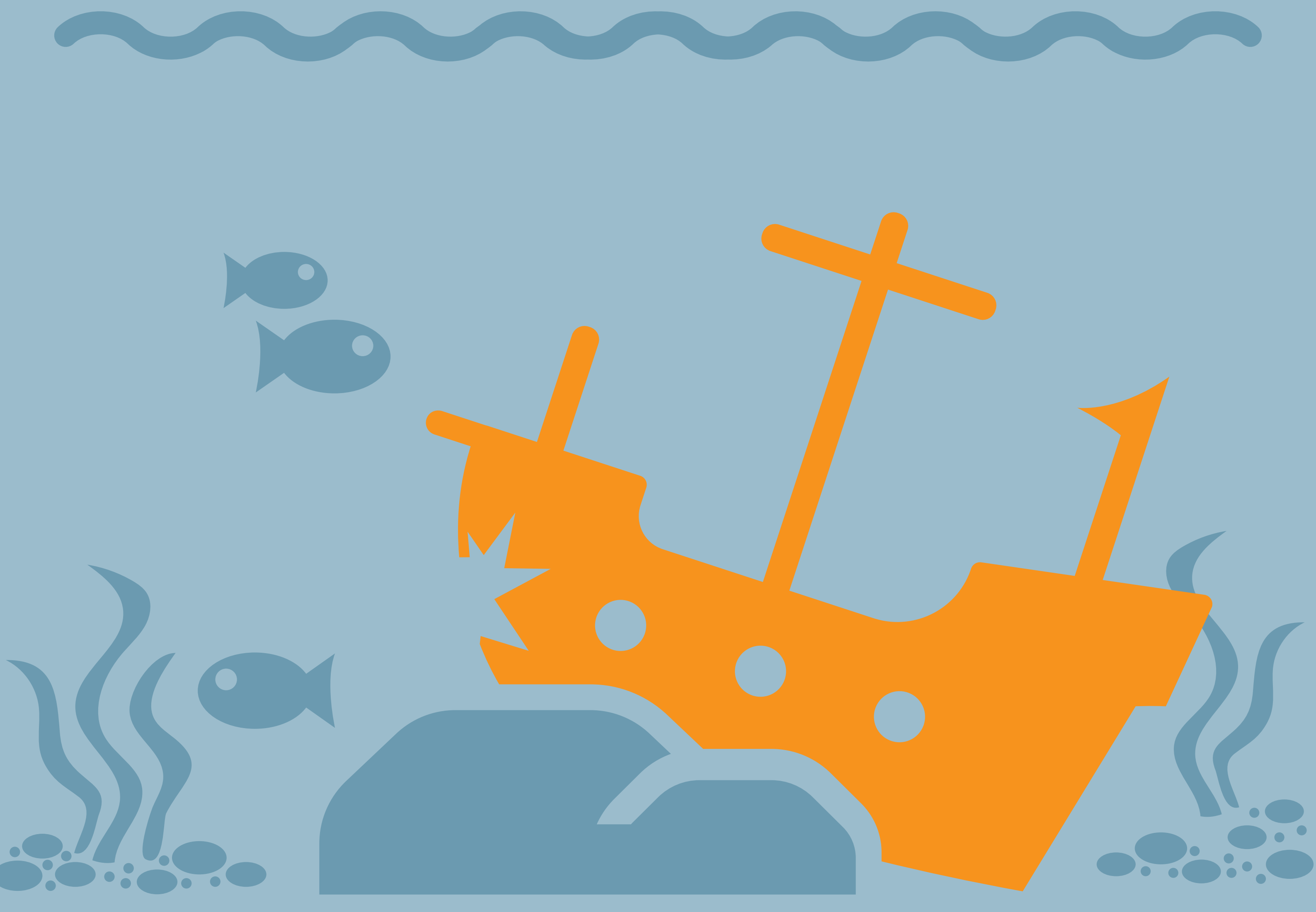
Baltic Marine Environment Protection Commission

