Chapter 6
Managing Potentially Polluting Wrecks in the United Kingdom

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6.1 The Inception of Wreck Management in the UK

The battleship HMS *Royal Oak* was at anchor in Scapa Flow in Orkney when, in the early hours of 14th October 1939, the German submarine U-47 entered the harbour and fired a salvo of torpedoes at *Royal Oak's* port side. U-47 then repositioned itself at close range and fired a further three torpedoes at the starboard side of the ship. The weather had been fair, so all the ship's hatches were open and consequently it took on water very quickly and sank in just 13 min with the loss of 833 of its crew.

HMS *Royal Oak* lies partially inverted on its starboard side in approximately 30 m of water, with the shallowest part only 3 or 4 m below the sea surface. The ship was fully loaded with 3500 m^3 of diesel and heavy fuel oil when it was attacked. An estimated 485–735 tonnes of oil were released during the sinking, and more was washed out during the subsequent war years. This leakage stopped by about 1945, but a gradual corrosion of rivets and seams eventually led to a slow but increasing leak of fuel from the wreck from about 1960. By the mid-1990s, disquiet about the increasing leakage, together with growing concern about the stability of the inverted wreck and the potential for a significant sudden release of oil, led to pressure for something to be done to protect the Scapa Flow environment.

In February 1995, the Secretary of State for Defence accepted that the UK Ministry of Defence had a moral responsibility to intervene as the owners of the wreck. In October 1996 a patch was placed over the area of worst leakage as a short-term measure while longer-term options were explored. In January 1999 an oil-collection canopy was fitted over the worst leak, but it was ripped off in storms a

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couple of weeks later, taking the patch with it. At this stage it was accepted that the best option was to remove the remaining fuel on board.

The Ministry of Defence turned to its Salvage and Marine Operations team. In 2001, a team of Salvage and Marine Operations engineering divers deployed on a pilot operation to prove the practicality of hot-tapping the tanks of HMS *Royal Oak*. Hot tapping involves attaching a valve to the tank boundary and hollow-cutting a hole concentric with the valve, making sure that the boundary is sealed throughout, so that oil isn't released. A hose can then be attached to the valve and the tank contents pumped out into another vessel. The wreck was boomed to collect any escaped oil. The pilot was successful, and a full hot-tapping operation was planned to remove the remaining oil.

The oil pollution from HMS *Royal Oak* forced the Ministry of Defence to face the environmental legacy of its modern naval warfare and the Wreck Management Programme was born in 2008 to proactively manage the environmental and safety risks associated with its remaining wreck inventory.

6.2 Current Wreck Management in the UK

UK-owned Potentially Polluting Wrecks (PPWs) are now actively managed between two different government departments, and a few other government departments also have an interest. Ships that were in the service of the Royal Navy or the Royal Fleet Auxiliary at the time of sinking are the responsibility of the Ministry of Defence. This includes ships that were taken up from industry for the war effort in World War I (WWI) and World War II (WWII), including tankers that were transporting fuel oil under the flag of the Royal Fleet Auxiliary. Ministry of Defence wrecks are managed by two teams, one within Navy Command who manage heritage issues for all Ministry of Defence wrecks, and one within Salvage and Marine Operations who manage the safety and environmental risks associated with wrecks through the Wreck Management Programme. The Ministry of Defence is responsible for an estimated 5600 PPW globally.

The Department for Transport has policy responsibility for approximately 5300 mainly merchant shipwrecks, which includes some PPWs. These came into government ownership largely through the War Risk Insurance scheme which provided payments to their owners for any loss due to enemy action during WWI and WWII. Depending on the nature of the insurance policy, the government then took ownership of the hull and/or cargo of the resulting wreck. There are, however, some wrecks where more than one government department may have an interest. For example, a preliminary assessment suggests that the Department for Transport owns the hull of the wrecked SS *Derbent,* which sank holding a cargo of Ministry of Defence-owned oil.

These UK government teams have a global remit, excluding wrecks in US waters. This is due to a 'knock for knock' agreement between the UK and the US which states that each government will waive all claims arising from or connected with negligent navigation in respect to any cargo (Provision of Mutual Aid Concerning Certain Problems of Marine Transportation and Litigation Agreement, 1942). This has enabled the UK and US governments to take responsibility for historic wreck risk management in their respective waters, which has been of mutual benefit. For example, problematic British wrecks such as the tanker SS *Coimbra* that sank off Long Island in 1942 leaked oil for decades until a project coordinated by the US Coast Guard hot tapped the wreck and removed an estimated 500,000 gallons of oil (Brennan et al., 2023). Conversely, the UK government has managed the US-owned SS *Richard Montgomery* located in the Thames Estuary.

