks and debris.
Average	Data which are affected by weather conditions and sea state to a slight or moderate degree. The dataset is suitable for the identification and partial interpretation of standing and partially buried metal wrecks, and the larger elements of their debris fields. Wooden wrecks may be visible in the data, but their identification as such is likely to be difficult.
Variable	This category contains datasets with the quality of individual lines ranging from good to average to below average. The dataset is suitable for the identification of standing and some partially buried metal wrecks. Detailed interpretation of the wrecks and debris field is likely to be problematic. Wooden wrecks are unlikely to be identified.

The sidescan sonar data were rated as mostly “Average” with some lines as “Good” using the above criteria. The positioning accuracy of the sonar towfish was relatively poor due to a combination of tidal currents experienced during the survey and the length of towed cable used (itself a function of water depth and current strength). The marine magnetometer data were rated as “Good” using the above criteria. The data were clear with very little spiking or background noise. The multibeam bathymetry data were rated as “Good” using the above criteria.

Geophysical Data – Technical Specifications

The sidescan sonar data were acquired using a Klein 3900 high frequency digital system deployed off the port quarter of the vessel. The system was operated at 900kHz with a range of 30 m per channel. Towfish positioning information was provided by manual layback during processing. Data was recorded digitally using SonarPro software as .xtf files.

The marine magnetometer data were acquired using a Geometrics G-882 Caesium Vapour magnetometer operating at a cycling rate of 10Hz. It was deployed piggybacked behind the sidescan sonar towfish on a 10 m cable. The data was digitally logged in Geometrics MagLog software as .GEOMAG files, and later converted to .txt files for processing and interpretation.

The 2014 multibeam bathymetry data was acquired simultaneously with the sidescan sonar and magnetometer data by Swathe Services Ltd using a R2Sonic 2022 system, operated at 700kHz. Motion reference was provided by an R2Sonic Integrated Inertial Navigation System and velocity

Case Study - UB-109: an example of geophysical survey methodology in a professional context

profiling by a Valeport Monitor SVP. The data were recorded digitally in QINSy and provided to WA as gridded and ungridded .pts, points, files.

Positioning for the survey was also provided by the Inertial Navigation System. All positions for the survey were recorded as WGS84 geodetic coordinates. These coordinates were projected into UTM 31N during data processing and all interpretation was carried out using projected coordinates.

The main survey lines were acquired with a southwest-northeast orientation in order to run parallel to the strong tidal stream in the area. This was necessary for the skipper to keep to the survey lines and to minimise the towed survey equipment being swept to the side by the strong tide.

Geophysical Data – Processing

Sidescan Sonar

The sidescan sonar data were processed by Wessex Archaeology using Coda GeoSurvey software This allowed the data to be replayed with various gain settings in order to optimise the quality of the images. The data were interpreted for any objects of possible anthropogenic origin. This involves creating a database of anomalies within Coda by tagging individual features of possible archaeological potential, recording their positions and dimensions, and acquiring an image of each anomaly for future reference.

A mosaic of the sidescan sonar data is produced during this process to assess the quality of the sonar towfish positioning. The survey lines are smoothed, and the navigation corrected by applying individual fixed laybacks as recorded during the survey. This allows the position of anomalies to be checked between different survey lines and for the layback values to be further refined if necessary.

The form, size, and/or extent of an anomaly is a guide to its potential to be an anthropogenic feature, and therefore of its potential archaeological interest. A single, small, but prominent anomaly may be part of a much more extensive feature that is largely buried. Similarly, a scatter of minor anomalies may define the edges of a buried but intact feature, or it may be all that remains of a feature as a result of past impacts from, for example, dredging or fishing.

Magnetometry

The magnetometer data were processed using Geometrics MagPick software in order to identify any discrete magnetic contacts which could represent buried metallic debris or structures. The software enables both the visualisation of individual lines of data and gridding of data to produce a magnetic anomaly map.

The data were loaded into MagPick and laybacks added as with the sidescan sonar data. The data were then smoothed, a trend fitted to the results, and then the trend values subtracted from the smoothed values. This was carried out in an attempt to remove natural variations in the data (such as diurnal variation in magnetic field strength and changes in geology). The processed data were then gridded to produce a map of magnetic anomalies, and individual anomalies tagged and images taken in a similar process to that undertaken for the sidescan sonar data.

Case Study - UB-109: an example of geophysical survey methodology in a professional context

The form and size of a magnetic anomaly is a guide to its potential to be an anthropogenic feature. Generally distinct magnetic anomalies with amplitudes of over 5 nT identified along a short distance are interpreted to be of anthropogenic origin.

Multibeam Bathymetry

Swathe Services processed the multibeam bathymetry data before providing it to Wessex Archaeology. Local tidal observations were recorded and used to reduce the data to Lowest Astronomical Tide (LAT). The true heave was applied to the raw data to correct for heave artefacts. The raw data were then cleaned using QLOUD, a 3D area based cleaning software which is part of QINSy. All obvious data anomalies were removed with extra care taken to not remove any real data from the areas in the immediate vicinity of the wreck site. The individual lines were then combined to create a grid which was used to further analyse the areas surveyed. Adjacent lines were used to determine areas of uncertainty giving a final grid which was exported to points files at 0.5 m and 0.25 m resolution. Ungridded data were also provided for individual lines as points files.

The multibeam bathymetry data were fully analysed to identify any unusual structures of the shipwreck or other anthropogenic debris. The gridded data were analysed using IVS Fledermaus software, which enables 3-D visualisation of the acquired data and geo-picking of seabed anomalies. The data gridded to 0.25 m provided much greater detail of the wreck and was used for the interpretation.

Geophysical Data – Anomaly Grouping and Discrimination

The previous section describes the initial interpretation of all available geophysical data sets. This inevitably leads to the possibility of any one object being the cause of numerous anomalies in different data sets and apparently overstating the number of archaeological features around the wreck site.

To address this fact, the anomalies were grouped together, allowing one ID number to be assigned to a single object for which there may be, for example, a magnetic response and multiple sidescan sonar anomalies.

Once all the geophysical anomalies have been grouped, a discrimination flag is added to the record in order to discriminate against those which are not thought to be of an archaeological concern. These flags are ascribed as follows:

Non-Archaeological	**U1**	Not of anthropogenic origin
	U2	Known non-archaeological feature
	U3	Non-archaeological hazard
Archaeological	**A1**	Anthropogenic origin of archaeological interest
	A2	Uncertain origin of possible archaeological interest

Case Study - UB-109: an example of geophysical survey methodology in a professional context

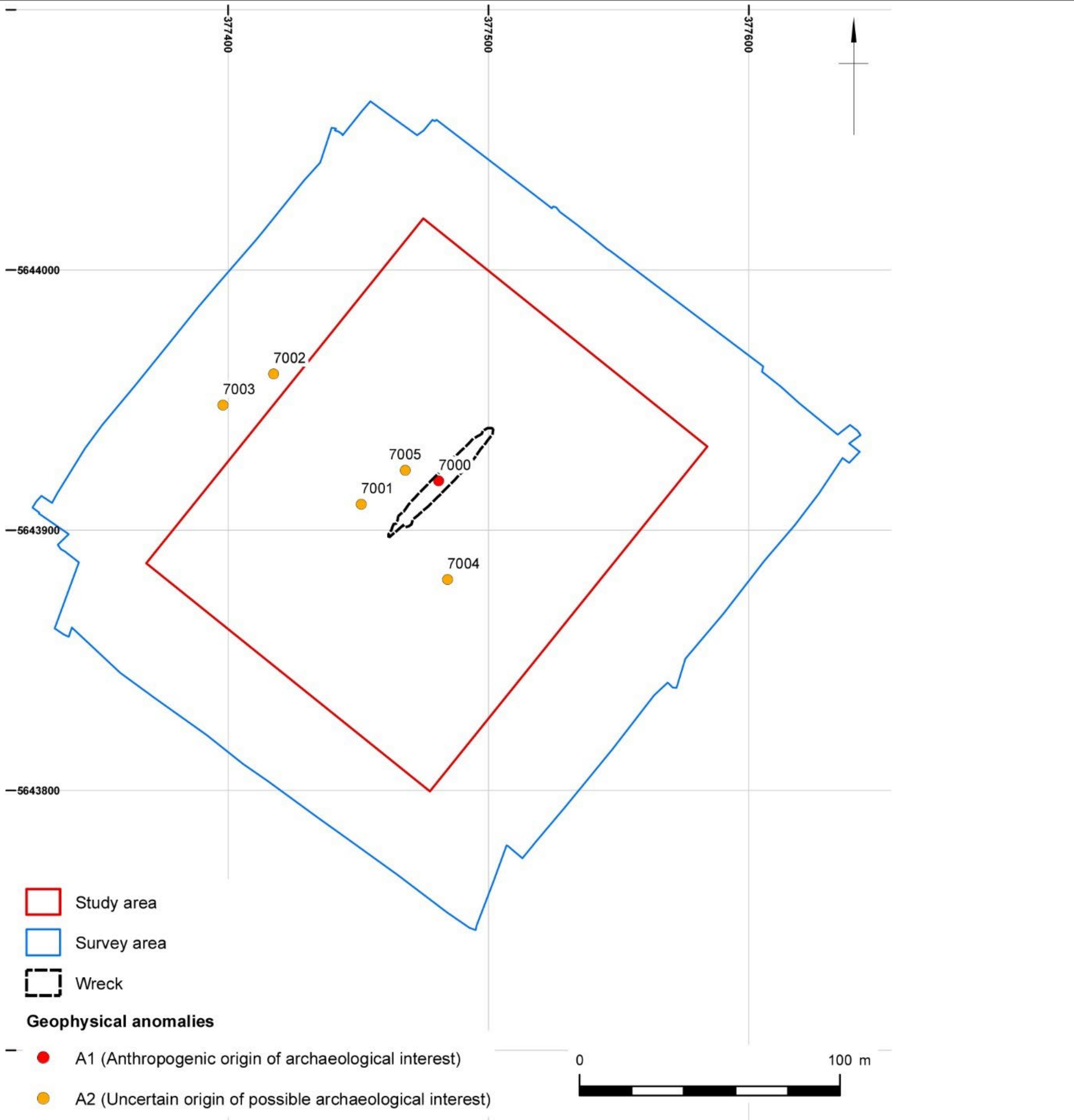
	A3	Historic record of possible archaeological interest with no corresponding geophysical anomaly

The grouping and discrimination of information was based on all available information but is not considered to be definitive. It allows for all features of potential archaeological interest to be highlighted, while retaining all the information produced during the course of the geophysical interpretation for further evaluation should more information become available.

All the features that were identified from around the wreck sites were then presented in an appendix in the report (Wessex Archaeology 2015b).

Case study - using geophysical survey on the U-8
Historic England requested a marine geophysical survey of the U-8 wreck site, as due to safety concerns about the location of the wreck site, diving operations were not permitted. The geophysical survey was undertaken by an Autonomous Underwater Vehicle (AUV). The survey comprised a pseudo-sidescan sonar, bathymetry and magnetometer survey. In addition existing MBES data was obtained from the UKHO. The survey identified a number of geophysical anomalies within the survey area.

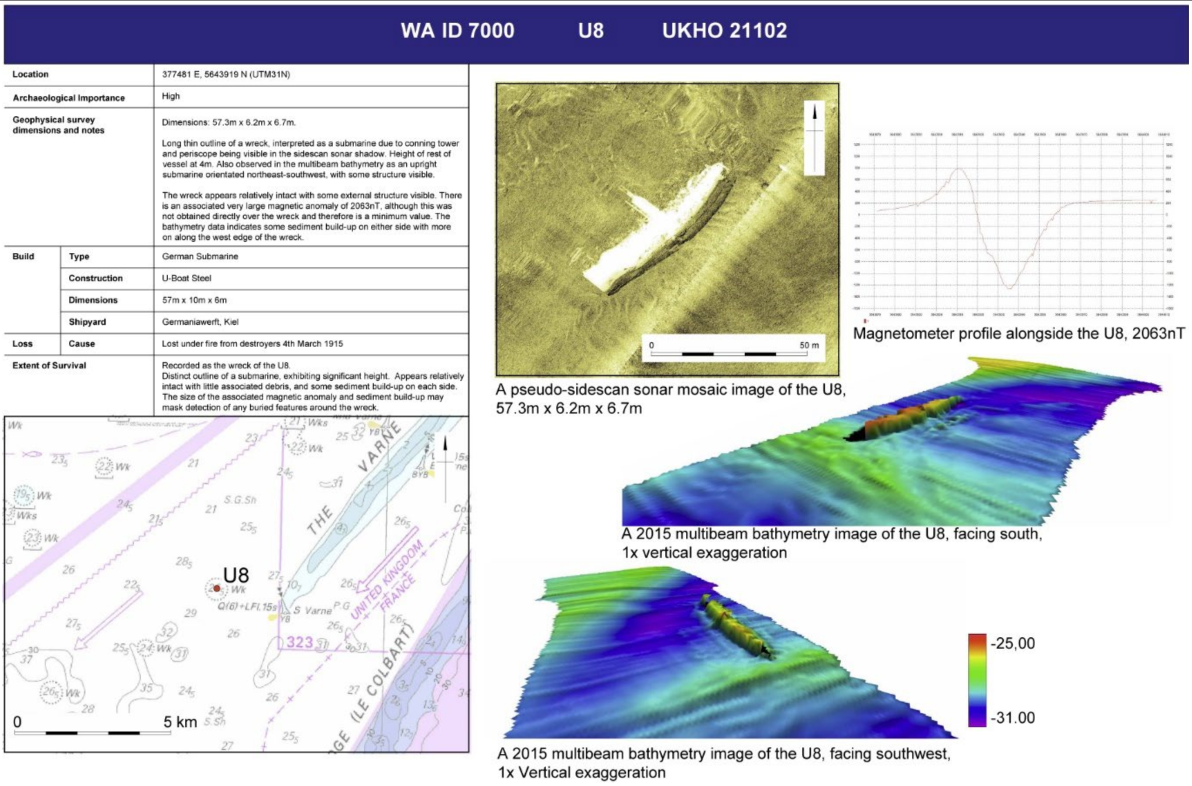
Case study - using geophysical survey on the U-8



Detected anomalies close to the UB-8 wreck were described in detail in one of the report appendices (Wessex Archaeology 2015d).

The results were also presented as a 'wreck sheet', a form of presentation commonly used in developer-funded marine archaeology:

Case study - using geophysical survey on the U-8



WA ID 7000 U8 UKHO 21102

Location		377481 E, 5643919 N (UTM31N)
Archaeological Importance		High
Geophysical survey dimensions and notes		Dimensions: 57.3m x 6.2m x 6.7m. Long thin outline of a wreck, interpreted as a submarine due to conning tower and periscope being visible in the sidescan sonar shadow. Height of rest of vessel at 4m. Also observed in the multibeam bathymetry as an upright submarine orientated northeast-southwest, with some structure visible. The wreck appears relatively intact with some external structure visible. There is an associated very large magnetic anomaly of 2063nT, although this was not obtained directly over the wreck and therefore is a minimum value. The bathymetry data indicates some sediment build-up on either side with more on along the west edge of the wreck.
Build	Type	German Submarine
	Construction	U-Boat Steel
	Dimensions	57m x 10m x 6m
	Shipyard	Germaniawerft, Kiel
Loss	Cause	Lost under fire from destroyers 4th March 1915
Extent of Survival		Recorded as the wreck of the U8. Distinct outline of a submarine, exhibiting significant height. Appears relatively intact with little associated debris, and some sediment build-up on each side. The size of the associated magnetic anomaly and sediment build-up may mask detection of any buried features around the wreck.

A pseudo-sidescan sonar mosaic image of the U8, 57.3m x 6.2m x 6.7m

Magnetometer profile alongside the U8, 2063nT

A 2015 multibeam bathymetry image of the U8, facing south, 1x vertical exaggeration

A 2015 multibeam bathymetry image of the U8, facing southwest, 1x Vertical exaggeration

Further reading:

National Heritage List for England No. 1430265 (U-8) SM U-8 - 1430265 | Historic England

Wessex Archaeology. 2015b. UB 109, off Folkestone, Kent, Report No. 83803.34

Wessex Archaeology. 2015d. U8, off South Varne Buoy, English Channel, Undesignated Site Assessment, Report No. 108280.14

Notes on external inspection and survey methods used by the project

Exterior survey methods used during the project are listed in the table below, together with other techniques that are likely to be useful in surveying the exterior of a submarine.

Technique	Notes
Visual inspection	Visual inspection can be divided into two categories derived from the offshore diving industry: general visual inspection (GVI) and close visual inspection (CVI). 1) GVI is a visual survey of the whole submarine wreck or a substantial part of it. This is very similar to a recreational dive visit to a wreck. By comparing what you see during the dive with a plan of that type of submarine, it is often possible to map out accurately those parts of the submarine that survive.

Technique	Notes
	2) CVI is a detailed visual inspection of individual features of a wreck – for example a detailed look at a propellor and shaft, or an examination of the deck gun. It may or may not involve cleaning marine growth from the feature to make inspection easier. Although CVI will naturally follow GVI, they can be carried out in the same dive – the distinction is only really important in terms of recording what you have done in an organised way. For example, the main areas of corrosion on a submarine hull can be marked down on a laminated plan during an initial GVI, with these areas then measured and sketched on a dive slate in more detail during CVI.
Direct measurement	Measurement is at the heart of archaeological survey. Direct measurement here means the use of a tape measure to record the dimensions of the wreck. Submarine wrecks are generally large, so unless you have the luxury of a lot of time, it is best to identify key measurements relevant to what you need to know. For example if the bow of the submarine is missing and you wish to know in which compartment the break occurred, then by measuring the distance between a recognisable feature, the measurement can be applied to a scale plan of that particular type. Techniques such as photogrammetry and the use of imaging sonar now offer quicker and often more accurate ways of taking measurements.
Photography	Handheld and colour CCTV helmet mounted video was the main means of recording visual data for the project. Therefore, still photographic survey for the project tended to use the same small compact cameras and action type cameras used for the handheld video. These were small, simple to operate in the difficult diving conditions sometimes experienced, as well as easier for the diver to multitask with. The type of camera and lighting used is not critical, provided that it achieves the consistent quality required. A camera scale divided into 100 mm or 200 mm colour bars is normally placed in front of the object being photographed. However, photographs are usually viewed in the context of a report, so if time is short then it may be more effective to use the time required to carefully place a scale to measure the object itself.
Video	Video survey for the project used action type cameras such as HD/4K GoPros and diver helmet mounted colour CCTV cameras of the type used for inspection work offshore. These generally met the video survey needs of the project. Their cheapness and ubiquity within both avocational and professional diving suggests that the increasingly sophisticated action cameras, now capable of 5K ultra-wide video, sophisticated stabilisation, moderately high frame rates and high resolution frame capture, are likely to be the video camera of choice for the foreseeable future.

Technique	Notes
Photogrammetry	Photogrammetry now offers the opportunity to quickly create accurate and scaleable 3D models of submarine wrecks and good results can be achieved using cameras, lights and laptop computers increasingly within reach of avocational budgets. Done carefully it is likely to achieve more accurate results than direct measurement in far less time and can be used to record the entire wreck or individual features. Photogrammetry is well established in maritime archaeology and is now part of what could be called the 'standard archaeological toolkit'. It has been used for high quality submarine wreck survey and offers the potential for very rapid survey. It must always be remembered that the result is a textured model and it is best to think of it as additional to still photography rather than a replacement. Photogrammetry has the added bonus that data acquisition for a whole wreck will result in a very thorough photographic or video record of the entire vessel[3]. Photogrammetry is difficult if there is a lot of suspended particles and algae in the water column. This may make it difficult or impossible to achieve a good result. Shooting the photographs and video from a much closer distance off the wreck may help, but in those circumstances the amount of overlap required to achieve a good result can make the survey time consuming and a good result is not guaranteed.
Sonar/laser	Although not used during the project, imaging or multibeam sonar offers a survey technique that is particularly suitable for very quickly surveying a large site in very poor visibility. Rather than a traditional sonar, which creates an image of the seabed either side of sonar as it is being towed, an imaging sonar is mounted on an ROV or is hand-held by the diver and can be pointed wherever required. The images can be either 2D or 3D. Low frequency sonar can survey 50 m or more ahead in an arc, well beyond visual range and unaffected by particulates and algae. Very high frequency sonar, which has a much shorter range, can be used to provide accurate measurements of both large and small objects. As the sonar is normally connected to recording and display equipment on the surface by a cable, it is best suited to professional surface supplied divers and ROVs. However, it is capable of being deployed by SCUBA divers from an anchored boat and versions are available that are tetherless and have a display that can be seen by the diver. The main drawback of this type of equipment is its cost, although tethered versions are available to rent. Laser scanners suitable for underwater use are very specialist equipment that are well beyond the budgets of most avocational divers. Capable of great accuracy and therefore usually with a lower range than sonar, they are affected by particulates.

[3] See Brown, S., 2018. *The Story of U.B.116. The First 100 Years*, Deep3D for a good example

Technique	Notes
Acoustic positioning	Acoustic positioning using long, short and ultrashort baseline systems has been extensively used in archaeological surveys by professional marine archaeologists in the UK for almost two decades. It was used during the project and also for the related survey of HMS A1, where it was used to record the position of UT test sites. It offers a means of accurately confirming the position and orientation of a submarine wreck where MBES data is not available and can also be useful in positioning outlying debris and in navigating divers in poor visibility. However, it requires some technical knowledge and experience and is difficult to use effectively without reliable voice communications between the diver and the equipment operator. It is also expensive to rent, so it is probably best deployed on fully funded investigations.
Marine growth/environment survey	Marine growth surveys were not part of the scope of the work undertaken for the project. However, they are useful for both ecological and archaeological purposes. Therefore, as a minimum it is recommended that a short description of the seabed, currents and light levels/visibility should be compiled, together with close-up photographs of sample areas of seabed and marine growth. The presence of bioturbation (burrowing by lobsters and crabs, etc.) should be noted. Obvious effects of the wreck on the seabed, such as scouring and the build-up of banks of sand should be recorded (locations, size, etc.).