Thematic assessment on Hazardous submerged objects in the Baltic Sea

Potentially polluting shipwrecks in the Baltic Sea

Shipwrecks

2025



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List of Abbreviations

AUV	Autonomous Underwater Vehicle
BAT	Best Available Techniques
GRT	Gross Registered Tonnage
BSH	the Federal Maritime and Hydrographic Agency of Germany
CEFAS	Centre for Environment, Fisheries and Aquaculture Science of the United Kingdom
CWA	Chemical Warfare Agents
DEEPP	Development of European guidelines for Potentially Polluting shipwrecks. DATABASE FOR POTENTIALLY POLLUTING WRECKS WITHIN THE MEDITERRANEAN CETACEAN SANCTUARY (EU Project 2004-2007)
DMSA	The Danish Maritime Safety Administration
DWT	Deadweight Tonnage
E-DBA	Environmental Desk-Based Assessment
ESRI	Environmental Systems Research Institute, Inc.
EUREF-FIN	European Terrestrial Reference Frame – Finnish 3-dimensional realization
FMIS	Riksantikvarieämbetets fornminnesinformationssystem. Information system for ancient objects having historic interest / Swedish National Heritage Board.
GESAMP	Joint group of experts on the scientific aspects of marine environmental pollution. Group of independent scientific experts that provides advice to the UN system on scientific aspects of marine environmental protection.
GIS	Geographical Information Systems
HELCOM	The Baltic Marine Environment Protection Commission
HoDs	Heads of Delegations
IOPAS	Institute of Oceanology, Polish Academy of Science
LOA	Length Overall of the ship
MADS	Map and Data Service of HELCOM
MaSiRi	Marine Site Risk Index
MBES	Multibeam Echosounder System
MFP	Naval Ferry Barge (marinefähr prahm). German 47 – 49 m long landing craft during the WWII.
NATO	North Atlantic Treaty Organization

NOOA	National Oceanic and Atmospheric Administration of USA
OSCAR	Oil Spill Contingency and Response (model by SINTEF)
ORO	Oil Recovery Operation
ORRA	Oil Removal Assessment Tool
PAH	Polycyclic Aromatic Hydrocarbons
RAUMBOOT	German type of minesweeper.
PPMS	Potentially Polluting Marine Site
ROLS	Remote Off-Loading System
ROV	Remotely Operated Underwater Vehicle
RULET	Risk Assessment Method for Wrecks by NOAA
RUST	Resources and Undersea Threats (NOAA)
SHIPWHER	Estonian Wreck Register, http://www.muinas.ee/shipwher-1
SBES	Sub Bottom Echosounder System
SIMAP	Integrated Oil Spill Impact Model
SSSS	Side Scan Sonar System
SwAM	Swedish Agency for Marine and Water Management. Havs och vattenmyndigheten (In Swedish). https://www.havochvatten.se/
SWERA	Sunken wreck Environmental Risk Assessment. EU BONUS project run in 2014 – 2016, https://www.syke.fi/projects/swera
SYKE	Suomen Ympäristökeskus. In English: Finnish Environment Institute
TAIFUN	Finnish Oil Suction System(s) onboard Naval Oil Recovery Vessels
TOR	Terms of Reference
UUV	Unmanned Underwater Vehicle
UWEX	Underwater Exploration Team. https://uwex.org/en/
VRAKA	A Risk Assessment Method for Potentially Polluting Shipwrecks, developed in Sweden

1. Introduction

Potentially polluting (or hazardous) shipwrecks are an emerging threat to the marine environment that has been given relatively small attention. A paper from the 2005 International Oil Spill Conference demonstrated that World War II (WWII) wrecks comprised the largest group of potentially polluting shipwrecks globally and were of particular concern because of their age. In the paper, it was estimated that there were 8,569 potentially polluting shipwrecks in the world's oceans and that 1,583 of those were tankers. 75% of the wrecks sank during the WWII (Michel, et al. 2005). More than eighty years later, these wrecks still pose a significant risk of marine pollution

Numerous warships that sank in the Baltic Sea were carrying hundreds of tons of bunker oil and were heavily armed. These shipwrecks are likely still filled with oil and other hazardous substances, in addition to containing naval mines, depth charges, and other munitions. Besides these naval vessels, numerous merchant vessels sank both due to military conflict and for other reasons, e.g., bad weather and load shift. Based on studies carried out on sunken ships and historical wrecks in the Baltic Sea area, there are thousands of old ships lying on the seabed. A large proportion of those ships are of archaeological interest and do not pose a hazard to the marine environment. However, the large amount of modern wrecked ships that used oil for propulsion and energy production poses an environmental hazard to the marine environment. Based on preliminary statistics, there are more than 1000 wrecks alone in the Baltic Sea area, which might still have large amounts of oil (as cargo or fuel oil) onboard that will cause significant pollution events in the case of an oil leakage. Most of these wrecks are WWII wrecks, probably heavily corroded and hence have a high probability of oil leakage into the environment (Pärt et al., 2015.)