The Ministry of Defence Wreck Management Programme aims to identify wrecks that still contain significant quantities of oil so that this can be removed in a controlled operation, as was done with HMS *Royal Oak*. Although some wrecks contain other hazardous materials, and all contain at least some munitions, oil has hitherto been the priority due to the potential volumes involved. The process begins with the prioritisation of the Ministry of Defence's entire post-1870 (when ships began the transition to fuel oil) shipwreck inventory based on criteria such as ship size and proximity to shore (Liddell & Skelhorn, 2018). This prioritisation, using easily accessible information, identified several hundred high priority wrecks including tankers and large warships lost with significant quantities of oil. Following prioritisation, several wrecks have been investigated further to identify and mitigate the environmental risks they pose.

The Department for Transport is building upon the work of the Ministry of Defence Wreck Management Programme and, following a desk-based review, continues to assess its wrecks in line with the standardised approach to the environmental risk assessment of potentially polluting wrecks (Goodsir et al., 2019). It has also made its wreck data available to develop innovative methods for identifying historic pollution, such as the Department for Environment, Food and Rural Affairs (Defra) Earth Observation Centre of Excellence project which aims to develop a tool for mapping historic oil spills using satellite data.

6.3 Distribution of British PPW

The distribution of Ministry of Defence wrecks mirrors the UK's involvement in WWI and WWII. The majority are concentrated in northern European waters with significant numbers in the Mediterranean and, to a lesser extent, the Far East and Baltic Sea. Patterns are discernible within these regional groupings. For example, the convoy routes across the Atlantic Ocean and round to the northern Russian ports can be picked out from the trail of wrecks left behind, while other concentrations denote campaigns or individual battles. A significant grouping of wrecks marks the UK's involvement in the Gallipoli campaign, for example, while the ebb and flow of the Battle of Jutland can be charted from the remains of the vessels sunk during that engagement.

The distribution of WWI UK merchant vessel wrecks reflects the enormous efforts of the Mercantile Marine to supply the country and its armies during the conflict. While this effort is mirrored in their geographical spread, the distribution also reveals significant temporal variation reflecting the way the war was conducted. For example, prior to the general introduction of the convoy system in 1917, the merchant fleet was subject to huge losses as individual ships were picked off by marauding U-boats. The loss rate fell significantly after the introduction of convoys.

While many of the wrecks remain to be discovered, the spread of WWII UK Merchant Navy losses again mirrors the strategic and tactical decisions that framed the conflict. The convoy system was initiated from the outset and the efforts of the axis powers to counter it can be discerned from the groups of merchant losses marking successful U-boat wolfpack, warship and aircraft attacks on individual convoys. Consequently, the day-to-day interplay between the axis and allied powers has implications at the present. The individual running convoy battles that frequently developed are marked by temporally, and sometimes geographically, confined groups of wrecks that may pose environmental and safety risks at the present day.

Although UK wrecks are spread around the world, they have not received equal treatment with regards the management of environmental and safety concerns. Most work has been concentrated within UK territorial waters. Further afield efforts have been patchier. In part this reflects the sheer volume of work close to home coupled with the costs and difficulties of operating more remotely. However, it also reflects the fact that an appreciation of the potential risks posed by legacy wrecks, and associated demand for action, varies between countries. For example, Norway has pursued an extremely proactive policy of oil removal from foreign legacy wrecks within its waters (Bergstrøm, 2014). Conversely, relatively little work on PPWs has taken place in the Mediterranean Sea despite the large number of losses that occurred there in both World Wars. However, this situation is likely to change with the first signs of initiatives to better understand the risks posed by Mediterranean wrecks.

6.4 Wreck Survey Techniques

Archival research is a useful starting point to determine what fuel and cargo a wreck might have sunk with, how much damage was caused at the time of sinking, and where the wreck now lies (Liddell & Skelhorn, 2018), but to minimise the assumptions in a risk assessment, the wrecks need to be surveyed (Hill et al., 2022). The same techniques are generally used, but not all wrecks are the same so the survey approach may vary from wreck to wreck. The chosen survey method(s) depend on how much (or little) is already known about the wreck and therefore the level of concern, the wreck location and depth, and the type of ship, its size and construction.