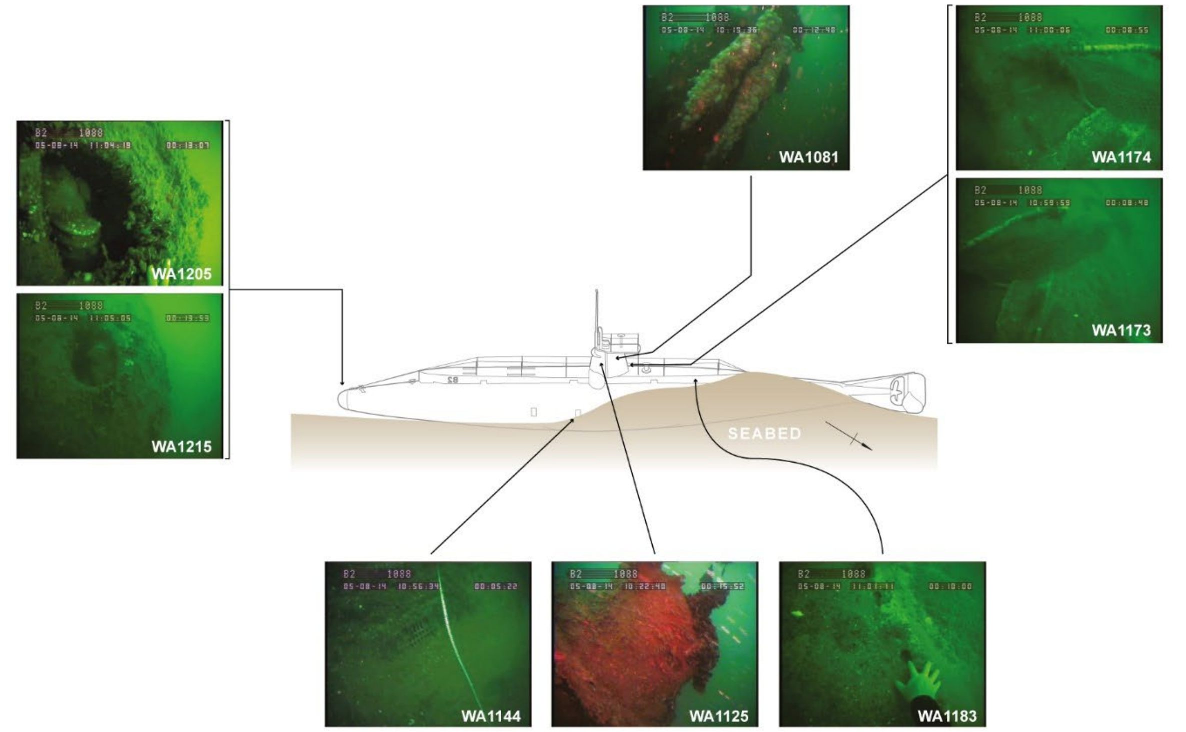
Case Study – integrating video, diver descriptions and plans

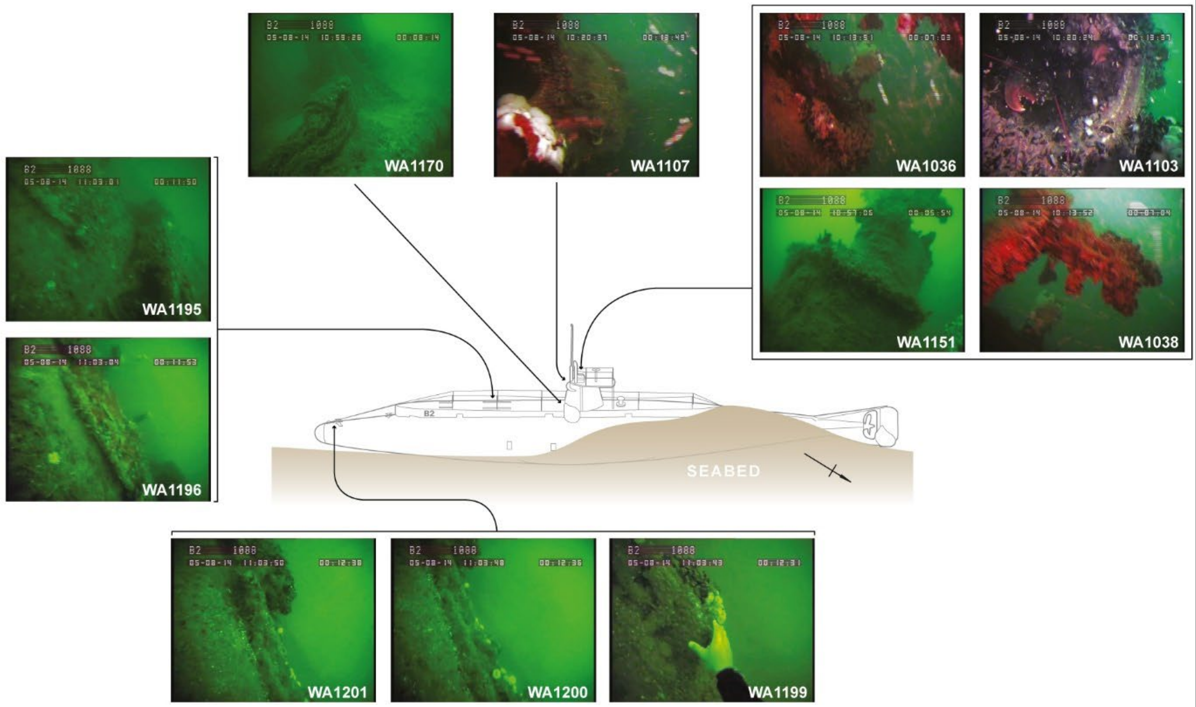
The table below is an example of how the project used video and diver descriptions gathered during the inspection of a submarine wreck, as well as plans of the submarine to produce a detailed inspection report.

Case study - describing the B2 submarine wreck using video and contemporary plans
In 2013 Wessex Archaeology was asked to carry out an archaeological assessment of the wreck of the Royal Navy submarine B2 off Dover (Wessex Archaeology 2013b). The wreck had already been correctly identified, but little detailed information about its condition was available at the time. After undertaking a geophysical survey that confirmed the position, orientation, extent and environment of the wreck, a short diving inspection was carried out. The description from the diver was then combined with video stills and is presented here in full as a model example of how to write a detailed description of a submarine wreck following a dive. It has been written in a ‘wreck tour’ style and the diver’s understanding of the wreck has been augmented by looking at contemporary photographs and plans obtained from both the National Museum of the Royal Navy and the web. The site had a short slack and the diver didn’t have time to take any measurements but using surface supplied equipment with recorded communications to the surface was able to describe the wreck as he swam around it. The same type of results could have been achieved using a dive slate to sketch and make notes.

Case study - describing the B2 submarine wreck using video and contemporary plans

The numbers in bold brackets in the text refer to the thumbnail video images in the illustrations.





General description

The wreck appears to be in good condition showing a continuous structure with the hull fairly intact. The boat lies relatively upright on the seabed listing c. 30 degrees to starboard. The hull stands out c. 1.5 m from the seabed with the conning tower rising a further c. 2 m above the deck.

Case study - describing the B2 submarine wreck using video and contemporary plans
The stern and bow are exposed even though the section aft of the conning tower is covered by c. 100 mm of sand amassed against the structure. From the conning tower to the bow the wreck is c. 21 m long. As might be expected on an exposed site, large amounts of the deck plating and the upper casing has corroded and, together with many of the deck fixtures and fittings, is now missing. At the time of the survey the submarine was draped by nets aft and forward of the conning tower that hid some of its features and further netting was found all around the site, but particularly on the portside. Even though some nets were lifted to reveal the features underneath no attempt to remove the bulk of the nets was made. The likelihood of debris associated with HMS B2 wrapped in the netting around the wreck is very high. For clarity the following paragraphs that outline the data gathered during the diving inspection are divided into six separate sections: bow, forward section, conning tower, aft section and stern. *Bow* At the time of the survey the bow was clear of sand and was undercut by scouring. The bow appears to be exposed with the height of the hull at the bow section noted to be well over 2 m. A hole on the upper part of the port side of the bow shows the operating crankshaft for the port side torpedo muzzle door (WA1205). The opening is quite regular and measures c. 350 mm in diameter. It shows a possible concreted external hinge or pad eye. By peering into the opening, the space visible inside the pressure hull was observed to be filled almost completely with sediment. *Forward section* From the bow towards the conning tower the submarine hull is mostly intact although one section shows signs of damage with the casing appearing to be ripped open on top. It is possible that this is the location where the SS Amerika hit the submarine at the time of its sinking, confirming the contemporary description of the incident reported in the newspapers of the time. Associated debris was found partly buried on the port side. Immediately aft of the bow are the forecastle pad eyes where the rigging was attached. Proceeding towards the conning tower, two large, paired L-shaped chocks run along the hull (WA1201). From this point up to the damaged area before the conning tower the port side is upstanding (c. 2 m) from the seabed and clear from marine growth or debris apart from some small strands of net. On the starboard side some debris is visible. The nature of this debris is currently unclear but it is possible that is part of the upper casing re-deposited onto the seabed. Also visible and of uncertain identification is a cylindrical hollow feature, possibly part of a winch mechanism or a bollard. Following the deck in a northerly direction towards the conning tower, the forward torpedo loading hatch is visible (WA1196). The hatch is closed and in good condition. Associated with the hatch are two curved features that rise on the starboard side. It is likely that they were either hooks used during loading operations or hatch hinges.

Case study - describing the B2 submarine wreck using video and contemporary plans
Aft of the hatch a section of upper casing seems to have retained its position and shape (WA1195). This might be particularly significant as it has been suggested that the B-class boats were the first submarines to be fitted with deck casings (Hool & Nutter, 2013) although this fact is not mentioned by any other sources. From this point on to the conning tower the foredeck is covered by netting and appears to be broken up. On the port side at an approximate distance of 3 m from the conning tower some flat plates protrude out of the seabed. They are entangled with nets and appear to be disconnected from the main body of the wreck. On closer inspection the plating seems to be attached together with a T-shaped support and shows some ribbing at the base. The feature's shape, dimension and location suggest the identification with a section of upper casing re-deposited from its original position. Back towards the hull, close to the conning tower, is a small grate (WA1143). The grate seems to be still in situ and therefore located on the side of the hull below the deck casing. A small flap and a rectangular opening are in the hull not far from the grating. Approximately 4 m forward of the conning tower a large amount of rolled netting hangs towards the portside. More netting hides two deck fittings just in front of the conning tower (WA1170). The net closest to the conning tower was partly removed and some thick flat plate was revealed standing upright underneath it. This feature is not identified although its position would be consistent with the fore hydroplanes (also called conning tower planes) that are shown in the historical photographs. If this feature is identified as the fore hydroplanes it would be a significant find as these were first introduced in the B-Class (Akermann 1989). During the removal of one of the heaps of netting a modern ratchet strap lever was found trapped in the mesh of the net. Removing the nets also revealed a wedge shaped area of damage that is located in a position that corresponds to the one recorded in the contemporary accounts of the HMS B2 accident. A circular hole is located just forward to the conning tower. The purpose of the hole is not clear and it could be either due to corrosion, or it could be the slot for one of the deck fixtures. Twisted metal debris corresponding with a geophysical anomaly was found c. 3 m NE of the conning tower (WA1142). *Conning Tower* With its truncated conical shape the conning tower constitutes the most prominent feature of the wreck (WA1161). It rises c. 2 m from the foredeck and it lies at an angle, approximately 30 degrees to starboard. Its condition is notable and the conical hatchway connected to the pressure hull still retains its shape although the outer plating is missing and appears to have corroded away. The conning tower upper hatch is open and the hatch door is in situ hinged towards the port side (WA1103). Concreted to the door there are two curved metal rods that form a semi-circular section above the conning tower entrance. The nature of these features around the tower is unclear but it is possible that they acted as a safety parapet around the submarine exit (WA1038). Divers reported the control room as being silted up with sand (Young & Armstrong, 2003). On top of the conning tower, in a forward and slightly starboard position, stands a pipe-like feature c. 0.5 m long and 0.2 m in diameter which is interpreted as a vent.

Case study - describing the B2 submarine wreck using video and contemporary plans
The periscope is missing and only a small hole suggests its possible previous location. However, it is unclear if it is that or a slot for a stanchion or pole to cover the conning tower bridge (WA1107). In 1998 the periscope was reported by Bob Peacock in Diver Magazine as “broken off by a trawl net and is lying to one side”. A large net that could conceal a pole-shaped feature of the dimensions of the periscope was found c. 4 m to the port side of the conning tower (WA1024). Immediately aft of the conning tower are two pipes (c. 2 m long and 0.3 m diameter) completely covered by colonies of bright white anemones (WA1081). They are symmetrically placed close to the centre line and rise from the aft deck level up to the first section of the conning tower (c. 2 m). These features are identified as vents or engine exhausts and were once covered by the hood of the conning tower. As illustrated in historical photographs of B class submarines it is very likely that the three vents, two aft and one on top of the conning tower, were fitted with cowl heads and, together with the steering wheel and shafting above the bridge deck, were removed for diving. It is unclear if the absence of the cowl heads on B2 is due to corrosion, trawling, or salvage, or if they were simply not fitted at the time of the sinking. On the stern side of the body of the conning tower, behind the two vent pipes, a rectangular scuttle is visible (WA 1125). At the bottom of the tower on the port side another small opening, possibly a scuttle or a drainage hole, is noticed. *Aft Section* Following the ventilators pipes down to the aft deck part of the railings and recesses for fitting the now missing superstructure/awning aft of the conning tower are visible (WA1174). About 1 m from the vents a stanchion c. 1.5 m long by c. 70 mm diameter is sharply bent towards the port quarter, in a northerly direction. Although covered by nets the feature is still attached to the deck centre-line at the base. On the top of the stanchion is a truncated cone joint (WA1173-1174). The pillar could be a shaft that was connected to the upper steering wheel installed on the aft end of the conning tower bridge, at the fore end of a small collapsible bridge platform located directly abaft the conning tower. Nets are present aft of the conning tower and up to c. 4 m in a northerly direction over the port side. At c. 1.5 m from the port side of the submarine a cylindrical feature (300 mm diameter x 1.5 m length) with toothed indentations on one end seems to be entangled in the fishing gear (WA1187). The nature of this feature is unclear. The compass binnacle which would have been located abaft the conning tower is missing even though an oval slot on the top of the hull may possibly indicate the position of its mounting. It is possible that it may have been impacted by fishing activity, contemporary or more recent salvage activity, or it may still be situated in the interior compartments since it may have been stowed in the vessel prior to the collision. Proceeding north towards the stern at the level of the hull casing it is possible to see some elements related to the upper deck casing. A small rectangular hatch is visible at c. 2 m from the conning tower base on the port side. The indentation that connected the upper casing to the

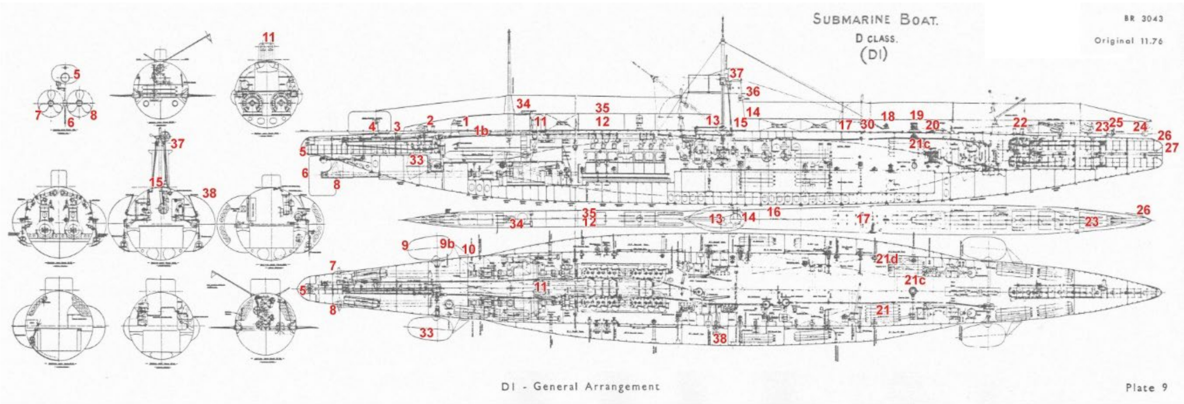
Case study - describing the B2 submarine wreck using video and contemporary plans
pressure hull is present and also the drainage slots (holes of c. 150 x 60 mm, spaced c. 0.3 m) which run along the port side of the upper hull (WA1183), are visible. At c. 7.7 m from the conning tower, just aft of the mid-ship area, the submarine becomes increasingly buried in the substrate (c. 100-150 mm of sand) as the wreck is partially covered by a small sand wave butting up against it. *Stern* Although Wessex Archaeology did not dive this section during the survey, the description that follows is based on information and photographs available from local divers and other sources used to inform this assessment. The stern is clear of sand, intact and with very little marine growth. The state of preservation is so good that it has been suggested that it is periodically buried and only recently exposed although it is known that was uncovered in 2008 and 2012 (Canterbury Divers Dive Report). The bronze tri-bladed propeller is still in situ as are the hydroplanes and the single steering rudder with the driving rods still attached. *Further reading:* Historic England Research Record 1452602 Heritage Gateway - Results Wessex Archaeology, 2013b. HMS B2. Undesignated Site Assessment, client report no. 83803.32 (HMS B2 Dover Approaches: Archaeological Report | Historic England) McCartney 2002 & 2008 Young & Armstrong 2003.

The following is another complete example of how the project used the high quality results of previous work to produce a comprehensive description of a submarine wreck. In this case, existing video produced by volunteer diver investigators was used to compile a description that was then used as evidence to support a case for designation.

Case study - making the most of existing data
In 2020 Wessex Archaeology carried out an archaeological assessment of the newly identified wreck of HMS D1**.** The depth of the well-preserved wreck and the impact of the pandemic meant that a new survey could not be undertaken. Instead, the archaeologist combined still images taken from a video shot by the team which had identified the submarine, with contemporary plans and photographs. This is presented in full as an example of the detailed description of a submarine wreck that can be prepared without having to dive. A similar exercise can be carried out using stills taken from dive videos posted on YouTube, although the video maker should be credited and their permission obtained. The D1, laid down in 1907 and launched in 1908, was the prototype for what became the basic RN submarine design for the next forty years. It was a ‘saddle tank’ design and the first of a new

Case study - making the most of existing data

generation of ‘overseas’ submarines, the previous designs having all been intended for relatively short-range ‘coastal’ operations.