Additional surveys in the Baltic Sea area also confirm the large number of wrecks. The Swedish Maritime Administration (Sjöfartsverket, 2011) identified close to 17,000 underwater objects in Swedish waters. Of these, 316 were identified as shipwrecks with a high probability of still containing oil. After detailed analysis, 31 wrecks were classified as an acute hazard to the marine environment. A similar analysis has been performed in Finland, where more than 400 wrecks in Finnish territorial waters were expected to contain oil, and 22 of them were classified to a high probability to contain more than 100 tons of oil (Rytkönen, 1999). The sea floor at the Estonian coastline also contains large numbers of shipwrecks, due to intense military operations during WWII. More than 700 wrecks have been detected in Estonian waters, only 84 of which have been identified. Of these wrecks, 14 were classified to have a potential for oil pollution. In 2024, the Danish Ministry of Environment published a study on the detection of historical wrecks with and without munitions onboard. The study stated that in Danish waters (including the North Sea, the Baltic Sea and the inner Danish waters), it is estimated that currently more than 10000 ship, submarine and aircraft wrecks rest at the seafloor, with many of these wrecks originating from WWI and WWII. In addition to bunker oil and fuel, oil-residues and other specific cargo, the war-related wrecks may contain large quantities of conventional and chemical warfare munitions (Andresen, 2022). Preliminary data received for this report also show a large number of shipwrecks in the eastern part of the Gulf of Finland, in Russian territorial waters, which also have potential for oil pollution. In addition, the coastal waters of Poland and Germany also contain many wrecks with potential for oil pollution.

Numerous events can result in oil being released from a shipwreck. The events can be split into three categories. The first are human activities that are directed at the shipwrecks specifically, for example, commercial treasure hunting and salvage, looting, and souvenir collection. Several of the activities have emerged in the last decades as a consequence of technological developments that now allow for the exploitation of areas where wrecks are located. The second category is human activities that affect the shipwrecks indirectly, for example, commercial fishing and offshore projects such as the placement of underwater cables, the construction of pipelines and other structures that are placed on the seabed. The third and last category is natural impacts, which include deterioration over time (corrosion), currents, tidal movements, and other natural physical, chemical, biochemical, and biological processes (Landquist et al., 2016, Peltokorpi, 2016).

As stated above, around 75 % of the wrecks containing oil sank during WWII. These have thus been on the sea floor for at least 80 years. The corrosion rate of steel in the Baltic Sea varies depending on several parameters, for example, the oxygen content close to the sea floor and the steel quality of the hull, but generally the corrosion speed is in the order of 0.03mm/year up to 0.07 mm/year (Sender, 2011). Thus, the steel on the hazardous shipwrecks may have corroded 2.4 mm – 5.6 mm. This process will eventually lead to a hole in the hull with the subsequent release of oil.

A shipwreck can release the contained oil in one singular event, for example, due to a human activity that leads to a large penetration of the hull or a collapse of the hull, or the oil can seep through small holes in the hull for a longer period of time. This might lead to other demands on authorities instead of a full-scale oil clean-up operation at sea and on shore. For example, continuous monitoring of the wreck site and where the oil ends up, and smaller clean-up operations that last over a longer period of time. The costs can, however, still be substantial.

A release of oil results in negative environmental consequences and economic costs, including environmental, socioeconomic, and clean-up costs. Rytkönen (1999) estimated that costs for underwater oil removal operations of shipwrecks are in the same order of magnitude as oil combating operations against surface oil slicks. In addition, Finnish oil combating authorities have recorded the cost of oil clean-up operations of the coastline of 16 000 euro/ton to 20 000 euro/ton. Lindgren et al. (2021) established that for oil removal operations from shipwrecks, the costs per ton of removed oil were far lower than the costs for oil clean-up operations of spilled oil in Swedish waters. Furthermore, these calculations do not include socioeconomic and environmental costs. Hence, proactive removal of oil from shipwrecks is a cost-effective approach to alleviate the problem. Another positive consequence, besides cost effectiveness, is that you negate the negative effect on the marine environment that would ultimately be the effect of the spilled oil.

The overall impact of oil on the Baltic Sea has decreased over the years. This can be seen in the HELCOM COMBINE monitoring program data (1977 - 2013) in surface sea water total oil concentrations, and as a decline in the annual number of observed illegal oil spills. However, eventually the volumes of oil contained in the more than 1000 shipwrecks in the Baltic Sea will be released and affect the marine environment. Today, there also exist local hot spots with elevated oil concentrations, usually in the sediment, due to leaking shipwrecks. Some known examples are the shipwrecks of Stuttgart and Franken in the territorial waters of Poland.

To conclude, addressing the problem of potentially polluting shipwrecks is essential to avoid new large oil spills in this already heavily impacted sea area. Performing oil removal operations is costly, but probably cost-effective. As resources are limited, it is necessary to perform investigations of the wrecks in a state’s territorial (and EEZ) waters, conduct risk assessment, and subsequent prioritization for remediation. To locate the resources towards the shipwrecks that constitute the largest risk to the marine environment.

1.1. HELCOM Expert Group Submerged

The Helsinki Commission (HELCOM) has acknowledged the need for options for solutions and an assessment of environmental risks posed by all types of submerged hazardous objects containing harmful substances, which may affect the environment, including wrecks containing oil (HELCOM, 2013). The HELCOM Expert Group on Environmental Risks of Submerged Objects (EG Submerged) has the task to develop and maintain, as well as monitor the application of, a HELCOM toolbox for assessment of site-specific environmental risks related to potential abandonment, relocation, and recovery or clean-up of dumped munitions and potentially polluting wrecks.