Survey techniques typically used to assess the structural integrity of wrecks and their tanks include comparison of ship plans with multibeam echosounder (MBES) and live feed video surveys using Remotely Operated Vehicles (ROVs) and towed side-scan sonar surveys. Where wrecks are surveyed over multiple years it is possible to follow the collapse (or illegal salvage) of the wreck over time. The deterioration of wrecks can also be detected by satellite imagery of oil spills. Advances in technology mean survey techniques are likely to evolve in the next few years. An increased use of autonomous vehicles to survey wrecks will reduce the carbon footprint of the Wreck Management Programme and increase its output.

Environmental surveys have been completed for some priority wrecks to measure concentrations of oil derived contamination within sediment, biota and the water column where historical and active leaks have occurred (e.g., Hill et al., 2022). Sediment is typically collected by grab or corer, and biological samples are collected by beam trawls; the type of equipment deployed is influenced by the sediment type, hydrodynamic conditions, and other hazards in the area. Water fluorescence (indicative of hydrocarbon concentration) is measured in real time and water samples are collected and analysed to convert fluorescence data to hydrocarbon concentration.

Oil spill modelling with integrated wind and current data can predict the transport and fate of oil in the marine environment, indicating likely areas of elevated seawater and sediment contamination. Survey design is influenced by model outputs, MBES bathymetry, and other anecdotal evidence such as prevailing seabed currents. Sample points are orientated along radiating transects centred on the wreck, with the primary focus on the most probable direction of travel of released oil to increase the likelihood of detecting contamination. Control samples may be collected away from the wreck for comparison.

Historic leaks can be detected in surface or sub-surface sediment layers because oil persists in marine sediments for many years. Fine sediments such as muds and clays have a higher tendency to accumulate Polycyclic Aromatic Hydrocarbons (PAHs), particularly in non-mobile sediments with low oxygen levels, and can be targeted to assess contaminant load and the potential impact of sediment resuspension. Total Hydrocarbon Content (THC) and summed PAH (ΣPAH) are quantified using coupled gas chromatography-mass spectrometry using accredited methods (Kelly et al., 2000). Elevated concentrations can pose a risk to organisms living or feeding in the region and reduce biodiversity there. Characterisation of the physical habitat and local ecology can be used to measure ecological health (Thomas et al., 2021) and provide a baseline of sensitive receptors for comparison with subsequent monitoring.

The Wreck Management Programme compliments its own surveys with other sources of information, predominantly from academia. For example, Bangor University shared MBES and dive footage of the tanker SS *Derbent*, which suggested the wreck was intact and required further investigation (see case study below). An equally useful resource is the diving community, who are passionate about wrecks and are generally committed to diving responsibly and respectfully. Community involvement has proved an effective way of documenting wrecks (Viduka, 2020) and given appropriate training, this can be extended to the environmental and safety management of wrecks.

6.5 Case Studies

A selection of case studies is presented to demonstrate the diversity of risks and challenges that wrecks present, and the action the UK government has taken to assess and, occasionally, mitigate the risks they pose.

6.5.1 RFA Darkdale

The tanker RFA *Darkdale* was stationed at the South Atlantic island of St Helena acting as a refuelling tanker for Royal Navy vessels when it was torpedoed and sunk by *U-68* on 22 October 1941. The wreck of the RFA *Darkdale* lies in James Bay, approximately 600 m offshore from Jamestown, which is the capital of the island, at around 45 m depth. The wreck had sporadically leaked small quantities of oil but a storm in the spring of 2010 led to a significant release from the wreck. St Helena has limited sources of income and there was concern that further large oil leaks could have seriously damaged the island's tourism and fishing industries. Consequently, Salvage and Marine Operations were alerted to the problem by the UK Foreign and Commonwealth Office.

Ship plans showed that the RFA *Darkdale* was a single hulled tanker with nine cargo tanks that were longitudinally divided into port, centre, and starboard tanks (creating a total of 27 smaller tanks) and a forward deep cargo tank. The tanker's total oil capacity was around 14,000 tons. Archival research revealed that the RFA *Darkdale* had been refuelled by a Norwegian tanker a few days before it was torpedoed, so it was highly likely that it sank with nearly full tanks.[1] Oil spill modelling indicated that an acute oil spill would impact local fishing and tourism industries so it was concluded that the risk must be mitigated (Liddell & Skelhorn, 2012). In early 2012 a team deployed to St Helena to assess the wreck's condition and its impact on the environment, and to prepare for an intervention.