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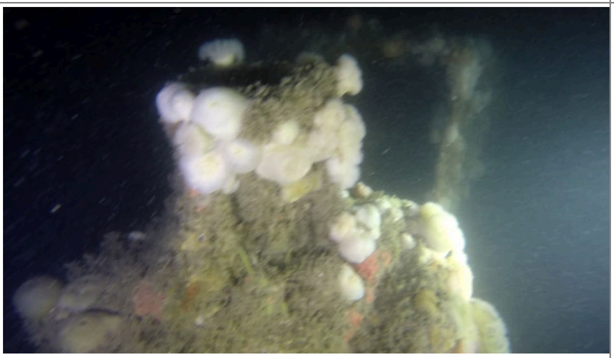
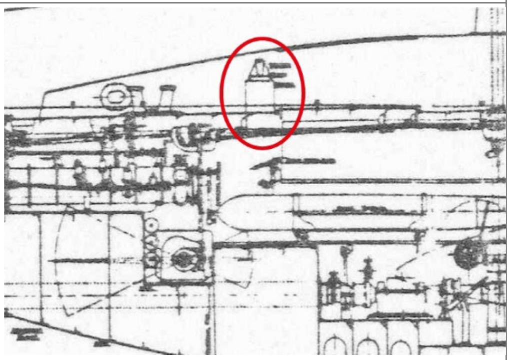
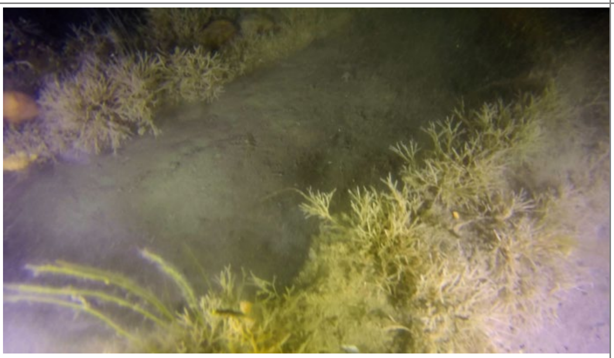
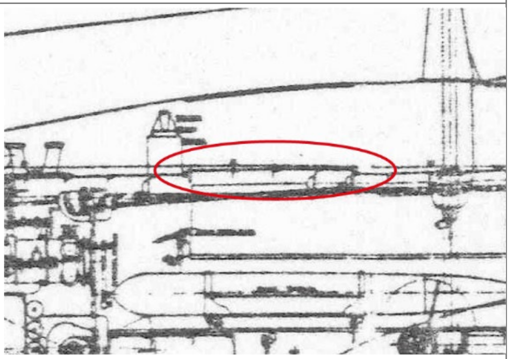
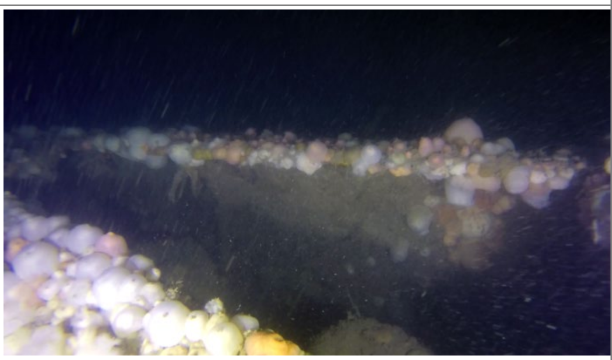
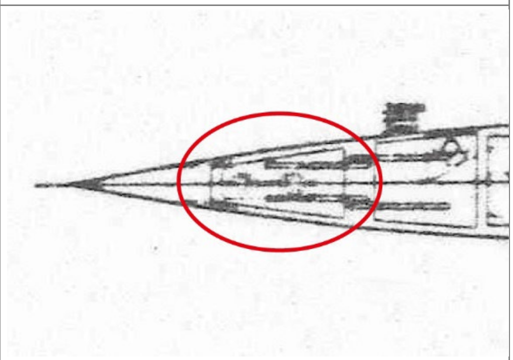
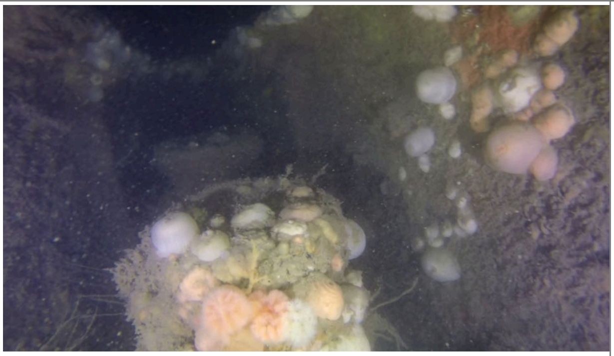
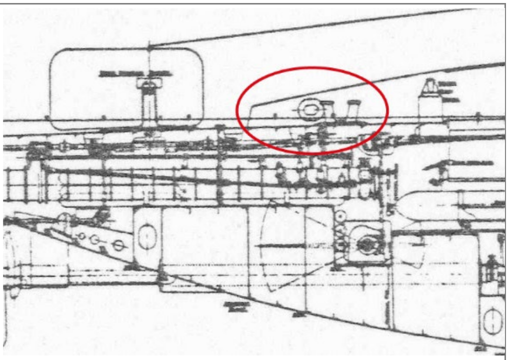
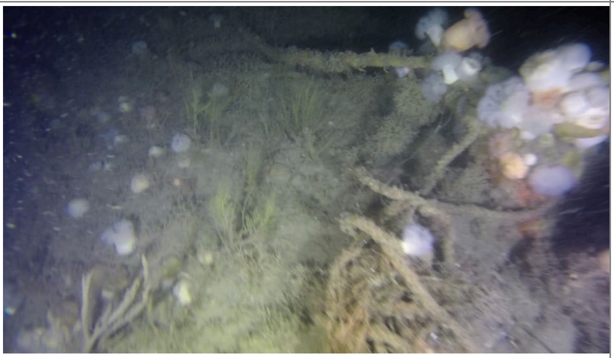
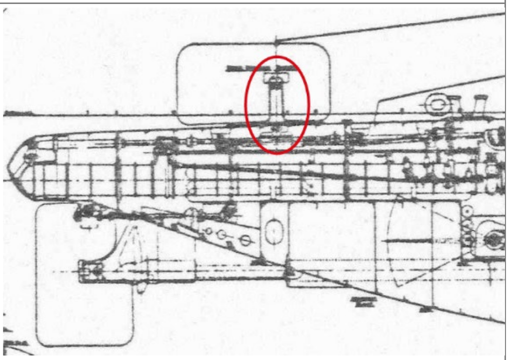
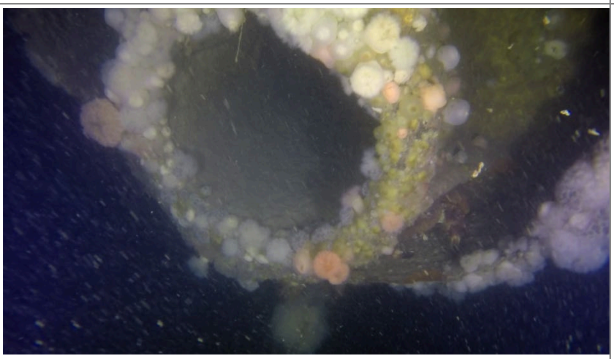
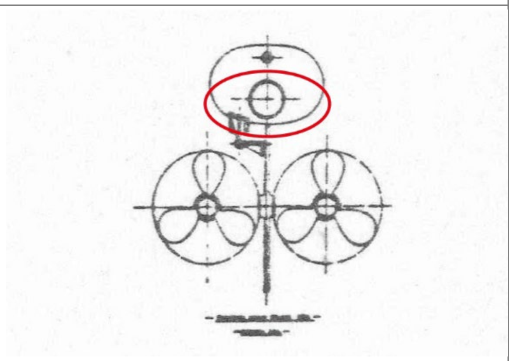
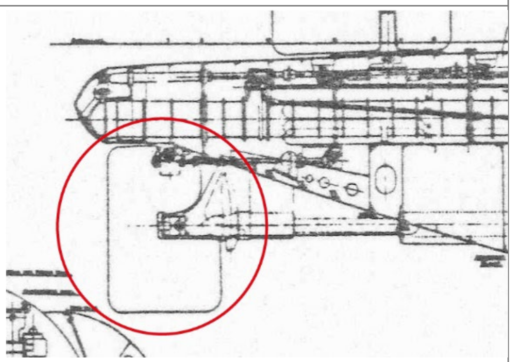
1		
1b		
2		

Case study - making the most of existing data		
2b		
3		Unidentified fitting
4		
5		
6		

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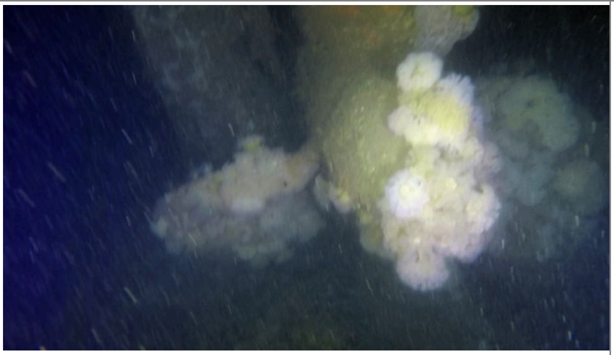
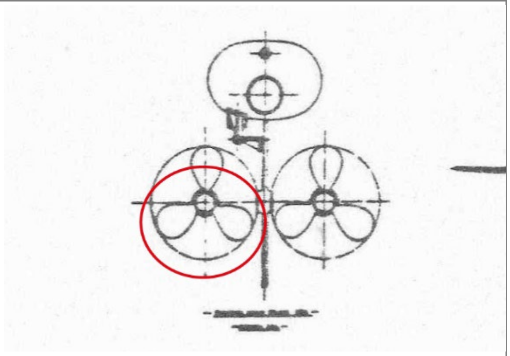
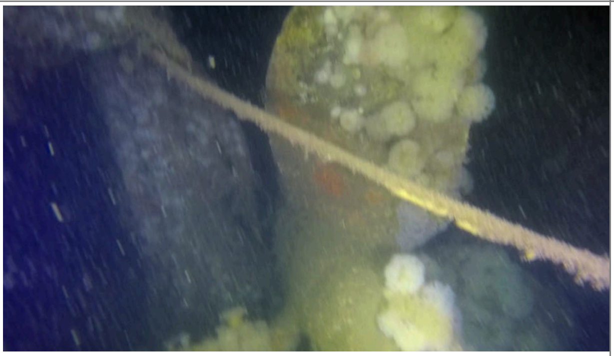
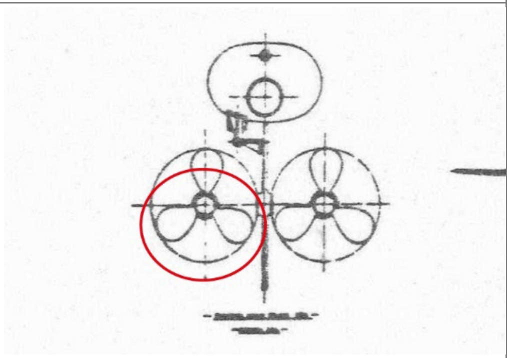
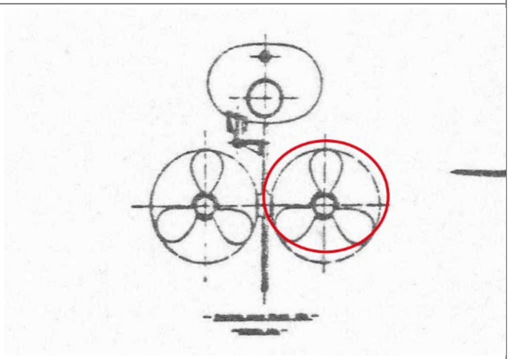
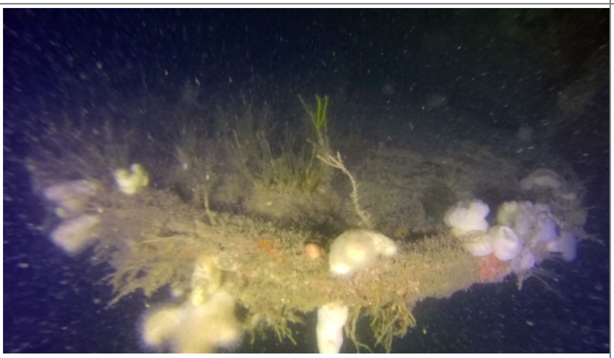
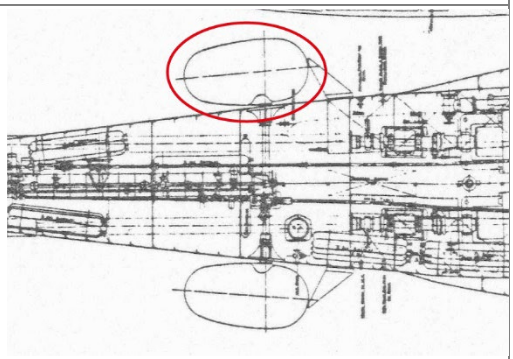
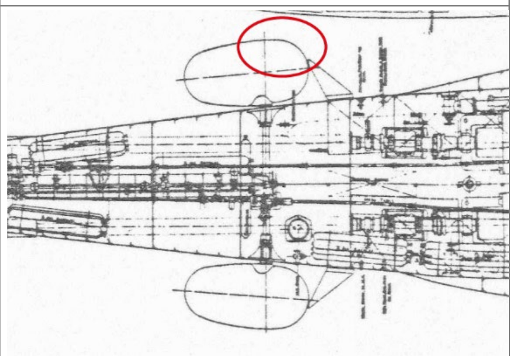
7		
7b		
8		
9		
9b		

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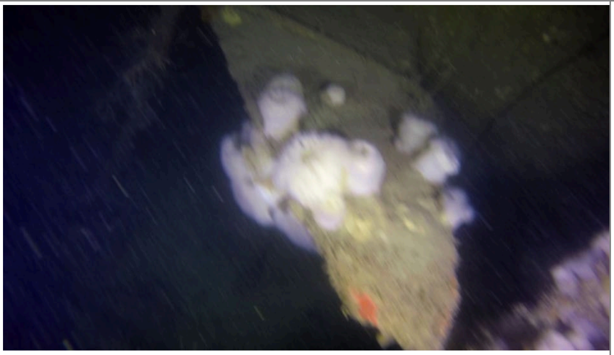
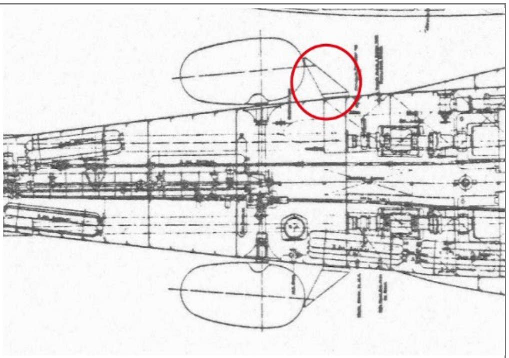
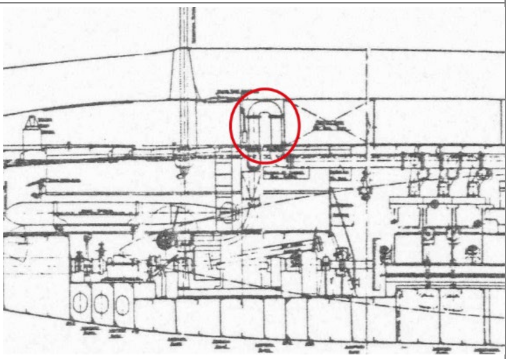
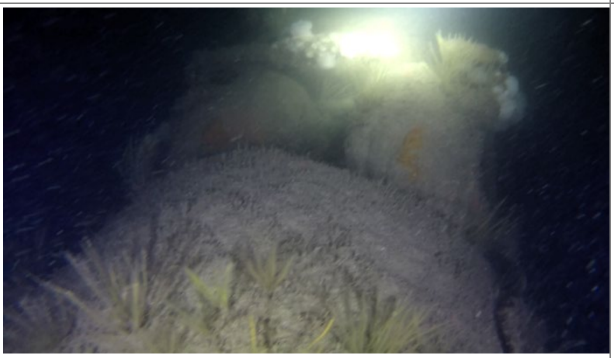
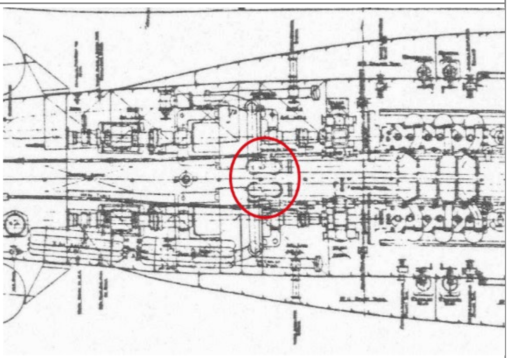
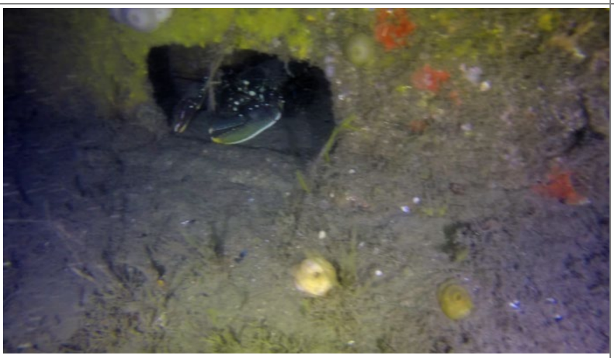
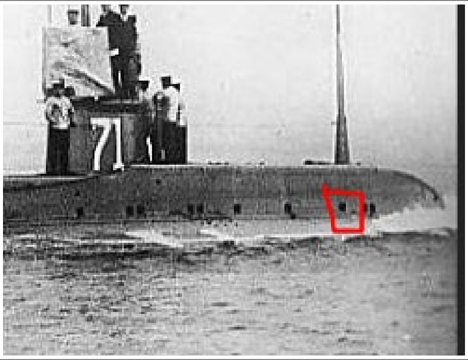
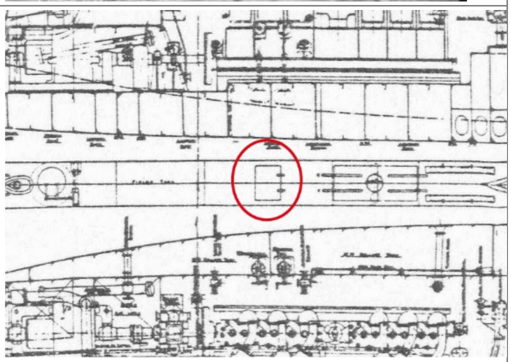
10		
11		
11b		
11c		
12		

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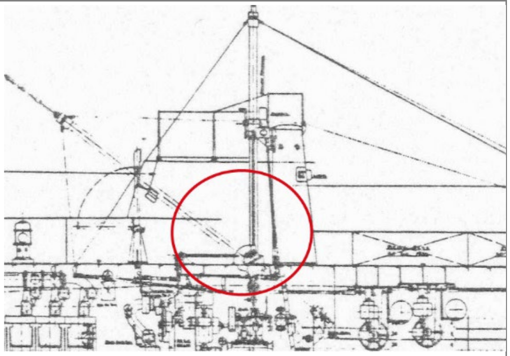
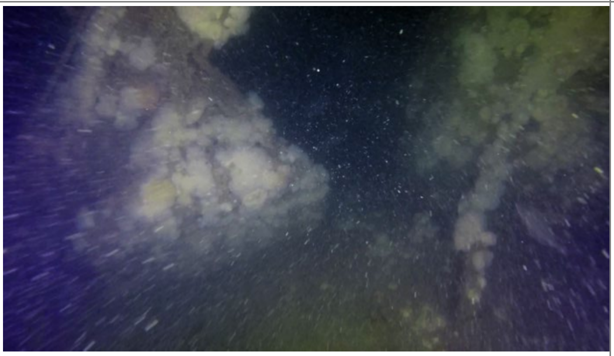
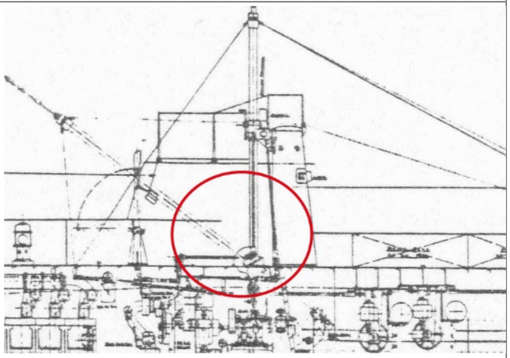
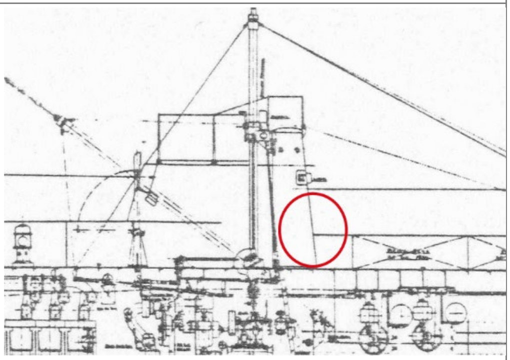
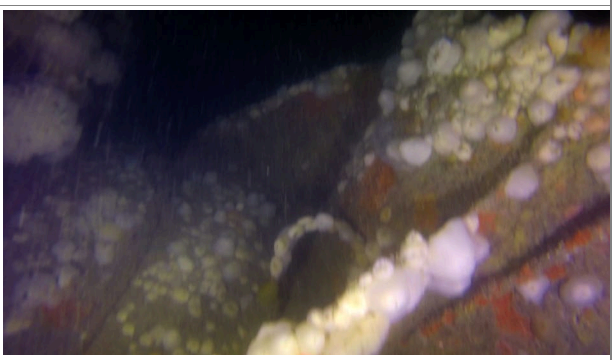
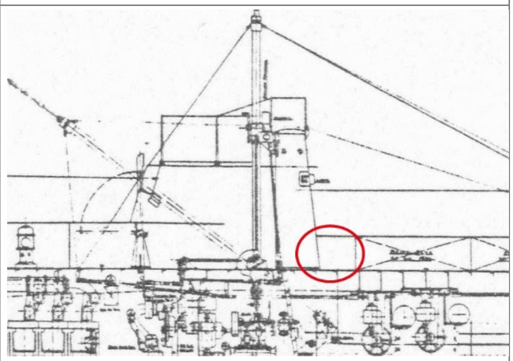
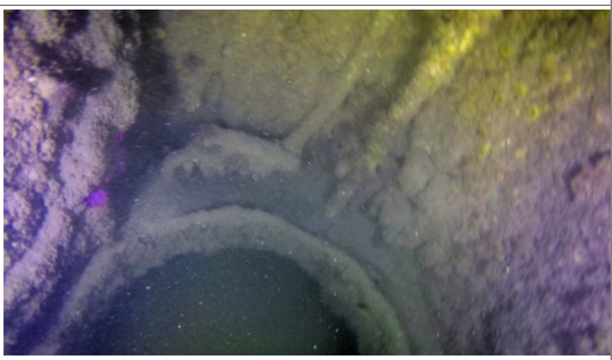
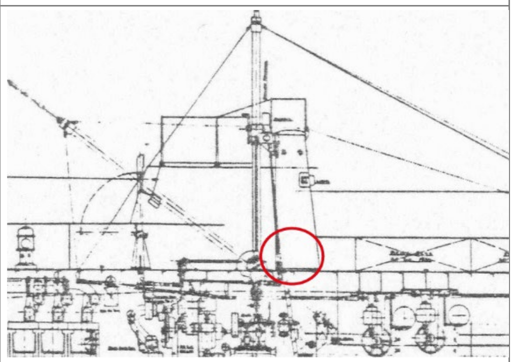
13		
13b		
14		
14b		
15		

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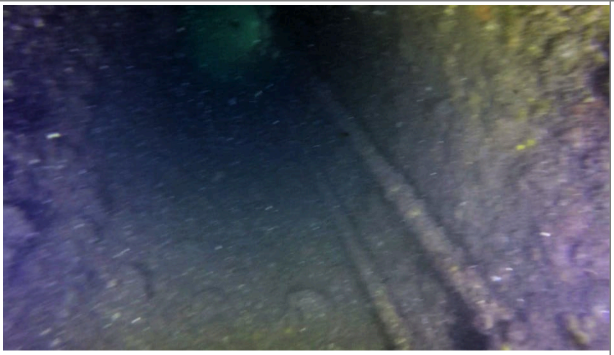
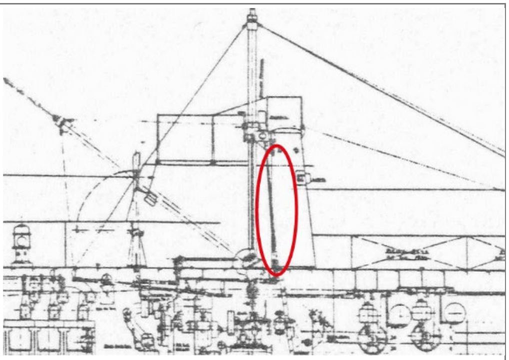
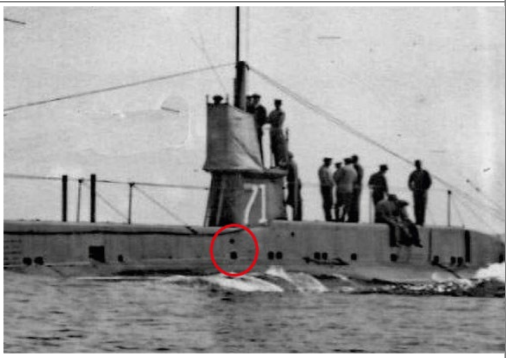
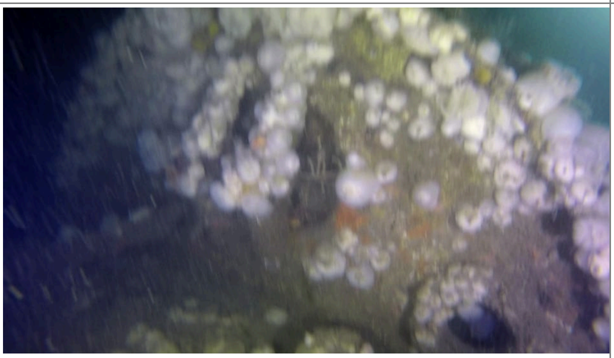
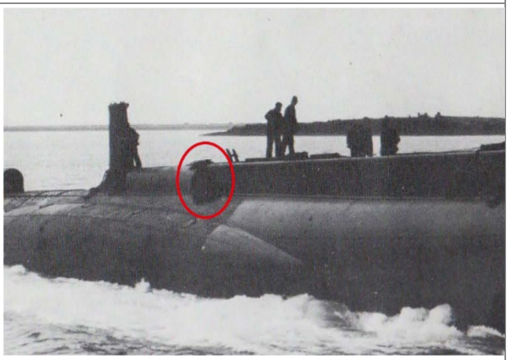
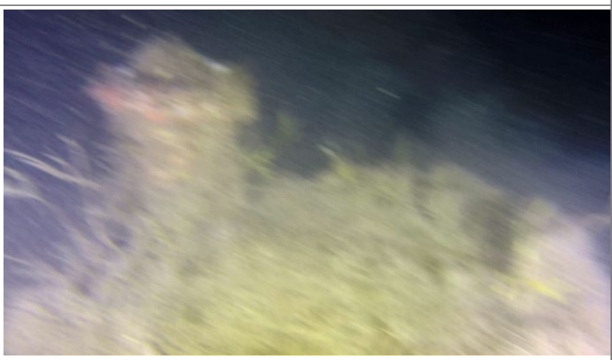
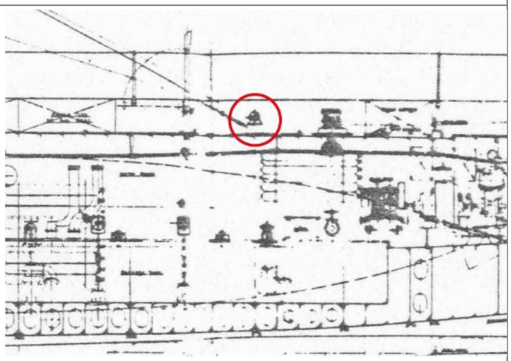
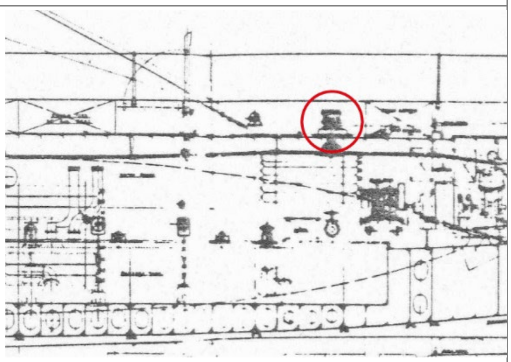
15b		
16		
17		
18		
19		

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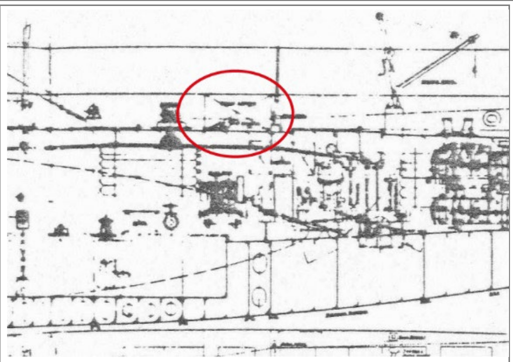
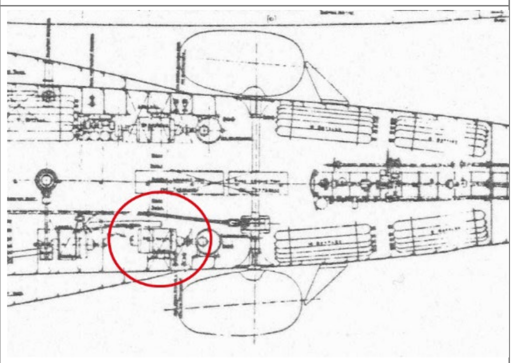
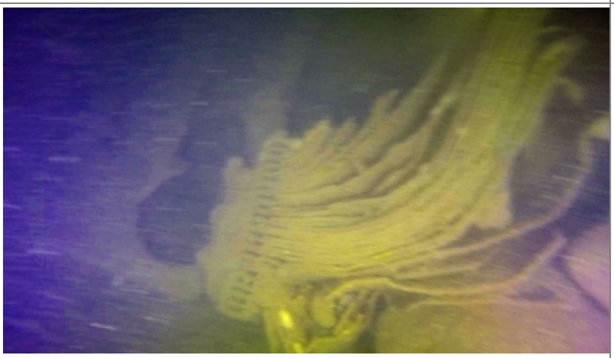
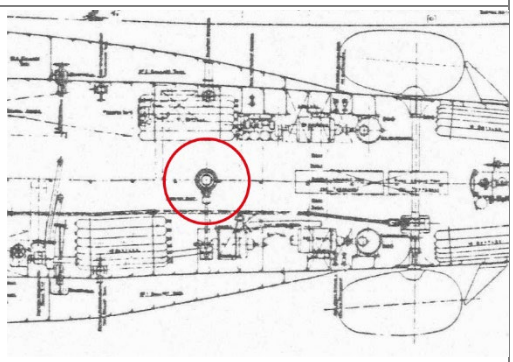
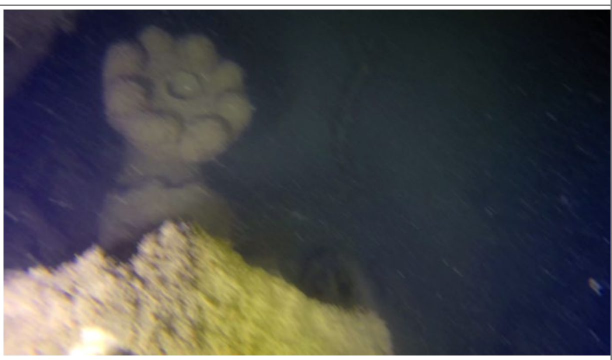
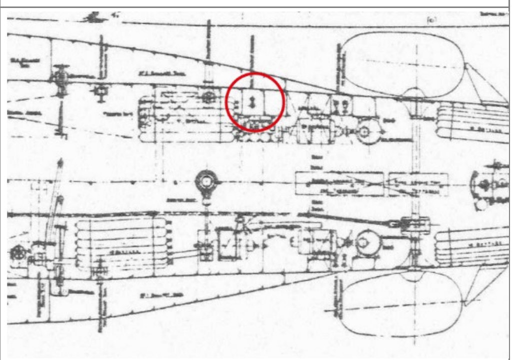
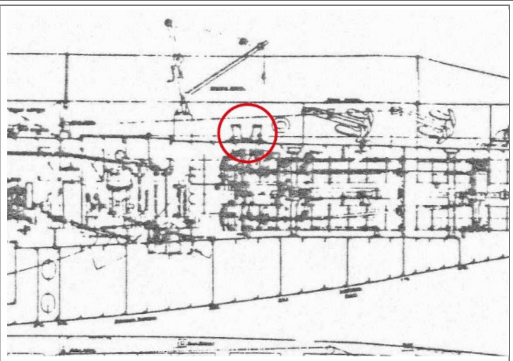
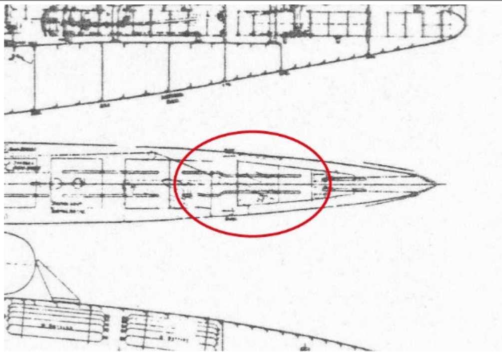
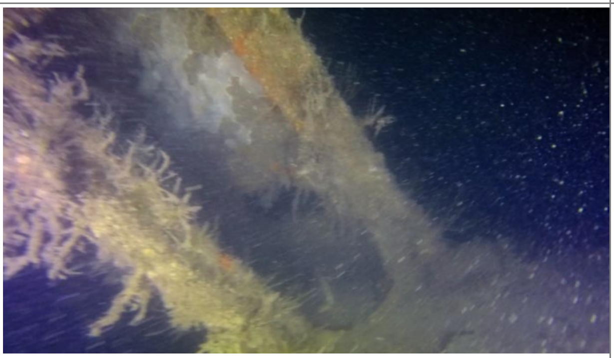
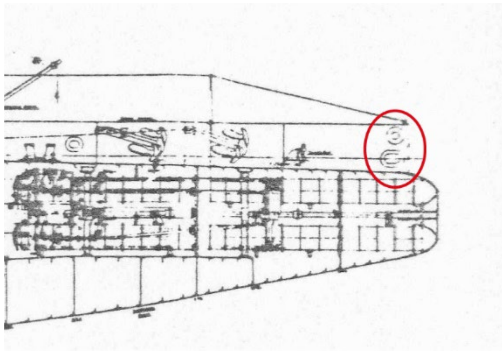
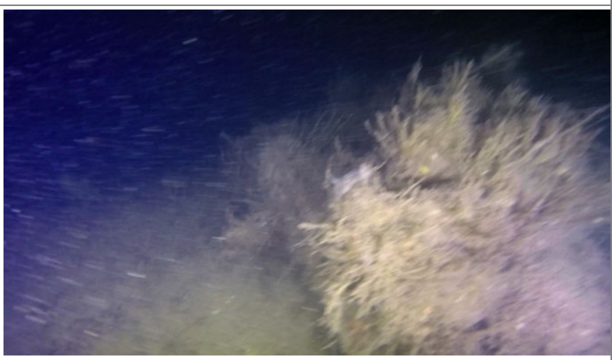
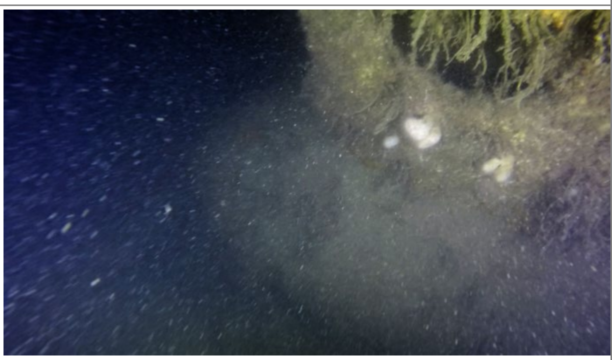
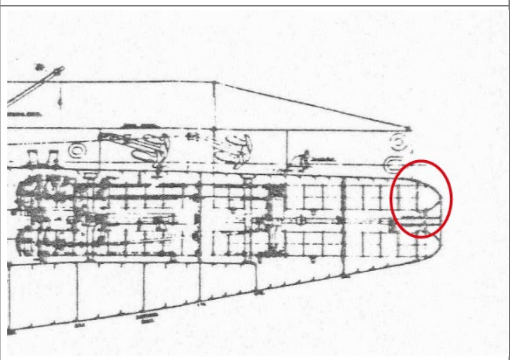
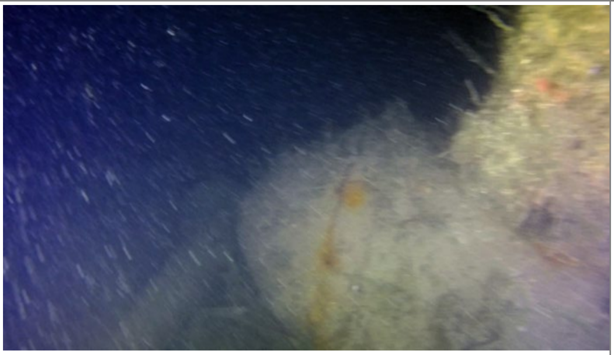
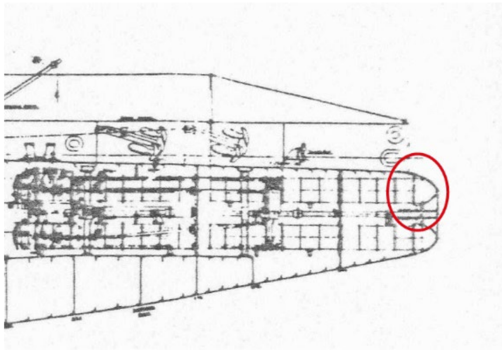
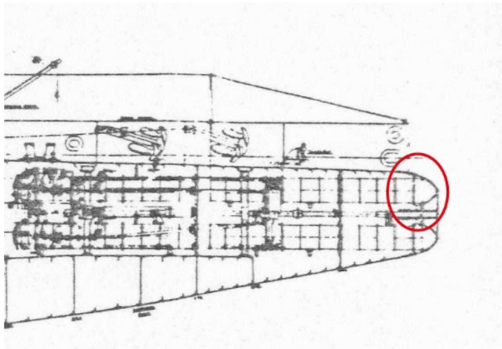
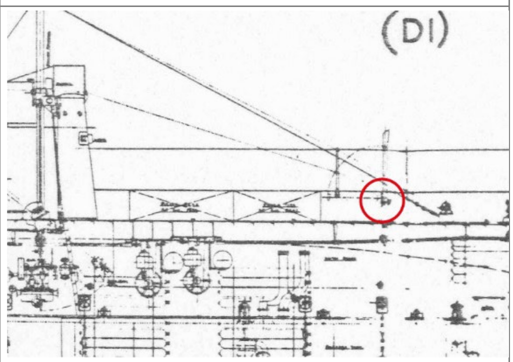
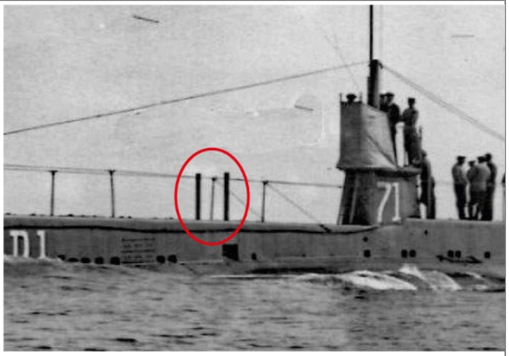
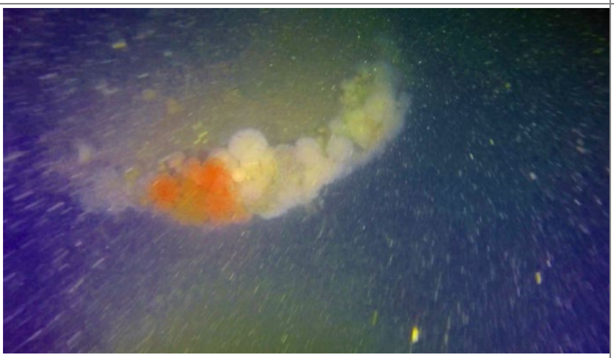
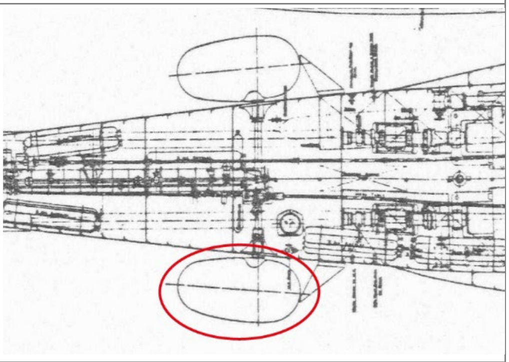
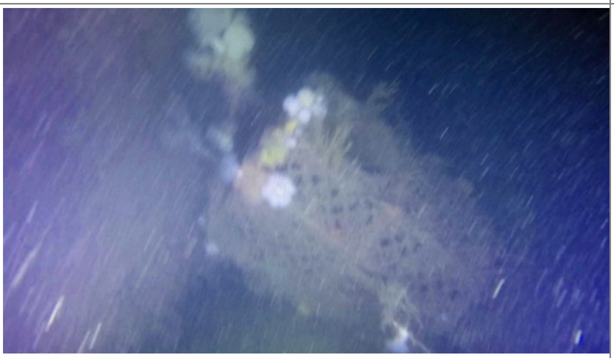
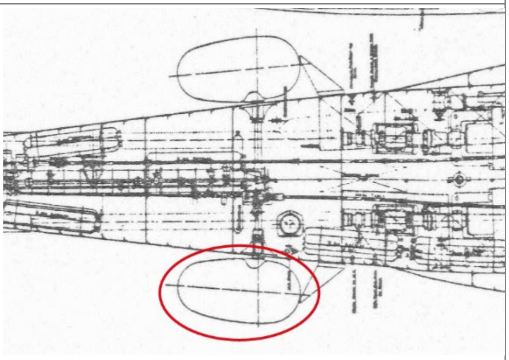
20		
21		
21b		Unidentified fittings within the pressure hull
21c		
21d		

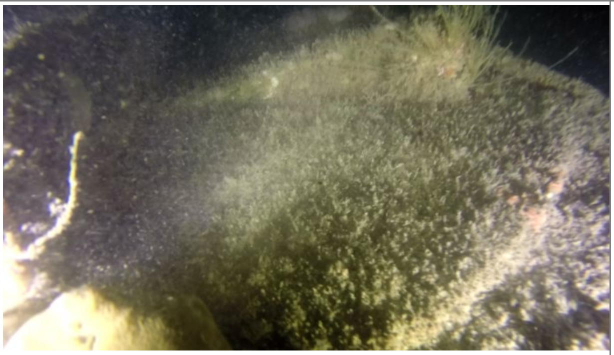
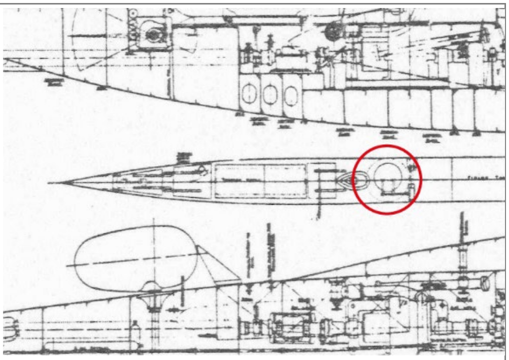
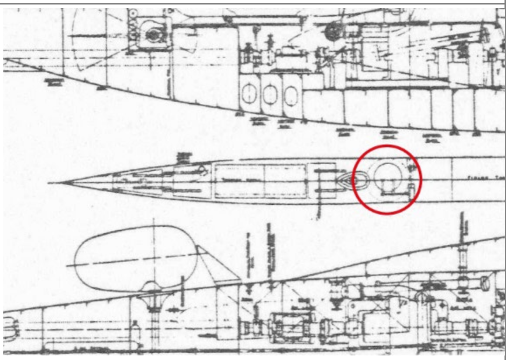
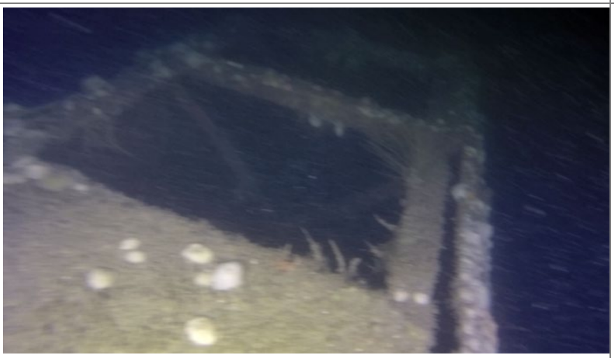
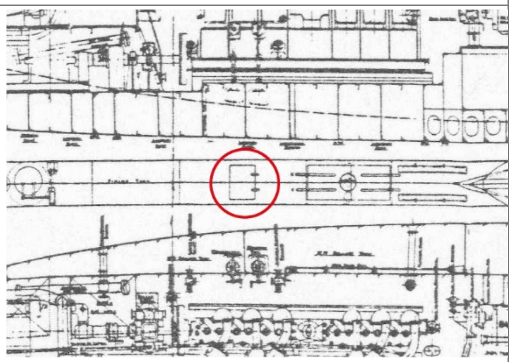
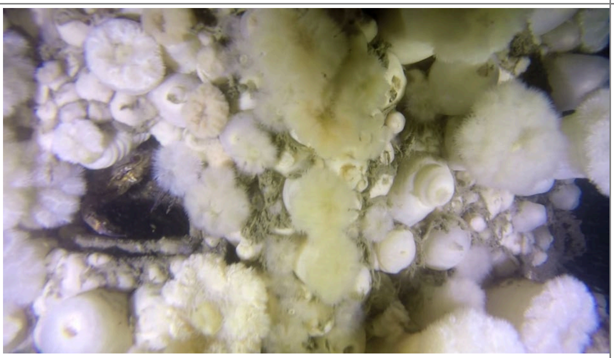
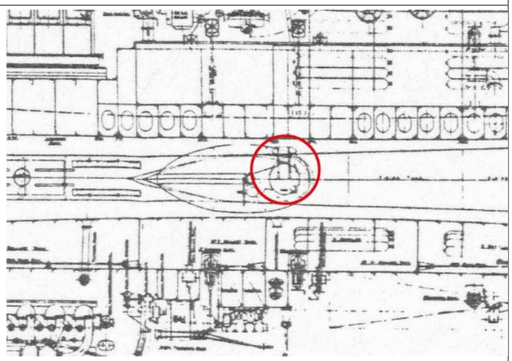
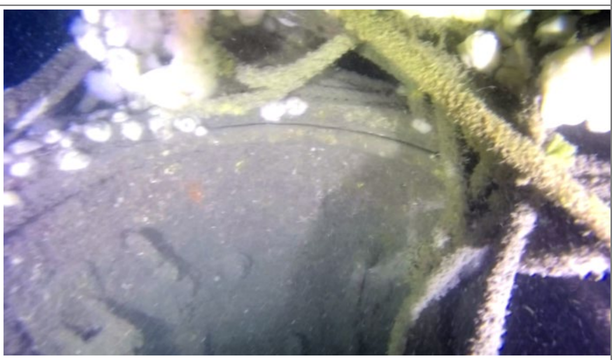
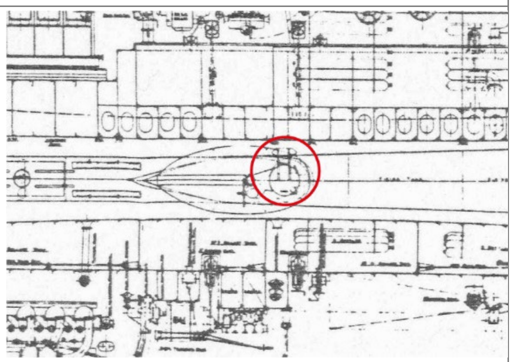
Case study - making the most of existing data		
22		
23		
24		
25		Unidentified fitting on forward deck, possible stanchion slot
26		