A side-scan sonar survey confirmed that the wreck is broken in two sections; the bow section is completely inverted, and the stern section lies on its port side (Liddell & Skelhorn, 2012). An ROV survey inspected the condition of the hull and identified five cargo tanks that appeared intact and so could still contain oil. Since each tank is longitudinally divided into three smaller tanks there were 15 potentially intact tanks that needed to be hot tapped. All data gathered were combined with a model of the ship to estimate that 2800–4500 m^3 of oil remained on the wreck.

An initial environmental assessment indicated that the oil was not noticeably elevated in the water column, but it was accumulating in local sediments and occasionally exceeded European Quality Standards. Analysis of local fish and

[1] Logbook of Norwegian oiler M/T Egerø for the period 23 August—30 October 1941—details provided in a letter from the Riksarkivet—The National Archives of Norway dated 20 October 2011.

shellfish generally showed low levels of hydrocarbon contamination, but around 10% of fish sampled exceeded European Quality Standards indicating they could be hazardous to human health if consumed. A wider in-depth survey showed that hydrocarbon concentrations in fish were below the EU regulation safe limit (Cefas, 2014), but a no fishing zone was implemented around the wreck as a precaution.

In 2015 a team deployed to St Helena to remove the remaining oil. The island of St Helena lies around 7000 km south of the UK and there was no functioning airport on the island at the time making this logistically challenging. All equipment and personnel travelled by sea from South Africa, and three ships were brought in from various locations to support the operation. However, the wreck lies just within surface supply diving depth and the bow lying inverted made accessing the tanks straightforward. Initially the plan was to hot tap using a tool designed specifically for wrecks. This tool was lowered onto the wreck using a crane and positioned by surface supplied divers before suctioning on and drilling through the hull, but it turned out to be unsuitable for this wreck. Instead, divers used a manual hot tapping system then attached hoses to pump out the tank contents, all whilst being monitored by the ROV. Most of the tanks held Admiralty Fuel Oil but there was one tank holding aviation gas, and this had deteriorated over the years, presumably due to microbial breakdown (biodegradation), resulting in an acidic product. The operation was successfully completed with 21 tanks hot tapped and approximately 2000 m^3 of oil removed, significantly reducing the risk of a major oil spill from the wreck.

6.5.2 RFA War Mehtar

The tanker RFA *War Mehtar* was in convoy FS50 travelling from Methil to Harwich carrying 7000 tonnes of Admiralty fuel oil on the night of 19 November 1941 when it was hit by a torpedo from the German S-Boat S-104 on the portside. The crew abandoned ship and the tug *Superman* took *War Mehtar* under tow. A second tug arrived in the morning, but *War Mehtar* sank and now lies 15 nm east of Great Yarmouth at a depth of 45 m.

The captain remarked in his casualty report that fuel leaked into the engine and boiler rooms after the torpedo attack, but he did not believe it escaped into the sea. However, the rescued engine room crew were ‘black with oil’, suggesting oil was in the sea. There are also conflicting statements on the extent of the fire. Due to the uncertainty over oil loss the risk was cautiously assessed at full capacity of 7000 tonnes of oil. The potential high volume combined with proximity to shore flagged the *War Mehtar* as a high-risk wreck for further investigation. The *War Mehtar* has undergone several phases of investigation which are described in Hill et al. (2022) and associated reports.

Oil spill modelling predicted that in a worst-case scenario of a total release of oil, around half of it would end up on the shoreline. Some oil sheens and occasional slicks have been reported as coming from the *War Mehtar*, yet water and sediment samples collected from around the wreck did not contain unusually high concentrations of hydrocarbons, so pollution from the wreck does not seem to be accumulating in the environment.

An ROV survey in 2017 showed that the wreck was riddled with holes, but rudimentary tracking on the ROV meant the holes could not be attributed to individual tanks. When oil appeared to be leaking from the wreck in 2018 further investigation was required to determine the contents of each tank, which was done the following year using high resolution ROV-mounted multibeam sonar and neutron backscatter. Neutron backscatter is a technique by which neutrons are fired through a tank bulkhead and neutrons that are returned are measured. The number of neutrons returned depends on the density of hydrogen atoms in the tank, which varies between water and hydrocarbon, so it is possible to detect interfaces between water and oil.