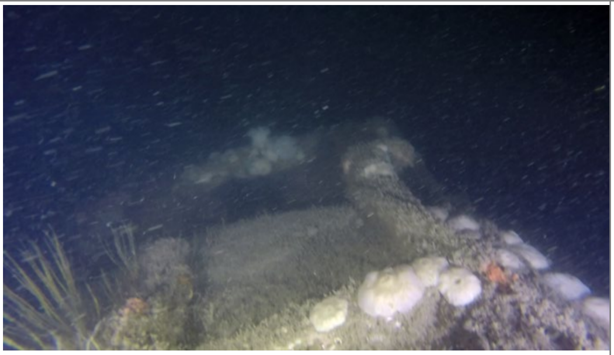
Case study - making the most of existing data

27		
28		
29		Displaced piping, possible exhaust
29b		Displaced piping, possible exhaust
30		

Case study - making the most of existing data

30b		
31		Complete decking and casing over the pressure hull
32		Area of active corrosion
33		
33b		

Case study - making the most of existing data		
34		
34b		
35		
36		
37		

Case study - making the most of existing data		
38		Possible saddle tank amidships

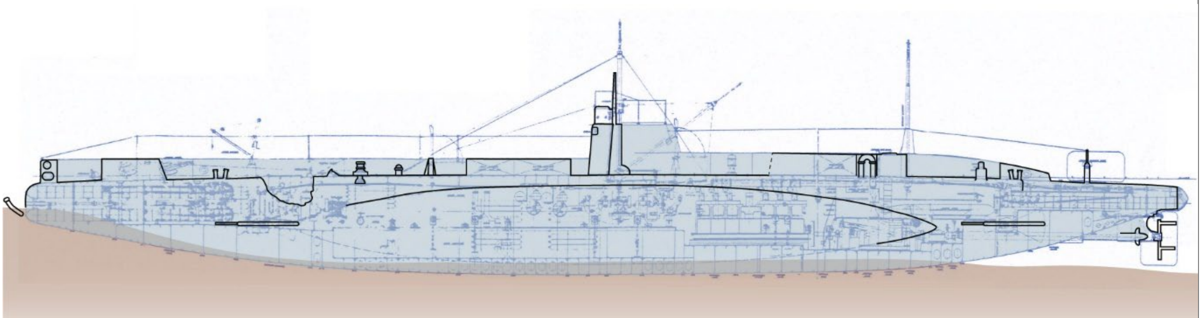
Seabed and ecology

The seabed is composed primarily of fine and silty sand. The wreckage provides habitat to crustaceans and in particular common lobsters (Homarus Gammarus) and edible crabs (Cancer Pagurus) that were observed in relatively large numbers. Sections of the remains are covered with white sponges and soft corals some of which are tentatively identified as dead men's fingers (Alcyonium Digitatum). Schools of small, unidentified fish populate the wreck and several conger eels (Conger Conger) could be observed in cracks and crevices.

General description

The wreck lies upright with no apparent listing and is aligned broadly north-east to south-west. It is reported by the team investigating the site that the bow is aligned to the north-east and the stern to the south-west.

The submarine is fully exposed at the stern end where the rear torpedo tube, two propellers and rudder overhang above seabed level, but it is partially buried at the bow where only one of the two torpedo tubes, the upper one, can be accessed.



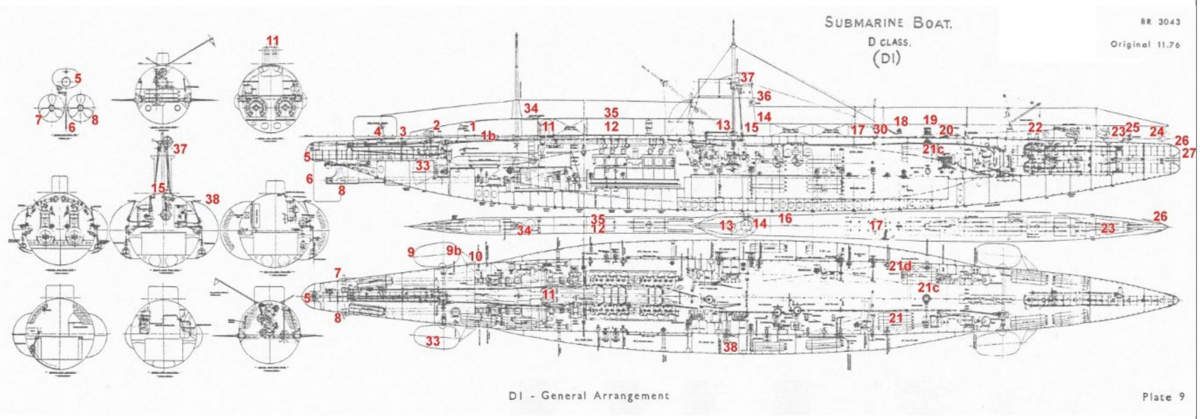
Overall, the remains are in a very good state of preservation with the inner pressure hull and outer hull still retaining their shape in one continuous and coherent structure. The pressure hull seems to be intact apart from a potential area of damage that was observed forward of the main winch, and few other inevitable smaller openings attributable to decay and corrosion. The more fragile ballast saddle appears to be largely complete with few plates that have parted in the upper section to the portside of the conning tower (38); and large sections of the foredeck and afterdeck casing are in a fair condition with of the deck fittings that are still in place. Fixtures that were observed in situ include the torpedo tubes, the two propellers, the main periscope, the conning tower with most of its fittings.

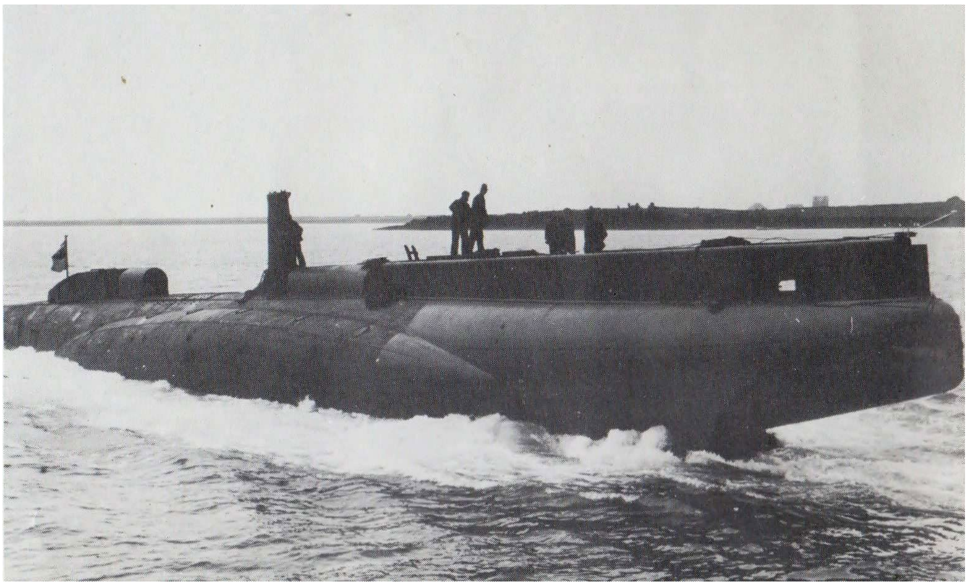
Case study - making the most of existing data
During the review of the video it became apparent that the submarine had been impacted by fishing activities at some point in the recent past. In particular, the presence of nets and ropes were observed around the propellers and the rudder (6, 7b and 8) and at least one lobster pot hanging on the stern hydroplanes (33b). Furthermore, wrapped around the periscope and in other locations further lengths of different ropes were noticed although it is not conclusive whether they are contemporary to the remains or could be associated with post-depositional disturbances. Most of the submarine surface is covered by a turf of marine growth and in most areas some signs of active corrosion could be noted (32). For clarity the following paragraphs that outline the data gathered from the review of the video are divided into six separate sections: stern, aft deck, conning tower, forward section and bow. *Stern* At the stern, the domed casing has fallen off leaving exposed the truncated end of the pressure hull. A single torpedo tube is visible lying within the lower quadrant of this section of the hull (5). The external cap of the torpedo tube is present and opened. The hinge is just above the opening of the tube, meaning that the cap swings on the vertical. The interior of the tube was examined, and it is empty. The remains of the single rudder are centrally placed, hanging below the torpedo tubes. The rudder's blade seems to have been completely eroded or corroded away, although its remnants could be within the debris that was seen underneath it. The framework and stock of the rudder are still recognisable (6). The rudder's alignment appears to be true to the centreline and there is not clear evidence of a skeg although the heel of the rudder was not thoroughly inspected. Two tri-bladed propellers are symmetrically positioned on the port and starboard sides just forward of the rudder (7 and 8). The boss cap of the starboard propeller was cleaned from the marine growth in order to expose potential markings, but it showed none. The shafts of the propellers are integral with the hull. The two oval-shaped aft hydroplanes are in place just above shaft level and seem to be set with no rise in a horizontal position (9 and 33). Damage is present in the fore part of the port hydroplane, possibly due to corrosion of the plating (9b). Triangular plate guards are fitted between the hull and the forward end of the hydroplanes (10). The remnants of a fishing net, lobster pots and associated ropes are spread across the rudder assembly, the two propellers and the aft hydroplanes. *Aft deck* The pressure hull from the stern to the conning tower seems to be structurally solid and for the most part complete apart from few irregular oval openings of an estimated size of 0.5 by 0.5 m that can be seen on the top of the hull corresponding with the engine room. The saddle tanks are in good condition although some of the outer upper plating is displaced in places. On top of the aft pressure hull the cylindrical pintle that provided support for the upper rudder is visible. The blade of rudder is not present, but the bar is still attached to top of the cylinder (4) and

Case study - making the most of existing data

probably used a cable tensioner or flagpole. There is a rope that is entangled around the base of the pintle.

Just aft of the start of the decking is a small circular flange-like fitting that protrudes from the pressure hull which is covered in netting. The function of this fitting is not clear but it has tentatively been described as a vent pipe (Plate1-3).





The aft deck casing is partially complete with alternate sections that are in good state of preservation with the plating of all sides still in situ and sections where the casing is partly or completely missing (1b and 2). Several scuttle openings are interspersed in the superstructure.

The deck casing box that contains the aft bollard is in good state of preservation. The top is missing, leaving a trapezoidal opening from which the bollard can be seen. The casing still retains the round fairleads on each side (2b) and rope is tidily coiled around the bollard in a figure of eight pattern.

Forward of the bollard is a section of deck casing that is missing revealing a derrick winch over a square pedestal (1). Next to it a series of plates that are placed athwartships might indicate the position of the aft torpedo hatch (1b).

Case study - making the most of existing data
The aft periscope and its mounting were not located during the inspection but the aft hatch of the so called 'aft conning tower' (BR3034, 1974) is in situ, closed with the hinges on the starboard side (34 and 34b). Forward of the hatch a large and relatively complete section of deck casing is present. Through a hole on the starboard side the U-shaped bends of the exhaust pipes can be seen (11 and 11b). A rectangular recess in the superstructure was noted in correspondence with the base of the exhaust pipes box (11c). Further forward the top of the deck casing is missing, revealing the internal cross struts (12 and 35) and further towards the conning tower some piping can be seen inside two round holes that pierce the pressure hull. Approaching the conning tower from aft, the periscope is visible slightly on the port side sitting right against the tower. The periscope looks erected and extends over a meter above the end of the tower (13). A possible mast is at the starboard side and a bracket potentially part of the hoisting mechanism was noted at the base of the tower (b). However, further investigation is needed to confirm the exact arrangement of these two features. The hood plating and the railing that were on the conning tower are not present and could have fallen or otherwise pulled onto the sand alongside the submarine. *Conning tower* The conning tower has a truncated slightly conical shape and appears to be fixed with vertical bracket plates onto the pressure hull (14 and 14b). Two small rectangular recesses, possibly for the navigation lights, are visible on the upper section (36). The upper hatch is circular and appears to be open. It is wrapped with a rope, probably not contemporary with the loss, and several latches that were used to secure the hatch are recognisable around the hatch coaming (1-37). At the base of the conning tower, towards the bow, there is a ragged opening in the metal. Through this area of damage, the interior of the conning tower can be seen. The lower hatch that is open and still retains its door hinged on the starboard side (15) and two rods, probably connecting the steering mechanism to the upper wheel on top of the tower, run vertically on the aft wall of the tower (15b). By looking into the hatch opening, it could be confirmed that this part of the pressure hull is almost completely filled with sediment. The sheathing and most of the external fixtures of the tower seem to have been removed at the time of the sinking or displaced due to the natural decay of the structure underwater. However, on top of the conning tower on the port side the presence of a telegraph with illegible writing on its face was reported. It should be noted that this has not been confirmed by the imagery made available to, and reviewed by, Wessex Archaeology. *Forward decking* A large portion of the foredeck casing is visible immediately forward of the conning tower (16 and 31). The superstructure ends with a rounded semi-circular section that contains circular openings, probably for receiving some sort of piping (17). This corresponds in the plans of D1 to the location of the forward firing tank. Sections of displaced flanged piping were noted on the starboard side not far from the presumed location of the hydroplanes (29 and 29b).

Case study - making the most of existing data

Two slightly angled pipe-like supports reinforced by a base with triangular brackets are symmetrically placed at either ends of the centreline on the pressure hull (30 and 30b). These might be vents and were presumably fitted with cowl heads when the submarine was on the surface as indicated in historical photographs of D1. However, their identification is not conclusive as their location is not certain.

Just forward of the superstructure, anchored on the pressure hull is a small winch (18) and further towards the bow is the large anchor winch which still tensions a rope that is coiled around it (19). Further ahead two cable holders are visible between two tensioned ropes which might be contemporary to the boat (20).

A large opening within the pressure hull can be found in corresponding with the forward torpedo hatch, approximately 6 m aft of the bow (21). It is unclear to which extent this is due to natural decay or post-depositional interference as the outward twist that has been seen in some of the plating could potentially indicate some sort of active force damaging the structure. Within the pressure hull amongst the objects that could be noted were the stiffeners that strengthen the side of the pressure hull, piping running on the port side, a transmission gear - probably part of one of the winches (21c), the knob of an unidentified valve (21d) and other unidentified debris (21b).

Over the opening, two tensioned ropes lead to a large fore and aft bollard (22). Around it four short lengths of L-frames suggest the former position of the casing and abaft it a round opening might have been the stand for a small derrick but this has not been conclusively identified.

Further towards the bow the two doors of a large rectangular hatch that accessed the anchors within the superstructure casing seem to be partly open (23). The anchors were not located. Just before the very end of the casing another round fixture, potentially a slot for a stanchion, is visible (25).

Bow

The superstructure is complete at the bow and has a blunt square shape that tapers almost to a point (24). The circular and oval openings at the very end of the casing are recognisable and still lined with their coamings (26). The exposed end of the pressure hull is unscathed, and the cap of the torpedo tubes is still in place. The cap of the upper torpedo tube has a pointed tip and it is closed, but slightly ajar (27). On the seabed, just in front of it there is some debris including what appears to be a section of flanged piping (28). The bow of the submarine is partly buried and disappears into the sand where the presumed second torpedo tube would be located in the vertical arrangement that is typical of the D-class.

Further reading:

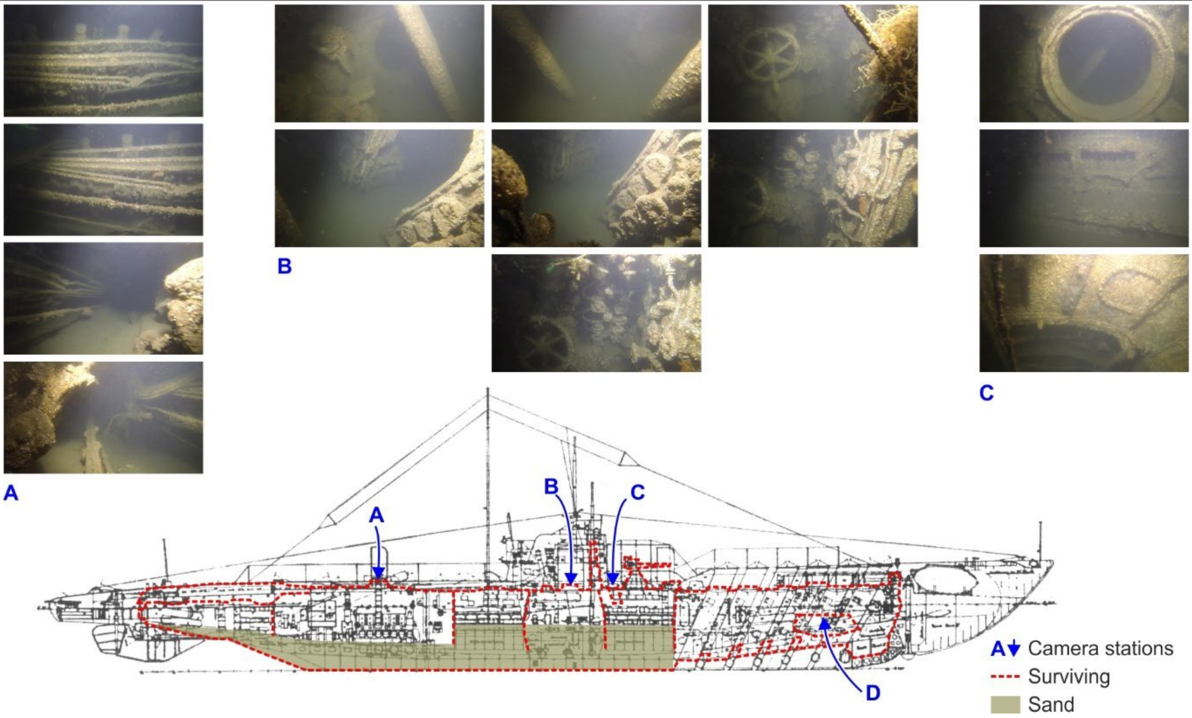
National Heritage List for England No. 1472317 https://historicengland.org.uk/listing/the-list/list-entry/1472317

Wessex Archaeology, 2020. HMS D1. Desk based Undesignated Site Assessment, client report no. 214390.14

Case study – inspecting the inside of a submarine without going inside

Case study - video inspection of the inside of UC-70
The UC-70 was lost in 1918 after being first bombed and then depth-charged off Whitby, North Yorkshire. Wessex Archaeology was asked by Historic England to carry out a condition survey (Wessex Archaeology 2017). The wreck is upright but listing to port in 21-24 m water depth. The pressure hull is intact, except for the aft end where divers appear to have used explosives to remove the non-ferrous stern torpedo tube. The initial inspection identified human remains in the damaged aft torpedo room. The presence of these remains meant that it was particularly important to avoid disturbing the interior of the pressure hull. A GoPro camera, together with a specialist 22,000 lumen video light was attached to a short pole to carry out a visual inspection through open hatches. The pole was lowered through the open engine room hatch, as well through the hatch between the control room and the missing conning tower and through a hatch just aft of the deck gun. Lowering and rotation of the camera was done consistently, with the camera being rotated very slowly clockwise 360 degrees from the 12 o'clock position at intervals as the pole was slowly lowered. The inside of the pressure hull was partially filled with a fine grained sand or silt and care had to be taken to ensure that this was not disturbed by the camera or light touching it. The upper part of the port side MAN diesel engine can be seen behind pipework and cabling in the images below (A). Half buried and trapped underneath piping in front of the engine is what appears to be a fishing pot. How that got in there is not clear. The camera was then lowered through the port in the pressure hull where the missing aft periscope had been. The video stills (B) show the casings of both the attack and search periscopes, the openings to the crew room and officers mess, and the wheel for raising and lowering one of the periscopes. The camera was also lowered through a small hatch immediately aft of the deck gun (C).

Case study - video inspection of the inside of UC-70



Further reading:

National Heritage List for England No. 1446103 SM UC-70 - 1446103 | Historic England

Historic England Research Record Heritage Gateway - Results

Wessex Archaeology, 2017. UC70, Off Whitby, North Yorkshire. First World War Submarine Condition Survey, Client report No. 108280.30

Young, R. & Armstrong, P., 2006. Silent Warriors: U-boat Wrecks of the United Kingdom, Vol. 1, Tempus Publishing Ltd.

Wrecksite.eu WRECKSITE - UC-70 SUBMARINE 1916-1918

Whitby Dive Site Dive Whitby - Whitby Dive Site (eskside.co.uk)

Wessex Archaeology: Our Work UC-70 submarine | Our Work | Wessex Archaeology

Approaches to artefact recovery

The project did not use excavation and the excavation of submarine wrecks for the purpose of simply recording them is rare.[4]

Excavation could be used to access buried sections of hull and debris and to investigate buried anomalies detected by the use of probes, metal detectors and magnetometers and sub-bottom surveys using parametric sonar or similar. Excavation may not be appropriate where there is a risk of

[4] See Holt, P., 2017. *The Resurgam Submarine: 'A Project for Annoying the Enemy'*, Archaeopress Archaeology and Resurgam Submarine (3hconsulting.com) and Excavation – The Friends of The Hunley for examples.

destabilising the wreck or uncovering delicate artefacts, releasing pollutants such as oils, or where there is a risk of disturbing human remains. It may also be subject to permissions and licencing and require significant resources. If you are considering it, you are advised to consult Historic England.

Recovering a submarine wreck is inevitably a hugely costly exercise that creates very significant ongoing responsibilities and costs. It would only be appropriate in the very rarest of circumstances.

The recovery of artefacts is only likely to be appropriate if they cannot be adequately recorded on the seabed and/or are at risk. Recovery also creates significant ongoing responsibilities and costs for looking after the objects recovered, which must be reported to HM Receiver of Wreck. Submarines and most of the artefacts they contain still have owners and are subject to sovereign rights.

The project undertook limited research to trace artefacts recovered from the submarine wrecks, but this was not prioritised because of limited budgets. Since the late 20th century divers have been recovering objects from these wrecks. Those that were recovered to add to public and private collections rather than for scrap or resale value are potentially traceable. For example, a propeller illegally salvaged from the U-8 was recovered from a private collection in Kent, before being returned to the German Navy. Good examples of research into recovered artefacts by private individuals and well-resourced projects are available online.[5]

Diver or ROV?

Almost all of the techniques used by the project can be carried out by remotely operated vehicles, or ROVs. These machines are not limited by decompression schedules and can carry a very wide range of survey equipment. As a result they are often capable of comfortably outperforming divers and, from a professional perspective, provide the significant advantage of not requiring a person to be put in harm's way underwater. Very low-cost, battery powered ROVs have become available in the last few years that can be deployed by teams of 1-2 to 100 m depth or more and which require little experience to operate. These increasingly capable vehicles have brought the cost of deploying an ROV down to a level which is now making the use of professional divers an expensive and therefore questionable option.

However, avocational submarine investigators are likely to continue using diving as the main means of accessing a wreck because the opportunity to dive is usually a major part of the reason why the investigation is being carried out. It therefore also follows that where avocational diver - professional partnerships are carrying out work, diving is likely to remain the main means of accessing a wreck. Furthermore, ROVs are not currently suitable for internal surveys and divers can have a performance edge in very poor visibility.

The advent of small, cheap but very capable battery-powered ROVs means that almost all of the survey work carried out during the project could have been undertaken by ROVs.

Wreck ecology

The recording of marine life associated with submarine wrecks falls outside of the scope of the advice in this document. However, submarine wrecks can provide rich environments for marine life, which can interact with the wreck. For example, the presence of both hard and soft marine growth is

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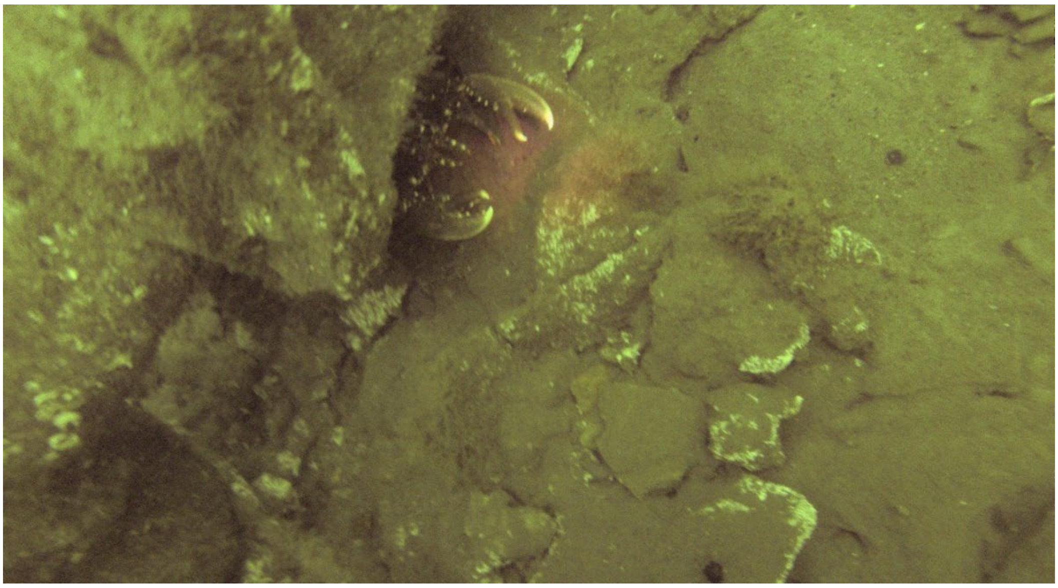
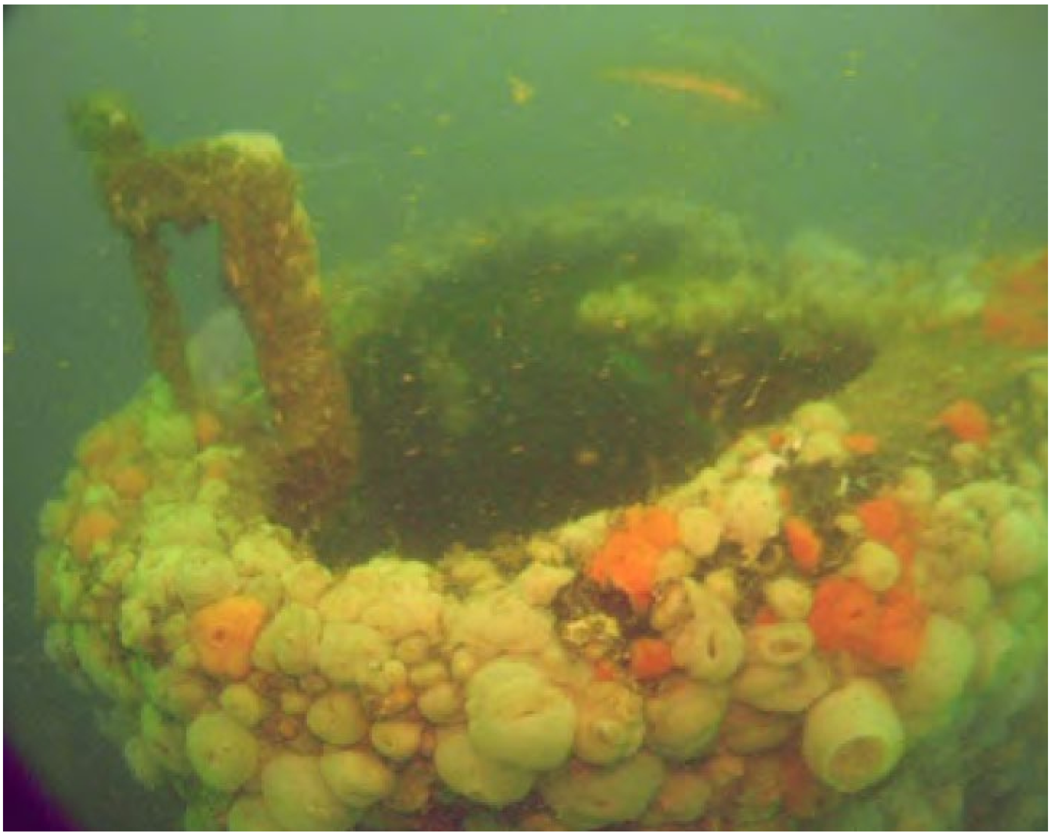
[5] For example, see Maritime Archaeology Trust, 2018. *Forgotten Wrecks of the First World War. SM U-90 Site Report*, and an online report by Simon Brown of deep3d on a brass hand wheel from UB-116 in Stromness Museum.

likely to have an impact on corrosion and bioturbation caused by molluscs can potentially disturb buried artefacts and human remains.



Lobster under the remains of the stern of UC-70

Hard and soft marine growth covering the broken up remains of the bow of the UC-92 in very shallow water just off Castle Beach, Falmouth



The rich hard and soft marine growth living on the conning tower of the deeper wreck of the very early submarine Resurgam off the North Wales coast. Images of marine growth typical of significantly deeper submarine wrecks where there is little natural light can be seen in Table 4 and Case Study about the D1 above).

Assessing the condition of a submarine wreck

What is condition and why assess it?

The condition of a submarine wreck is its current state relative to a previous 'baseline' state. The project took as its baseline the condition of the submarine in normal use, in as far as that was known. Understanding the condition of a wreck is very important in determining its vulnerability and for risk assessing it.

What do you need to know?

It is important to how much of the submarine in its baseline condition survives, what the overall condition of the fabric (structure) of the wreck is, what the reasons for the loss that has occurred are and what the 'condition trend' (rate and type of decline) is. It is recommended that Historic England's existing methodology is used (Historic England 2017a), as this will make the results comparable and easier to incorporate in a risk assessment (see Section 11).

Survival can be assessed against the following scale, which requires the 'percentage material loss' (PML; what proportion of the original submarine has been lost) to be estimated.

Description	PML
Very good	<20%
Good	21-40%
Medium	41-60%
Poor	61-80%
Very poor	>80%
Unknown	Unknown/uncertain

The condition of the wreck can be assessed against the following scale. Most of the submarine wrecks assessed by the project were rated 'E':

Rating	Description
A	Optimal, with very little or no erosion or deterioration.
B	Generally satisfactory, with minor localised erosion or deterioration affecting about 15% of the wreck.
C	Generally satisfactory, with more significant deterioration affecting up to 25% of the wreck.
D	Generally unsatisfactory, with severe localised damage, e.g. collapse or disappearance of a significant part of the structure.
E	Extensive significant problems, with widespread deterioration affecting at least 50% of a wreck.
F	Unknown. This is usually because the wreck has not been surveyed, if it is buried, or the survey is geophysical and there has been no visual survey.

The condition trend of the wreck should also be assessed unless the rating for condition is 'F'. Most of the submarines investigated for the project were rated 'B'. A score of 'A' is extremely unlikely:

Rating	Description
A	Improving – a visible improvement in condition.
B	Declining – condition is deteriorating.
C	Stable – no sign of recent or midterm deterioration. A wreck whose condition is ‘B’ should be considered as stable if the damage remains constant.
D	Unknown – usually because there is insufficient recent data.

Existing data

A submarine wreck will have inevitably been declining since the boat was lost. As condition needs to be assessed against a baseline, if a survey has not yet been carried out then that baseline will have to be assembled from existing data. It is also helpful to understand trend by looking back to the condition of the wreck when first discovered and when first dived to the loss of the boat. Online dive videos can be particularly useful in establishing changes in condition and trend since the wreck was discovered.

Understanding the impact of corrosion

Corrosion is a chemical reaction caused by an electro-chemical process that changes a metal such as steel into a different compound. This new compound is usually physically weaker and more vulnerable to erosion. This often leads to structural failure.

When the steel used for submarines is exposed to oxygen in water, iron in the steel oxidises to form a red iron oxide on the surface of the remaining steel. This is commonly called rust. Oxidation occurs up to five times more rapidly in salt water than it does in fresh. That is one of the main reasons why aircraft wrecks found in lakes are normally in a better condition than those found in the sea.

The following table shows the different types of corrosion that affect submarine wrecks.

Type	Description
Uniform or general corrosion	This is the most common form of corrosion and can occur on any exposed metal in contact with the seawater. It usually takes place evenly over large areas of the metal surface. The dissolved oxygen concentration in the water and the temperature tend to control the corrosion rate (the rate of corrosion usually doubles for every rise in temperature of 10°C). However, the material loss is normally very gradual and it can take a long time for structural failure to occur.

Pitting corrosion	This is localised corrosion and typically occurs on metals that form stable protective films. Pitting occurs when the protective film or paint barrier is removed or damaged, or sometimes where the internal structure of the metal is not uniform. They can usually be seen as small dish or hemispherical depressions or cavities. Temperature and chloride concentration help to determine how rapidly pitting occurs. Pitting corrosion can often be seen on stainless steel dive knives. It can repassivate but tends to be very aggressive and can result in rapid structural failure.
Crevice corrosion	This is another form of localised corrosion that tends to occur at a joint, under a washer or bolt head, around a rivet head or under solid debris where there is a 'crevice'. Chemical imbalance caused by the stagnant environment within the crevice accelerates the process. Wrought iron chains often suffer crevice corrosion.
Stress corrosion cracking	Parts of a submarine hull and equipment subject to high tensile stresses can be subject to stress corrosion cracking. This can manifest in corrosion fatigue, which can result in very rapid structural failure.
Galvanic corrosion	This is caused by two different metals coming into electrical contact while submerged. Seawater can provide this electrical contact. The more active metal (the anode) corrodes faster than the more noble and less active metal (the cathode). The greater the electrochemical difference between the metals, the more severe is the corrosion. If bronze is put into electrical contact with steel underwater, then the steel will corrode. Brass valves and bronze torpedo tubes may cause the surrounding steel plate to corrode more quickly when submerged in seawater. The impact of this type of corrosion can be particularly severe inside the pressure hull. This is normally flooded and the equipment there would have been designed without the expectation that it would be filled with seawater.
Microbiologically induced corrosion (MIC)	Within minutes or hours of a metal being exposed to seawater, a biofilm forms on its surface in a process called microfouling. The biofilm is made up of microbial colonies. Over time algae will grow and barnacles and mussels will grow from larvae. This radically alters the environmental conditions at the surface of the metal. This then causes localised pitting corrosion. If bacteria are present that reduce sulphate in sea water, highly corrosive hydrogen sulphate will be formed between the biofilm and the surface of the steel.

Paint coats on the hulls of submarines create a barrier that physically stops oxygen and water reaching the metal and therefore the process of oxidation. However, paint coats have to be regularly renewed to stay effective. They therefore have little impact in slowing corrosion on submarine wrecks. The same applies to galvanised or electroplated parts.

Modern ships and boats are often protected from saltwater corrosion by attaching a more reactive metal to their steel hulls and shafts. 'Anodes' of zinc or magnesium are typically used. Because they are more reactive, they 'sacrifice' their ions to the oxygen instead of the steel ions. As a result the 'sacrificial anode' corrodes instead of the steel. However, over time the anodes waste away.

Eventually protection is lost if they are not renewed. Historic submarines will almost certainly have already lost the protection of any anodes that were fitted to them.

The surface of an unprotected steel hull exposed to seawater will oxidise. The layer of oxide on the steel then gradually thickens. Because it is weak, it does not bond well to the remaining steel and gradually spalls off. This spalling can be accelerated by impacts and by erosion. Spalling exposes fresh steel to oxidation.

This process is complicated because of the hard layer of concretion that forms on metal structures in seawater. This is a combination of iron corrosion products and marine organisms (see Table 10).

Some steels have stronger oxides and therefore decay more slowly. For example stainless steels form a naturally stable chromium oxide film. This adheres more strongly to the steel and prevents water from coming into contact with unreacted metal, protecting it. This process is called passivation. Aluminium forms a similar protective layer. However, mild steel does not have chromium and therefore does not form a protective layer. These protective layers may be extremely thin and difficult to see, but they are still sufficient to prevent further oxidation occurring unless damaged.

Archaeological research has identified seven major factors that influence corrosion on iron and steel shipwrecks. These are listed in the table below. Changes in any of these can influence the speed and extent of corrosion. It is therefore necessary to measure them if the corrosion processes affecting an individual submarine are to be understood and quantified.

Metal composition and structure	Certain metals have greater corrosion resistance. For example, the alloy elements of stainless steel react with seawater to form a thin protective layer, slowing corrosion. Very high carbon steel is also more resistant. Copper, bronze and brass are also resistant.
Composition of the seawater in and around the wreck	Higher dissolved oxygen content, salinity and conductivity tend to accelerate corrosion. Lower pH tends to accelerate corrosion.
Temperature	Corrosion rates normally increase as the temperature of the seawater increases.
Water movement	The effect of this is complicated, but corrosion tends to be greater in high energy environments, for example where a wreck is subject to strong tidal currents or is in very shallow water affected by waves. Enclosed areas of the wreck not subject to water movement, such as inside intact pressure hulls, are conversely likely be subject to less corrosion.

Marine growth	The death of colonising algae leaves layers of calcium carbonate on the metal of a wreck. This acts as a suitable surface for the growth of other marine organisms and iron oxide from the corrosion process diffuses into it. This mix of corrosion product, calcium carbonate and living organisms forms a semi-permeable barrier between the metal and the seawater. The presence of this concretion causes chemical changes that reduce the oxygen in contact with the metal surface and generally acts to reduce the rate of corrosion.
Seabed composition and depth of burial	Corrosion rate is controlled by the availability of oxygen in the burying sediments, by whether it is disturbed or not and by microbial activities.

Although these factors can be measured and the broad principles of how they affect wreck are understood, they interact in complicated ways. For example, although higher temperatures normally result in increased corrosion rates, this can be affected by the insulation that concretion provides. Although a low seawater temperature might be expected to reduce the rate of corrosion, it results in higher dissolved oxygen, which acts to increase it. Furthermore, the localised environment can have a significant effect. A study of plate thinning on the then 61 year old wreck of the battleship USS *Arizona* in Pearl Harbour demonstrated that the loss of plate thickness varied widely depending upon the location of the test site along the length of the wreck and whether it was on the port or starboard side (Murphy et al, 2008). Understanding how the process of corrosion is affecting a wreck is a complex task, requiring significant effort and some specialist knowledge.

Fortunately the gross effects of corrosion can be seen and mapped on a submarine through careful visual observation. The progressive loss of metal from the steel structure of a submarine wreck caused by corrosion tends to be most noticeable on the steel plates that form the shell of the pressure hull, the external tanks, the casing and rudders and hydroplanes. Loss of metal causes the steel plates to become thinner, and this eventually results in holes appearing in the plates. In the case of the thin plates of the tanks and casing, this can eventually cause them to almost disappear. However, pressure hull plates are thicker and may be of higher grade steel. The effects of plate thinning can therefore be less obvious to the diver's eye and mapping and measuring plate thinning therefore requires a more technical approach[6].

Corrosion may also affect the attachment of deck equipment such as guns by wasting and loosening rivets and bolts. Impacts from trawl nets can then cause the weakened attachment points to pull away. Alternatively wasting can result in them ultimately failing, in which case the equipment may fall off the hull onto the seabed. Conning towers are also very vulnerable to this.

Visual inspection

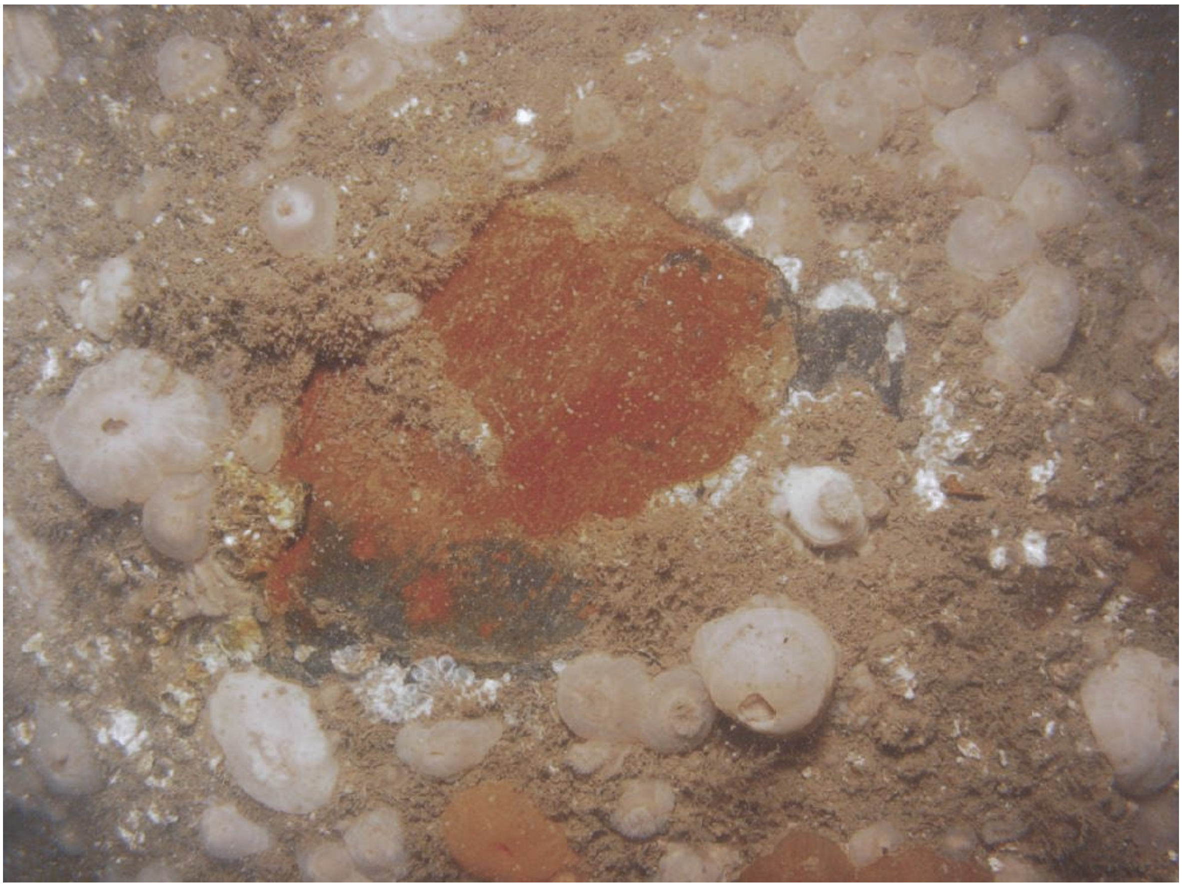
GVI (general visual inspection) and CVI (close visual inspection) can be used to visually assess the effects of corrosion. By mapping holes in plating and other wasting caused by corrosion, a more accurate record of the condition of the submarine can be developed.