A 3D model of the wreck was created from the multibeam sonar data and compared to data collected during a survey in 2014 to identify any changes to the wreck in the previous four years (WAVES, 2019; Lawrence et al., Chap. 11, this volume; Fig. 6.1). The ship's plans were laid over the 3D model to locate the extent of each of its seven longitudinally divided (port and starboard) oil tanks, as well as its bunker fuel tanks (Fig. 6.2). This meant that each tank could be assessed from the multibeam data and the ROV could be positioned onto each for an individual assessment with the neuron backscatter unit. The multibeam survey showed that nine of the 14 cargo oil tanks had holes and/or cracks and were therefore open to seawater, and the oil fuel bunker tanks had completely collapsed.

The neutron backscatter unit was calibrated against a breached tank before taking readings from apparently intact tanks. All readings indicated water, not oil, within each tank (WAVES, 2019). This evidence gives confidence that, although small volumes of oil are occasionally released from the wreck, there remains no large volume of oil that poses a significant environmental risk.

6.5.3 SS Derbent

The steam tanker SS *Derbent* was on a voyage from Liverpool to Queenstown (the former name of Cobh, Ireland, prior to the 1930s) with a cargo of 3700 tons of fuel oil on 29 November 1917 when it was torpedoed on the port side by U-96. The wreck lies 6 nm north-east of Anglesey, Wales, at a depth of around 45 m. Today, the wreck is regularly dived and in 2014 researchers at Bangor University completed a multibeam sonar survey of the wreck. It is lying on its starboard side facing south-east and, as of 2014, appeared to be intact with the oil tank hatches sealed.

The potential for the *Derbent* to contain as much as 3700 tons of oil combined with its proximity to the shoreline escalated the wreck as a priority for further investigation. There had been no documented oil leaks from the wreck, and oil spill modelling predicted that a major release of oil could impact the British coast and have a high impact on local marine life.