It is particularly important to map areas of active corrosion. Where concretion is missing, for example because of abrasion caused by a shot rope or grapnel, or trawl gear, this is usually easy to

[6] The speed of thinning should not be over-estimated. A Japanese midget submarine lost in over 400 m depth off Pearl Harbour in 1941 was estimated to have suffered an 11% loss of hull thickness in 61 years (Wilson et al. 2007 Corrosion Studies on the USS Arizona with Application to a Japanese Midget Submarine (unl.edu))

detect because the metal will normally have a red or bright orange colour when a torch is shone on it.

UB-107 off Flamborough Head. Active corrosion of the damaged hull above the Forward Battery Compartment. The corrosion layer formed by fouling and oxide has spalled off, possibly as a result of a recent impact. This has exposed the surface of fresh steel, which has begun oxidising and is an orange colour in the diver's torchlight.



Fresh corrosion on the pressure hull of the early submarine Resurgam observed in 2006. Like the UB-107, it is not clear whether the concretion has spalled off naturally or has been knocked off by an impact.

pH testing of seawater

pH testing of seawater at wreck sites may be carried out using a commercially available drop-down instrument, using the methodology provided in the instrument manual. These can be rented from marine survey equipment rental companies. This will be suitable for samples from the vicinity of a wreck.

However, if samples from the immediate environment of a wreck are required, then a hand-held pH tester unit can be used. The following methodology should be used for each sample:

1. a 200 ml seawater sample will be taken in a clear plastic bottle by the diver from a client-defined position on the site, normally on the seabed next to the wreck;
2. the sample should be sealed by the diver, taking care to ensure that no gas bubbles are trapped within the bottle;
3. a record of the sample location, time and water temperature at the sample site should be created; and
4. the sample can then be recovered to the surface.

Surface analysis should follow the testing unit's instruction sheet, but will follow a similar procedure to the following:

1. the unit will be calibrated on site before use;
2. the unit's electrode is then immersed in the sample whilst stirring gently;
3. when the unit is ready (a stability symbol disappears on screen), a pH value automatically compensated for surface temperature is displayed, together with the temperature; and
4. the pH at the temperature recorded at the depth of the sample can then be calculated if required.

pH testing of surfaces

Analysis of pH readings can indicate whether corrosion is occurring. It will give an estimation of corrosion products forming and help assessing whether environmental changes, such as the addition of anodes, will prevent or reduce corrosion.

pH testing on submerged metal shipwrecks is often carried out using a pH meter connected to a flat surface glass electrode which has a pressure compensation to ensure equalisation of pressure with the internal reference solution. To collect pH readings, the concretion must be removed to expose solid metal, and the electrode placed on the newly exposed metal surface where the acidity of the microenvironment of the corroding metal surface is measured. This must be achieved with minimal ingress of seawater, which is alkaline and therefore affects the accuracy of any measurements.

Corrosion potential measurement

The corrosion potential of a metal, termed 'Ecorr', is the voltage difference between a submerged metal (e.g. a metal shipwreck) and a standard reference electrode.

Voltage readings indicate the relative degree of reactivity of the underlying metal. For concreted marine iron, the more negative values of Ecorr reflect a lower corrosion rate, while more anodic (less negative) data indicates a faster rate of corrosion.

Corrosion potential measurements are taken using a platinum working electrode and a calibrated Ag/AgCl sea reference electrode connected to a high impedance digital multimeter in a waterproof housing. This type of instrument, which is small and easy to handle underwater is widely used offshore and is cheap to rent. Measurements must be taken on newly exposed metal, so any corrosion product/concretion should be removed prior to measurements being taken.

A Buckley Bathycorrometer. A very commonly used underwater CP gauge that is simple to operate and understand, as well as cheap to rent. The rugged hand-held gauge is middle left.

Electrical continuity surveys

Electrical continuity surveys provide information about the electrical connectivity of the different parts of a submarine wreck. These surveys are particularly important if it is planned to attach anodes to the submarine to stop or slow corrosion. For example, if testing has shown that two sections of the hull are not electrically connected, then they will need to be protected by different anodes.

These surveys are carried out using a high impedance digital multimeter connected to two waterproofed resistance probes. Resistance readings are taken with the probes against bare metal at set intervals around the wreck structure. Low resistance readings indicate good electrical conductivity and suggest that metal plates and frames, for example, are in good condition and still connected. High resistance readings indicate poor conductivity and may indicate that there is no metal connection at a particular point.

Direct thickness measurements

Direct thickness measurements have been used to carry out accurate measurements of the thickness of metal plates (e.g. Russell et al. 2006). Unlike iron, the corrosion of steel underwater does not result in a remnant layer that preserves the original surface of the steel. As a result the most accurate measure of metal loss is to measure the thickness of the surviving metal and compare it with the original thickness, if known from historical records. By comparing as built and current thickness, absolute and percentage loss can be calculated.

Although calipers can be used to measure thickness, they can only be used where there is access to the back of the plate, for example where there is already a hole or the edge of a damaged plate is exposed. It is also possible to measure thickness by drilling or cutting through the plate (Russell et al. 2006) and drilled holes can be plugged, but this causes damage to the fabric of the wreck and may accelerate corrosion, so should be avoided if possible.

Additional environmental measurements

In addition to the specific measurements described above, the water depth at each measurement point and the length of the drill hole from the surface of the concretion to bare metal should also be taken as this provides useful information about the variability of corrosion environment growth around a site which can be helpful when interpreting results.

For all the above techniques, measurement of dissolved oxygen, temperature and salinity should be taken at each shipwreck site through the water column at 0.5 m intervals to provide comparative intra-site information regarding the corrosion environment.

Ultrasound

Underwater thickness measurement (UTM) using a hand-held ultrasonic thickness gauge is a low cost and reasonably simple solution. UTM has been used in the offshore industries for many years to carry out non-destructive testing (NDT). Whilst its application to submarines is not entirely free from destruction, the equipment can be rented or even borrowed and it does not require technical expertise to either take measurements or interpret them, making its use suitable for both professional and avocational divers.

Thickness measurement of the pressure hull of the A1.The probe is being held against the bare metal of the hull plating behind the wrist monitor. The image on the right shows a similar gauge and probe on the surface.

Testing locations should be carefully selected and mapped. For example, if you are studying the effect of corrosion on the pressure hull consider the following:

- select a number of test sites along each side and along the top of the pressure hull to ensure you develop an understanding of the impact of corrosion across the entire hull;
- select a test site close to an existing hole or broken edge of the plating only if you want to study whether this damage is accelerating corrosion;
- select a location close to a non-ferrous fitting such as a pipe or bearing only if you want to study whether galvanic corrosion is affecting nearby steel.

Measurements cannot be taken through a thick layer of concretion. In many cases it will therefore be necessary to remove a small area of it just big enough to insert the probe of the gauge onto exposed metal. However, leaving the metal exposed will accelerate corrosion at this point and may result in a hole in the plate, as well as destabilising the concretion around it. Although it can be made good with epoxy putty that sets underwater (or hydraulic cement), the process is inevitably destructive. The decision whether to carry out a UTM survey therefore needs to take this into consideration and should use the minimum number of testing locations.

Case study - measuring the thickness of steel hull plating on the A1

Surface supplied diver taking a UT measurement of the A1 hull through a small hole in the concretion.

A-class coastal submarines were built and commissioned between 1901 and 1903 and were the first submarines designed specifically for the Royal Navy. HMS A1 was sunk in the Solent off Chichester as a target in 1911 and was first dived in 1989 as a result of a fishing snag. It is a designated wreck, so the work described below required a licence under the Protection of Wrecks Act 1973 to carry out.

In 2012 Historic England decided to carry out a condition survey in order to develop the methodology for using a recently purchased ultrasonic thickness gauge. This is an instrument designed to measure the thickness of solid materials without destroying them. This is called NDT, non-destructive testing. UT gauges have been used for underwater inspection of oil and gas structures for many years but have only recently been adopted by archaeologists for survey of metal wrecks.

Case study - measuring the thickness of steel hull plating on the A1

UT gauges work by transmitting a short ultrasonic (high frequency sound) pulse through the metal. The pulse reflects off the back wall of the object. It reflects back and forth until it runs out of energy. The time taken for the first echo to be received gives the thickness of the metal. As well as being accurate, UT gauges have the great advantage of not requiring physical access to both sides of the object being measured. This makes them ideal for measuring the thickness of the pressure hull shell plating of a submarine.

The UT gauge was a version of an instrument used all over the world in the oil and gas industry for subsea inspection. Instead of relying on one echo, this gauge listens to three consecutive back wall echoes. This produces a more accurate measurement and allows the gauge to distinguish between the back wall of the metal and flaws, cracks and pitting in the metal, which also cause echoes.

Calibrating the gauge against a test piece. The probe has to be pressed against the surface to make good acoustic contact.

To take a thickness measurement, the probe of the UT gauge is first calibrated against a steel plate of known thickness. An ultrasound couplant should be used if this is done in air, otherwise place the test plate in water when you do this. Underwater the probe should be held with gentle pressure directly on the surface to be tested.

The gauge will work through paint and can distinguish between the back wall of the object and any concretion adhering to it. The surface roughness caused by heavy corrosion can make

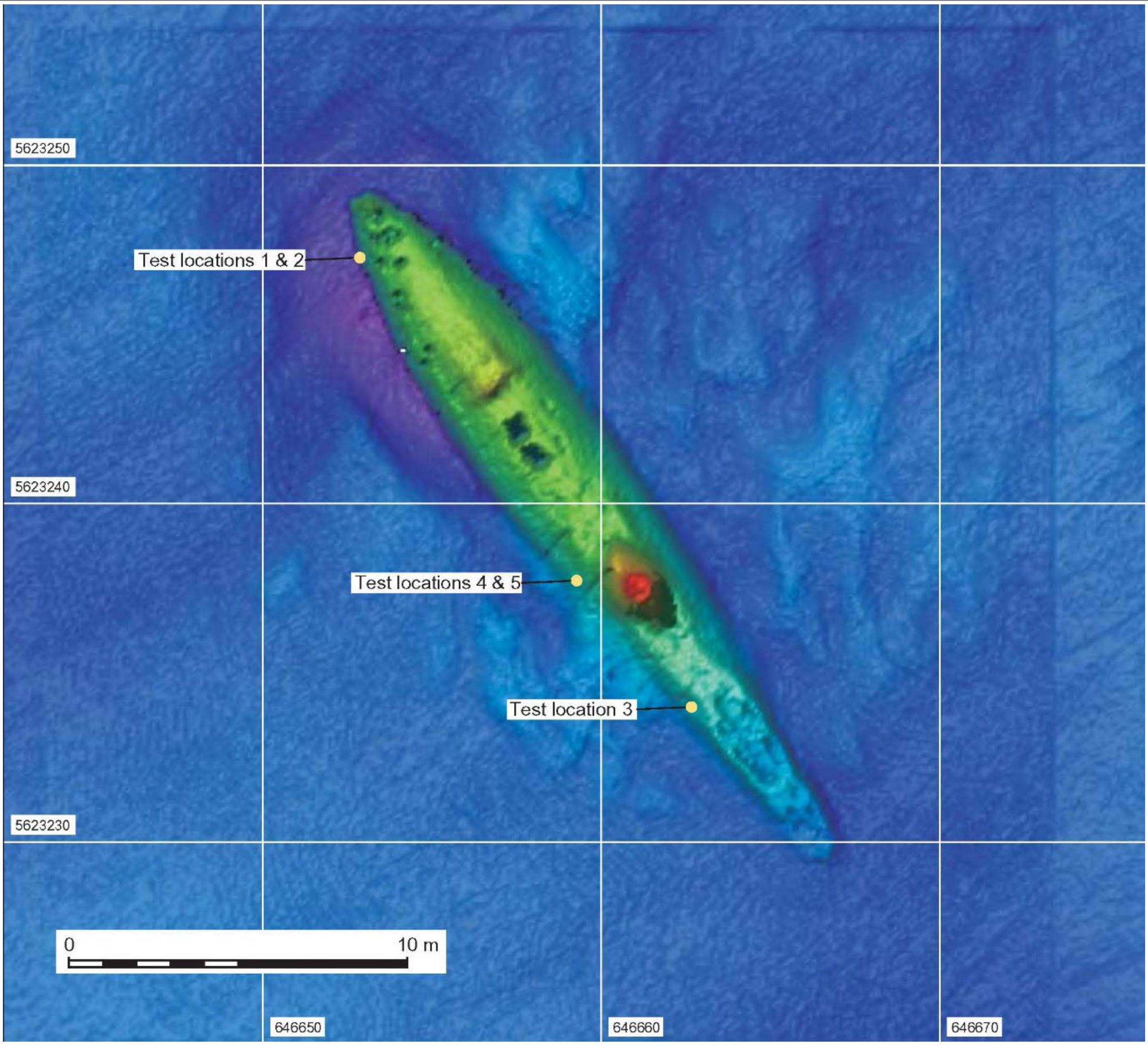
Case study - measuring the thickness of steel hull plating on the A1
measurement difficult, requiring the probe to be moved around to obtain a measurement. However, it will not work easily or reliably through concretion. Therefore the decision was taken to remove a small section of concretion as each test point on the A1 to allow the probe to be held against the metal surface below. This is inherently destructive because if left alone, it could be expected that corrosion pits would form at each test location, possibly leading to holes forming in the shell plating. Therefore, an air driven drill and chisel were used to ensure that only a small hole in the concretion was made. Immediately after taking the measurement, the hole was also filled with a waterproof underwater epoxy resin. This comes in two parts as a putty and can be mixed underwater by kneading the parts together (it is best to use pH neutral resin).

Hole in the concretion adhering to the pressure hull made to allow access for the UT gauge probe. It is important to record the process to verify that it has been done correctly. Note the roughened surface of the pressure hull plating below – this is the result of wasting caused by corrosion. Scrubbing the bottom of the hole allows this to be seen.

Case study - measuring the thickness of steel hull plating on the A1

Another test hole filled with epoxy resin. The reddened area is where marine growth has been scrubbed away. Videoing this allows you to prove that the hole made for testing has been repaired properly.

Case study - measuring the thickness of steel hull plating on the A1



Test locations. Two test holes were made at each location, 10-20 cm apart. The locations chosen for testing were 1 m aft of the bow, 3.85 m aft of the conning tower and in line with the conning tower. Ideally more locations would have been chosen, but the number chosen had to balance the benefits of the information acquired against the intrusive nature of the survey.

The results of the survey were as follows. The gauge was first tried without removing the concretion, which varied between 9-20 mm thick. It is important to know how thick the plates used to build the submarine were. The records of the Director of Naval Construction state that the shell plating of the pressure hull was ½ in (12.7 mm) thick, although the records of the builders, Vickers, record that the outer and inner plates were 7/16 in (11.1 mm) and ½ in respectively (the plates were arranged in alternate raised and sunken strakes or rows). The measurements taken suggest that there has been significant wasting of the plates due to corrosion, with the loss being 44-66% or 50-76%, depending upon the original thickness.

Test Location	1	2	3	4	5
Thickness through concretion	Fail	Fail	Fail	Fail	Fail

Case study - measuring the thickness of steel hull plating on the A1

Thickness on bare metal	Fail	5.6mm	Fail – no solid metal	8.4mm	5.7mm
Depth of concretion	15-20 mm	15-18 mm	10 mm	9-11 mm	-

Further reading:

Wessex Archaeology. 2006c, A1, Bracklesham Bay, Designated Site Assessment Archaeological Report, Unpublished Report Ref: 53111.03jj

Important Note - Cured epoxy resin is very tough and normally non-toxic. However, until it is cured (hardened) appropriate precautions should be taken to protect yourself and the environment. Wear gloves to handle it, mix only what you need and avoid resin that becomes crumbly when being mixed or applied underwater.

Chemical analysis

Work done by the US National Parks Service on the wreck of the battleship USS *Arizona* at Pearl Harbour suggests that it is possible to assess the corrosion rate for submarines by analysing the properties of concretion samples (Russell et al 2006). However, this is likely to require specialist knowledge and the assistance of a suitable laboratory.

Assessing risk

The work carried out on each of the submarine wrecks investigated by the project included a risk assessment. This provides valuable information that can inform whether a wreck site needs to be managed and how this is best achieved. It can also inform decisions about whether archaeological investigation is needed and when it should be funded. It is therefore good practice to risk assess submarine wrecks.

Risk is the chance or likelihood that the condition of a submarine wreck will deteriorate in the future. That deterioration can be rapid or slow. It can be caused by natural process or the effects of human activity. Given that submarines are metal objects in seawater, they are inevitably deteriorating and therefore at risk. The question is therefore how great is that risk in relation to individual wrecks.

Risk can be a specific short-term threat. Otherwise it is a combined assessment of all of the things likely to affect the condition of a wreck over time. This risk assessment is a key factor in determining whether a submarine wreck is managed, for example by designating it under the Protection of Wrecks Act 1973. It may also have a bearing on whether funds can be made available for its study and care.

In order to assess risk, there must be a baseline against which to measure likely changes in the condition of a wreck. The recording work described elsewhere in this guidance can provide this baseline.

The conclusions reached by a risk assessment need to be comparable and objective. It is therefore highly desirable for risk assessment of different wrecks to use a common methodology. Historic England has devised a methodology to be used by themselves and both professional and avocational archaeologists and divers called *Historic Wreck Sites at Risk: A Risk Management Toolkit* (Historic England 2017a). This should be used for risk assessing all submarine wrecks in ETW, or in any other circumstances where Historic England advises regulators on heritage, for example in the UK Exclusive Economic Zone off England.

The Toolkit requires three broad factors to be applied when assessing risk:

- the current condition of the wreck;
- the vulnerability of the wreck; and
- the trajectory of the wreck, in other words whether it is declining or stable.

A separate Historic England Risk Assessment Template Sheet should be completed for each submarine wreck being assessed. This can be downloaded in Word format. The recording fields should be completed using the options available on pages 5-12 of the Toolkit. Information concerning the environmental designations can be obtained from the MAGIC portal.[7] 'Class listing' should be the correct vessel type from the Historic England Maritime Craft Thesaurus.[8] Condition trend is very unlikely to be 'improving'. Overall condition is likely to be E or F. In assessing 'Survival', consider the evidence for loss of external tanks and free-flooding casing, not just the pressure hull. Seabed sediment can be determined from online BGS Seabed Sediment mapping if video or descriptions of the seabed around the submarine are not available.[9]

To assess the risk itself, use the decision tree on page 14 of the Toolkit. There are three levels of risk: low, medium and high. There is no formal definition of special interest in relation to submarine wrecks, but the decision tree is referring to physical features of the submarine. These will include wreck features that do not usually survive or are in exceptional condition, as well as features relevant to the rarity of a particular submarine type or the historical circumstances.

Consider risks created by both natural processes and human activities and the interaction between the two. For example, corrosion is a natural process and likely to be the biggest influence on the long term condition of a submarine wreck. However, it can be exacerbated by impacts caused by fishing gear and by the small grapnels sometimes used by dive boats. It is important that risk assessment should be reliable, so do not advance an opinion as fact and take care to make it clear if there is any doubt. The following is the risk assessment created by Wessex Archaeology for UB-78.

Wreck or Site Name	UB-78

7 MAGIC (defra.gov.uk)

8 Various websites, including Forum on Information Standards in Heritage (FISH). http://www.heritage-standards.org.uk/wp-content/uploads/2020/02/MaritimeCraftType_class.pdf

9 GeoIndex Offshore | BGS

NRHE /UKHO No.	EH Region	Restricted Area	Principal Land Use
1388897/13449	South East	N/A	Coastland 1: Marine
Latitude WGS84)	51° 1.034′ N		
Longitude (WGS84)	01° 16.486′ E		

Class Listing	Period	Status
Submarine	First World War	Non-designated site
Licensee	Nominated Archaeologist	Principal Ownership Category
N/A	N/A	C: MoD
Seabed Owner	Navigational Administrative Responsibility	
Crown Estate	Dover MRCC	

Environmental Designations
G: NONE

Seabed Sediment	Energy
sG sandy gravel and G gravel	Medium

Survival
Very Good

Overall Condition	Condition Trend	Principal Vulnerability
E: Extensive significant problems	B: Declining	NAT

Amenity Value: visibility
A

Amenity Value: physical accessibility	Amenity Value: intellectual accessibility
A: Full	C: no interpretation

Management Action	A: no action required
Management Prescription	M: no management prescription required
Notes:	

The wreck of the First World War German submarine UB-78 lies at one location in two sections within territorial waters off Folkestone, Kent. It is almost fully exposed. The UB-78 was lost in 1918 whilst attempting to pass through the Dover Barrage and the separation of the hull into two pieces is thought to have occurred at the time of loss and as a result of the explosion of one or more mines.

The site is well known to the local diving community and is occasionally dived. Although the propellers have been salvaged, Wessex Archaeology has not come across any evidence to suggest that the submarine is unusually vulnerable to salvage. Although limited surveys have now been carried out, including a diving survey by Wessex Archaeology in 2014, it has not been fully recorded.