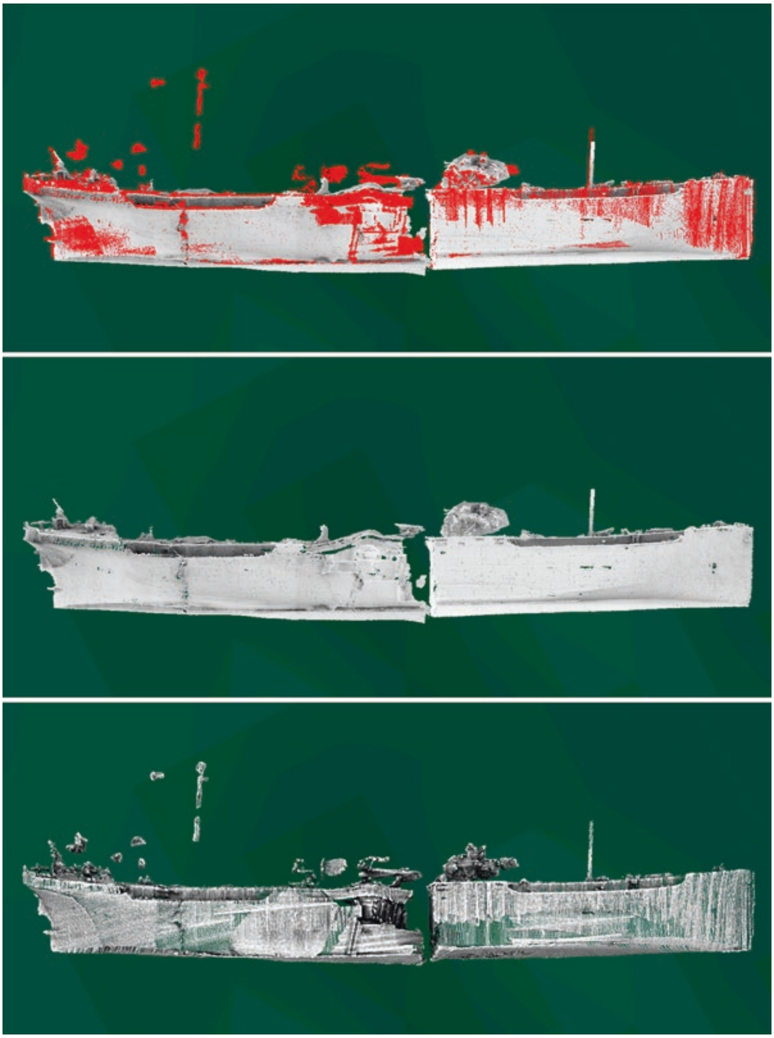

Fig. 6.1 3D model created from multibeam sonar data collected in 2014 (top) and 2019 (middle) and the two combined (bottom: 2019 data in grey and 2014 data in red) to identify changes in the wreck between the 2 years. (WAVES, 2019)

In 2022 a high-resolution ROV-mounted multibeam sonar and neutron backscatter survey was completed to determine the contents of each of the wreck's tanks, as was done on the RFA *War Mehtar* in 2019. The neutron backscatter survey indicated that each tank contained only seawater (WAVES, 2022). The multibeam data collected were compared to the 2014 Bangor University survey and showed almost total collapse of the wreck to one side (see Lawrence et al., Chap. 11, this volume). Despite the collapse, there were no reports of oil washing ashore in the region between the two surveys, suggesting the oil was released decades ago.

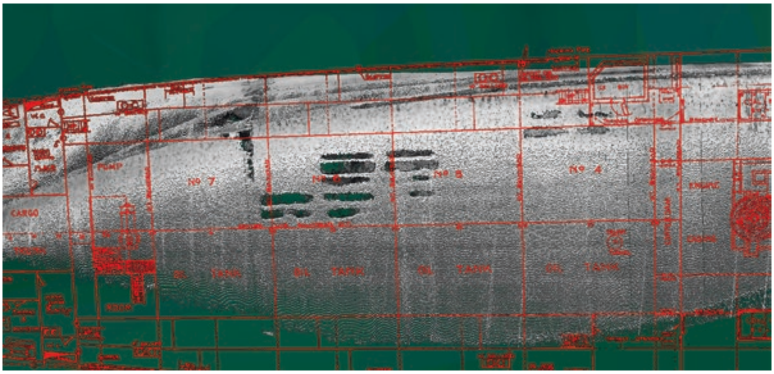

Fig. 6.2 3D model with general assembly plan overlaid, showing the bottom of No.6, No.5 and No.4 tanks with missing plating. (WAVES, 2019)

The significant collapse of the wreck demonstrates how potentially unstable wrecks are when lying on their sides, compared to upright or inverted. This has prompted further analysis of wrecks hitherto surveyed to look for patterns of ship attitude and level of deterioration.

6.5.4 HMS Prince of Wales *and HMS* Repulse

The battleship HMS *Prince of Wales* and battlecruiser HMS *Repulse* were sunk by Japanese aircraft on 10 December 1941 off the east coast of Malaysia. The wrecks were both designated as 'Protected Places' under the Protection of Military Remains Act 1986 (PMRA 1986) in 2001. However, this has proved difficult to enforce and, in fact, in international waters PMRA 1986 is only enforceable against British citizens or British-flagged ships interfering with the wreck. Consequently, the wrecks have been salvaged, along with other wrecks in the region including the Japanese Usukan wrecks (Holmes, 9 February 2017a), and HMAS *Perth* and HNLMS *Kortenaer* (Holmes, 3 November 2017b). Although not known for certain, it is generally assumed that the wrecks were targeted because they were built with 'prenuclear' or 'low-background' steel which is needed for the manufacture of Geiger counters and medical equipment (Manders, 2020).

There was naturally a public outcry at the damage to the last resting place of hundreds of crew: 327 on *Prince of Wales* and 508 on *Repulse*. There were also concerns of the impacts on the environment since the *Prince of Wales* and *Repulse* were believed to have each been holding 1000–3300 tons of oil, and the smash and grab techniques of the salvors took little account of the risk that this oil could be released. Oil spill modelling of acute oil spills from the wrecks predicted that south-east Malaysia could be impacted in the northeast monsoon period and southwest

Vietnam could become oiled in the southwest monsoon period. Satellite imagery captured oil leaking from the wrecks in 2014, but no reports of oil washing ashore were apparent.