The submarine is in a reasonably good condition considering the circumstances of loss and the ongoing effects of corrosion. It has lost some deck, conning tower and other casing and deck fittings. Both of its propellers were salvaged in the late 20th century and other items have been removed. No human remains were observed during this survey, although they are likely to be present within the main section of the wreck.

The principal long-term vulnerability of this site is likely to be the ongoing process of corrosion, which will inevitably result in the eventual collapse and destruction of the wreck. Although our understanding of its impact on both this and other submarines would benefit from further corrosion-specific survey, halting or slowing its progress is not currently practicable. There may be some risk to external fittings if they are used for moorings.

No formal management prescription appears to be appropriate, although English Heritage has the opportunity to benefit from the strong encouragement to local engagement provided by the investigation of this and other local First World War sites in 2014 by undertaking further related fieldwork and/or engagement in the region.

Using the ‘decision tree’ method of risk assessment, risk assessed as LOW. The data source used for this risk assessment is the Archaeological Report (Wessex Archaeology 2015c).

Risk assessed as		LOW	
Data Source	CON	Date and Initials	Wessex Archaeology, January 2015

Mitigating the effects of corrosion is possible in theory but very difficult to achieve in practice due to the large size of submarine wrecks. Attaching sacrificial anodes to the hull and equipment has been tried for historic submarine wrecks, for example on the wreck of the very early Resurgam submarine off North Wales. This aims to arrest the corrosion of the wreck by turning it into a cathode. It is expensive, particularly for large structures, requires technical knowledge and patience to attach the anodes correctly to protect the entire structure, and is very time consuming to set up. It also requires regular monitoring and the replacement of exhausted anodes, so it creates substantial ongoing obligations that are very difficult to sustain. Its application to submarine wrecks will therefore probably be limited to the selective preservation of features of special interest on these wrecks.

Sacrificial anode attached to the top of conning tower of the very early Resurgam submarine off North Wales in 2006

Pollution Risks

Pollution risks were not assessed as part of the project. Although there is potential for lead acid battery leakage, the main pollution risk from First World War submarines lies in the diesel and other fuel oils carried for the engines. Pollution risk obviously depends on the presence of oil and this depends on the presence of intact tanks. Due to the damage that relatively weak external tanks tend to suffer at the time of sinking or thereafter and the lapse of time, it is unlikely that external tanks will contain any significant quantities of oil, although damaged tanks can probably still retain residual quantities. Tanks within the pressure hull are more likely to retain fuel oil because they will be protected by the pressure hull.

Assessing pollution risks – UC-7
The UC-7 was a single-hulled UC I boat of the UC-1-10 series. They carried 2.5 tonnes of fuel and 0.4 tonnes of lubricating oil, with the fuel oil tanks situated below the engine (ADM186/407). It is thought that it may have been carrying up to two tonnes of the fuel oil when lost off Zeebrugge in 1916, probably as a result of hitting a mine. The wreck appears to be in two sections, with the split between the conning tower and the mine chutes. The mine chutes are empty and the boat was not torpedo armed and had no large calibre deck gun. The aft hatch is believed to be open and the aft section may therefore be silt filled. Otherwise the stern section of the pressure hull appears to be intact. There is a therefore a risk that the fuel tanks are intact and oil-filled. *Further reading:*

Assessing pollution risks – UC-7
ADM186/407 Wrecksite.eu U-boat.net Termote, T. and D., 2009. Schattern en Scheepswrakken, Davidsfonds, Leuven.

Significance and protection

Significance

Following National Planning Policy Framework guidance (Ministry of Housing, Communities and Local Government 2021), the significance of a heritage assets, including archaeological sites, historic buildings and historic wrecks, can be broadly defined as its value to this and future generations because of its heritage interest. Heritage interest can be archaeological, architectural, artistic or historic (Historic England 2019).

- *Artistic interest*: a submarine wreck is highly unlikely to have artistic interest.
- *Historic interest*: is what the wreck may illustrate about past lives and events, either directly or by association with. For example, the possibility that UB-109 was the last submarine victim of the barrage built across the Straits of Dover that did so much to stop the U-boat campaign from forcing Britain out of the war in 1917-18 and a victim of the famous Dover Patrol can be argued to lend it historical significance.
- *Architectural interest*: for a submarine, the interest of its design can probably be seen as equivalent to architectural interest. That could be a wreck that is a rare example of a particular design, or an unusually well-preserved example of an important or particularly common design. The U-8 is a rare surviving example of early U-boat design.
- *Archaeological interest*: is what future archaeological investigation of the wreck may reveal about our past that needs protecting. Surviving archive material concerning the detailed design and operation of both British and German submarines of the First World War is far from complete and therefore detailed future archaeological investigation of their wrecks is likely to add to our knowledge of them.

The Strategic Assessment carried out in 2014 (Cotswold Archaeology 2014) was commissioned by Historic England to produce a list of the best surviving examples of the different types of submarines found in ETW. To do this it applied the questions below to each submarine wreck:

At particular risk?	**Already protected?**
Significant – by merit of either service record or rarity of type?	**A less 'significant' boat?**
Well identified?	**Unknown, or known only by type?**
Part of a group – in terms of location and/or of a specific campaign?	**An isolated example?**
In good condition?	**Dispersed into debris?**

As the aim of the Strategic Assessment was to inform future approaches to designation, it then assessed them against the criteria for designation as protected wrecks under the Protection of Wrecks Act 1973, or for scheduling as an 'ancient monument' under the Ancient Monuments and Archaeological Areas Act 1979. Both approaches followed the guidance in the 'selection guide' on ships and boats published by Historic England (Historic England 2017b and 2019).

Following this process a list of 11 submarine wrecks were identified by Historic England as being of special interest and potential candidates for further investigative work. For example, U-8 was in the list because it is an example of a rare, early U-boat. UB-30 was selected because it was a representative of an important submarine type, the UB II. D5 was chosen because it was the first independent design, although its real significance lies in the fact that it is an example of the first class of British submarine designed to act offensively, i.e. overseas.

Designation and scheduling

A submarine wreck can be protected by:

- designation as a 'scheduled monument' under the Ancient Monuments and Archaeological Areas Act 1979;
- designation as a 'designated wreck site' (often called a 'protected wreck site') under the Protection of Wrecks Act 1973; or
- designation as a 'controlled site' or 'protected place' under the Protection of Military Remains Act 1986.

For designation as a 'Controlled Site' under the Protection of Military Remains Act, the wreck must be less than 200 years old. To be designated as a 'Protected Place' under the same Act, it must have been lost on or after 4 August 1914, the date that Britain declared war on Germany.

Submarine wrecks cannot be 'listed' under the Planning (Listed Buildings and Conservation Areas) Act 1990 unless they are intact and permanently grounded and fixed to dry land, or their components have been deliberately incorporated into a permanent terrestrial structure. A submarine is highly unlikely to be listed if it is afloat and can be moved or it has been abandoned and has come to rest on the ground, for example a mud flat or riverbank.

Wrecks outside of ETW cannot be protected using the Protection of Wrecks Act 1973 or Ancient Monuments and Archaeological Areas Act 1979. The Protection of Wrecks Act 1973 applies to wreck below Mean High Water (MHW), the Ancient Monuments and Archaeological Areas Act 1979 could theoretically be applied to wrecks above MHW.

Decisions on scheduling and designation are made by the Secretary of State, based on advice received from Historic England. It is often itself receiving advice from archaeologists and other heritage professionals, as well as members of the public.

In order to be designated or scheduled, the submarine wreck or its contents must be of historical or archaeological importance. The considerations used to determine whether a wreck should be designated or scheduled are called the 'non-statutory criteria' and are set out in the Historic England selection guide *Ships and Boats: Prehistory to Present* (Historic England 2017). *Ships and Boats: 1840-1950 Introduction to Heritage Assets* (Historic England 2016) may also be of interest. Although a brief assessment of the criteria was given for each submarine wreck by the Strategic Assessment, this exercise was repeated during the further work carried out on individual wrecks in 2014-18 and benefitted from the more detailed evidence available as a result.

The 'historical' criterion can be split into considerations of historical associations, and those relating to social, economic and mercantile history. For the purposes of this guide, historical association is taken to mean any identified vessel which played a key role in England's national history or which is associated with a historical figure of national significance. Where this can be firmly established historic significance would be a compelling factor in assessing the vessel's national importance. Historical claims can be particularly relevant for vessels in terms of their cargos, their crews, their construction, the trades they plied and the routes they served.

The definitions for the non-statutory criteria were developed quite a long time ago. They are subjective and lack a 'scoring system', so the following was adopted and accepted by Historic England during 2014-18:

- *Uncertain* – insufficient evidence to comment;
- *Variable* – the importance of the wreck may change, subject to the context in which it is viewed;
- *Not Valuable* – this category does not give the site any special importance;
- *Moderately Valuable* – this category makes the site more important than the average wreck site;
- *Highly Valuable* – this category gives the site a high degree of importance. A site that is designated is likely to have at least two criteria graded as highly valuable;
- *Extremely Valuable* – this category makes the site exceptionally important. The site could be designated on the grounds of this category alone.

The non-statutory criteria are not submarine-specific, so examples of how the criteria were interpreted during the more detailed investigations of individual submarines are given in the table below. The reports were compiled by different authors.

Criteria	Selection Guide notes	How it was applied
Period	Vessels from all periods are important in reflecting technological advances in construction and materials, and provide evidence of trade networks, industry, and transport. Those vessels which best illustrate or epitomise this development have a strong claim to national importance.	(From the UC-70 report (Wessex Archaeology 2016d) Moderately Valuable. UC-70 was launched during the First World War in 1916 and sank in the final year of the war, 1918. As with all German submarines which actively took part in the First World War, UC-70 epitomises the submarine as the new strategic weapon that determined and revolutionised naval warfare. In this sense the UC II class is representative of a crucial phase of the U-boat Campaign. The design of UC II class was produced at a time when a policy of unrestricted warfare was pursued and a minelaying U-boat with a capability which brought within range the whole British coastline was needed. After the first eight experimental boats were ordered in July 1915 and recognised as effective, it became apparent that more U-boats were needed to engage in unrestricted naval warfare. Significantly, at the beginning of 1916, Grand Admiral von Tirpitz made inquiries as to how many of these UC boats could be made ready by the end of 1916. On 11 January 1916, 31 UC II, including UC-70, were ordered. This order was the first large commission for the German submarine industry and brought with it

Criteria	Selection Guide notes	How it was applied
		the advantages of mass production. The UC II type became the first mass produced U-boat with considerable numbers being produced. In this sense UC-70 is a good example of the mid-war efforts of the German war effort. As suggested by Rössler (1997) the order of new U-boats by von Tirpitz represented the shift in the commitment to the U-boat cause by the Grand Admiral “who from a sceptical position on the efficacy of U-boats progressively become convinced of their indispensable role in the war”. At first the response of the German government was tepid towards the idea of a new unrestricted marine warfare campaign. Von Tirpitz had to resign in protest in March 1916 and in February 1917 the Government declared the resumption of the unrestricted marine warfare campaign. It is significant that UC-70 took part in this important phase of the conflict leaving for its first patrol under the command of Fürbringer. By taking into account the development of German submarines during the First World War, UC II was a comprehensive revision of the smaller UC minelayer concept and the enduring qualities of the class are demonstrated by the fact that the prototype, named Project 41, was used as a baseline for the design of the later UB III class. The site should be considered of special interest in the light of the anniversary of the First World War as part of the commemoration of German submariners. In this sense, the presence of exposed human remains constitutes an extraordinary and tangible reminder of the tragedy of the war.
Rarity	The rarity of vessels’ remains for periods before 1700 is such that any firmly dated vessels from this period are likely to be of national importance and may merit scheduling. For vessels of later date, particularly those types for which examples survive today, scheduling will always be under exceptional circumstances only.	(From the U-8 report (Wessex Archaeology 2015d) Extremely Valuable. U-8 is the only remaining U-boat of its type. U8 was one of four coastal torpedo attack U-boats constructed in 1908 by Germaniawerft. U-6 and U-7 were both sunk by torpedoes in 1915 and have never been located. U-5 was mined but then raised and toured internationally to raise funds post-WWI and then broken up. In the broader sense, U-8 is also the only extant representative of the 14 U-boats powered by Korting heavy-oil type engines and sunk in English waters. U-11 is the other example and it has not been conclusively located on the seabed. One final feature to contribute to U-8’s rarity is that it is the only U-boat known to have been sunk as a result of effective use of an explosive sweep.
Documentation/ finds	Our understanding of shipbuilding, transport, trade and industry can be greatly enhanced by the survival of historical documentation relating to particular vessels and their service. Where	(From the report on D5 (Wessex Archaeology 2016b) Moderately valuable. A number of primary and secondary sources provide detailed descriptions of the characteristics of the design of the D-class. However, ad-hoc solutions and innovations fitted to each submarine are often not documented in the

Criteria	Selection Guide notes	How it was applied
	interpretive documentation can provide evidence for especially strong historical claims, for example confirming a ship to be the last of its type, this may be a key factor in establishing its importance. Similarly, significance can be enhanced by the existence of artefacts such as those held in museums.	written sources. Historical photographs and blueprints of the D-class and D5 are available and published in different sources. Primary sources such as the contemporary accounts of the accident by Herbert and Turner are available in the well-researched book Silent Warriors by Young and Armstrong (2003). Vol. XII of the Naval Staff Monographs published after the war details the history of the naval operations during the first German raid at Yarmouth presenting the official British version of the attack. The telegrams and signals broadcast in relation to the Yarmouth Raid on 3 of November 1914 are also available in appendix B of the monograph (Naval Staff 1925). The description of the actions taken by Admiral Hipper and his I and II Aufklärung Gruppe during the bombardment of Yarmouth on 3 of November is covered in a publication by Gary Staff (Staff 2014). Documents regarding the loss of D5 at the National Archives in Kew includes the reports of the deaths of the members of the crew of the letters and notes regarding the disposal and storage of the logs of the submarine and a letter from the captain of HMS Maidstone reporting the list of the casualties (ADM1/8401/405, ADM1/8404/481). The National Maritime Museum Greenwich stores a series of boxes of folded ships plans and photographs pertaining to the D-class submarines (ADBB0728, ADBB0729, ADRB0342, ADBB0734, ADBB0735, ADMB0063, VIZB0141, FORB0010, ALB1327, and ADBB0736). The Imperial War Museums hold in the Burton-Bass collection; a series of black and white prints of British submarine types featuring D-class submarines (Catalogue number 2005-02-31). Although this documentation has not been accessed there is currently no indication that it will revolutionise our archaeological understanding of this type of vessel or their activities. In addition there is substantial documentation related to the wider historical and maritime landscape context of the East Coast War Channels during the First World War (Firth 2014).
Group value	In some instances a vessel's importance may be strengthened by an association with other vessels of a similar type, for example the group of gunpowder boats at Waltham Abbey (Essex), which allow for comparative study. Association within a wider context which reflects their use can also be a consideration. In the case of	(From the UB-30 report (Wessex Archaeology 2019) Extremely valuable. UB-30 is also representative of an important class of submarine, the UB II type boats operated by the German Navy. The significance of this representative status within UK TTW has been highlighted in the strategic desk-based study for the major Historic England thematic study of First World War submarines. Group value is also provided by the very numerous wrecks associated with the East Coast convoy routes, including the nearby designated wreck of the

Criteria	Selection Guide notes	How it was applied
	hulks (vessels that have been stripped and abandoned), as well as having intrinsic interest, they can contribute to the story of a landscape, and its long-term evolution and management.	UC-70 north-west of Whitby. The UB-30 is part of the archaeology of a major battlefield of the First World War, fought in coastal convoy routes in the North Sea and English Channel. The British victory over the German coastal U-boat offensive in 1917-1918 ensured the continuing flow of war materials and contributed significantly to the overall Allied victory in 1918. This campaign has been the subject of a major thematic investigation and study by Historic England. UB-30 is associated with an important historic vessel, the Dias. Built as H868 Viola in Hull in 1906, as HMT Viola it was one of the vessels that hunted down and sank the UB-30. The Dias, after being used as a whaler, was laid up in 1964 and is now beached at Grytviken in the British Overseas Territory of South Georgia. The ship is reported to be one of only four surviving British vessels that saw active service in the First World War and, perhaps more importantly, is believed to be the oldest surviving steam trawler in the world. Steam trawlers revolutionised the fishing industry in the late 19th and early 20th centuries and contributed to the overfishing that continues to affect fish stocks on the UK Continental Shelf. Attempts are being made to bring the trawler back to Hull. The association between an undoubtedly important victor and UB-30 as victim undoubtedly enhances UB-30's significance.
Survival/ **Condition**	Given the range of materials used in boatbuilding, survival of vessels can be highly varied, from the survival of the sand-imprint of the ship at Sutton Hoo or fragment of the log boat at Shardlow (Derbyshire) to the concrete boats of Second World War date at Purton (Gloucestershire). Given the rarity of surviving vessels of pre-1700 date, even fragmentary survivals are likely to be of national importance although a judgment must be reached as to the degree of survival and intactness. For vessels of later date, increasingly complete survival, allied to strong archaeological and historical importance, will be expected before scheduling would be considered.	(From UB-107 report (Wessex Archaeology 2016c) Not valuable. The UB-107, like many iron and steel wrecks of this period are in a declining condition due to both corrosion and the activities of salvors. Whilst the latter is probably time-limited by the removal of larger non-ferrous metal parts of the wreck during the late 20th century and the impact of the former is to some extent limited by robust strength of the pressure hull of a typical U-boat, the condition of the wreck will continue to decline. Collapse and dispersal will inevitably be the ultimate long-term outcome. However, this vulnerability is highly unlikely to be addressed by designation, as cost-benefit analysis of effective protective measures is unlikely to be favourable.
Fragility/ **Vulnerability**	Highly important archaeological evidence from some wrecks can be destroyed by the selective or uncontrolled removal of	(From the UC-70 report (Wessex Archaeology 2016d) Highly Valuable. It has been reported that the wreck of UC-70 has been the target of illicit salvage operations in recent times, provoking widespread

Criteria	Selection Guide notes	How it was applied
	material by unsympathetic treatment by works or development or by natural processes. Some vessel types are likely to be more fragile than others and the presence of commercially valuable objects within a wreck may make it particularly vulnerable. Vulnerable sites of this type would particularly benefit from protective designation.	condemnation (McDonald 2003; Campbell and Davison 1999, https://www.youtube.com/watch?v=meKjbeioQy8). These activities, which are alleged to have entailed the use of explosives, have apparently resulted in ongoing damage to the structure of the wreck. The corresponding UKHO report notes that the torpedo tubes and both of the manganese bronze propellers had been removed from the wreck prior to 24 November 1995. There are human remains present, and there is a significant risk associated with unauthorised recoveries which should be mitigated. Although it is believed that there is a widespread feeling within the diving communities that UC-70 should be respected as a war grave, the evidence of previous salvage activities highlights the risk. Furthermore, the exposure of modern human remains on a site that is freely accessible by recreational divers is likely to be considered disrespectful and unethical, especially by the German authorities. It is possible that the opening at the stern might have destabilised the archaeological context within the pressure hull, accelerating decay and possibly starting an erosion process which the silty sediment had previously sealed. Internally, the fittings such as gauges, wheels, valves and machinery parts within the pressure hull are easy to access from a large opening at the stern and through the hatches. It is reported that two fine Chinese plates of the 18th century were recovered from the galley in 1993 (http://wrecksite.eu/wreck.aspx?1704). The external structure of the submarine seems to be relatively robust with evidence of corrosion and thin plating within the norm for a First World War site.
Diversity	Assets may be selected for designation because they possess a diverse combination of high quality features, others because of a single important attribute. The importance of wrecked vessels can reflect the interest in their architectural design, decoration and craftsmanship, or their technological innovation or virtuosity, as well as their representativeness. Consideration should be given both to the diversity of forms in which a particular vessel type may survive and to the diversity of surviving features.	(From UB-107 report (Wessex Archaeology 2016c) Moderately valuable. It is Historic England's stated intent that the sample of protected sites should reflect a wide variety of vessel forms (Historic England 2016: 11). Although a German First World War long range U-class submarine now forms part of that sample, no example of the equally important coastal class boats has been protected. However, there are better preserved examples of the class that are likely to be considered more important in terms of this criterion.

Criteria	Selection Guide notes	How it was applied
	Some vessel types may be represented in the surviving record by a wide variety of building types and techniques which may be chronologically, regionally, or culturally conditioned. The sample of protected sites should reflect this wide variety of forms. In addition, some wrecks may be identified as being of importance because they possess a combination of high quality surviving features or, occasionally, because they preserve a single important attribute.	
Potential	England's maritime past is one of its most defining characteristics throughout all periods. Evidence for the construction and use of vessels gives us great insight into not only the exploitation of our immediate marine environment, but also into the development of wider trade and transport networks. This is especially true of earlier periods which are lacking in the rich literature and documentation of later times. Surviving vessels may also provide evidence of their use and construction, reflecting technological developments which in some instances may be all but lost. The potential which a vessel has for answering questions about our maritime past will be a consideration in establishing its importance. If remains of a cargo survive it is likely to add very considerably to the vessel's significance, for its evidence of trade and material culture at a particular point in time.	(From the D1 report (Wessex Archaeology 2020) Moderately valuable. The pressure hull tube may contain machinery and other equipment and some of the machinery, such as the diesel engines, that were prototypes and fitted for the first time in a submarine, hence they are likely to be extremely rare and deserving further studies if they are present. The possibility remains, however, that they had been removed prior to sinking. The pressure hull is accessible but there is evidence that the section amidships might be completely filled with sediment. The area forward of the conning tower seems to be clear of sediment and easy to access from a large opening. The interior of the submarine is very likely to hold undisturbed deposits and to retain most of the content that it sunk with. No human remains are expected to be within the hull. There is no apparent debris trail although some detached items from the superstructure and outer plating are expected to be laying either exposed or buried within the proximity of the submarine at mud-line level. Two possible features, which could be possibly associated debris, were observed in the MBES data within the vicinity of the submarine but these have not been investigated.

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