A team deployed to determine the state of the wrecks and the likely remaining volume of oil in each. If there remained significant quantities of oil it would have been prudent to remove the remaining oil before the rest was released during salvage operations. Speaking with local wreck divers proved invaluable. Not only were they documenting the demise of the wrecks, but they knew their exact location which was most useful when the official coordinates turned out to be inaccurate.

The wrecks were surveyed using towed side-scan sonar and high resolution ROV-mounted multibeam sonar (Salvage and Marine Operations, 2019; Fig. 6.3). The imagery showed extensive damage to both wrecks, particularly *Repulse*, perhaps since it lies in slightly shallower water (54 m compared to 68 m in the case of *Prince of Wales*). In addition to causing oil spills, the physical damage to the wrecks resulting from the use of explosives and grabs has severely impacted the marine ecosystem that had developed around the wrecks. Photographs taken by recreational divers in the years prior to the salvage show that *Prince of Wales* and *Repulse* were once home to a diverse community of marine life, including corals and sponges, providing havens for small fish and food for parrotfish, manta rays and sea turtles. The explosives used to gain entry to the wrecks have dislodged the organisms that once encrusted them and removed the habitat. The hard coral now lies in bone-like fragments on the seabed; the wrecks are colourless and lifeless except for a few fish.

When the sonar images were cross-referenced with ships plans it was possible to identify which tanks could remain intact. Based on this, it was estimated that a maximum of 400 m^3 and 250 m^3 remained on *Prince of Wales* and *Repulse*,

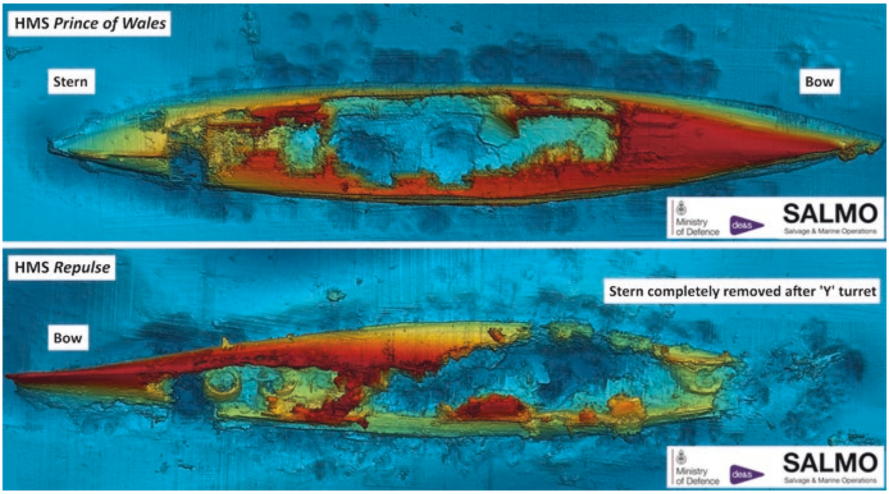

Fig. 6.3 Multibeam sonar image of HMS *Prince of Wales* (top) and HMS *Repulse* (bottom). (Salvage and Marine Operations, 2019)

respectively. This is a significant volume of oil, but there was evidence that more salvage had been occurring prior to our arrival, suggesting it was an ongoing process. It therefore seemed unlikely that significant quantities of oil would remain on the wrecks by the time an intervention could be planned and initiated.

6.6 Summary

Although wrecks have always been dealt with reactively in the UK, it is only since the 1990s that their environmental impacts have been considered, and since the inception of the Wreck Management Programme in 2008 that they have been actively managed. This relatively recent change to the UK's approach to wreck management is in response to changing sensibilities and understanding around the environmental and human health impacts of oil pollution in the sea.

Wreck management in the UK evolves as more is learnt about the subject area, including identifying gaps in knowledge. Assessing PPW in UK waters keeps the UK government busy but there is also a great feeling of responsibility to those living with British PPW in their waters overseas and an awareness that some people will be more impacted by a leaking wreck than others (Hill, 2021). The UK government does not adopt an out of sight, out of mind policy, and instead actively engages with the governments of nations where the UK has left behind legacies of war.

Despite attempts to proactively manage the risks associated with British PPW, the sheer quantity (around 10,000 wrecks globally) compared to available resources means that the proactive side falls far short of sufficient, and consequently much work is done in reactive mode. However, as demonstrated through the case studies, there is an ongoing programme of work that aims to mitigate risks before they materialise.

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