The Terms of Reference of EG Submerged were agreed upon by the HELCOM Heads of Delegation meeting HELCOM HOD 43-2013. EG Submerged worked under the supervision of the Response Working Group to compile and assess information about all kinds of hazardous objects and assess the associated risks. The Terms of Reference for the EG Submerged were renewed in early 2022 and span up to 2026 with a broader mandate, to finalize the Submerged Assessments for publication. EG Submerged consists of experts nominated by the HELCOM Contracting Parties and is open to observers according to HELCOM procedures.

HELCOM EG Submerged was chaired by Jacek Bełdowski (Institute of Oceanology PAN – Poland), Jorma Rytkönen (Finnish Environment Institute – Finland), and Fredrik Lindgren (Swedish Agency for Marine and Water Management – Sweden) during the development of this assessment report. The group convened several times to arrive at the results presented in this assessment report, under the supervision of the HELCOM Working Group on Reduction of Pressure from Sea-based Sources (WG Sea-based pressures).
While the terms of reference of HELCOM EG Submerged requested an assessment on various submerged hazardous objects, this report only covers the issue of potentially polluting wrecks. The thematic assessment on Hazardous Submerged Objects in the Baltic Sea - Warfare Materials in the Baltic Sea was published in 2024.

1.2. Objective and scope of the report

The present assessment report has the following three objectives, which are based on the ongoing work on potentially polluting shipwrecks (PPW) in the Baltic Sea:

1. Inventory of wrecks in the waters of HELCOM contracting parties (chapter 3).
2. Methods available for assessing the risks of potentially polluting shipwrecks and how to prioritize between wrecks (chapter 4).
3. Available methods for performing in situ investigations and oil removal operations of wrecks (chapters 5 and 6).

The assessment report focuses on PPWs in the Baltic Sea. There are a great number of shipwrecks in this enclosed sensitive body of sea, and the threat of oil spills from these wrecks is substantial. The report is structured in the following manner. The first part of the report describes various national and international measures to address the problem of potentially polluting shipwrecks. It also describes how the various HELCOM contracting parties address the problem, which national authorities are responsible for, and what databases exist that catalogue the problem and the type of information included. It also includes examples from contracting parties on performed risk assessment and oil removal operations. The second part of the report focuses on the various available methods for carrying out risk assessments of PPW and possible ways to perform in situ inspections of the wreck. Finally, it addresses how to conduct salvage measures on wrecks containing oil and various aspects that affect the salvage operation.

2. National and international measures to address the issue of potentially polluting shipwrecks

2.1. General

In a previously made compilation from 2010 (Svensson, 2010), it was concluded that the potential pollution from shipwrecks was an environmental issue, but one that received little attention. No research on pollution from shipwrecks in the Baltic Sea was found in database searches, and although the topic had been raised a few times, nothing had been done within the HELCOM framework (Svensson, 2010).

Today, each of the HELCOM Contracting Parties has national authorities that are responsible for addressing the issue of shipwrecks in some regard. However, even though response to oil and chemical spills is well coordinated and responsible authorities are well defined, the direct responsibility for proactively working to reduce the risk of hazardous shipwrecks is in most cases not well defined. In this assessment, a lot of information was made available, especially from Sweden and Finland, and the amount of data presented for individual contracting parties varies. This is partly due to a lack of available information but also because in some countries no authority is responsible for the management of wrecks.

2.1.1. Example – responsibilities of national authorities in Sweden and Finland regarding shipwrecks

Sweden currently has a large-scale wreck program, which includes historical and in situ investigations of wrecks, risk assessment and prioritization, and subsequent oil removal operations of polluting shipwrecks. The participating stakeholders have defined roles in this work, which is led and coordinated by the Swedish Agency for Marine and Water Management (SwAM). SwAM also performs the risk assessment and prioritization for oil removal operations of wrecks and controls the funding for the operations. Finally, the authority has competent and experienced contractors to carry out the oil removal operations under the framework agreement. Other participants in the workgroup are:

- The Swedish Maritime Administration performs hydrographic surveys to examine the status and position of shipwrecks. They are also responsible if a wreck is located in a fairway and constitutes a hazard to navigation, as well as for assigning a shipping company (insurance company) an oil or wreck removal operation in Swedish territorial waters or EEZ, according to the Nairobi convention. The convention entered into force in Sweden in 2018.
- Swedish National Maritime Museums and the Swedish National Archives contribute historical information regarding the ship and events during the wreckage.
- The Swedish Coast Guard and the Swedish Armed Forces (the Navy) assist where possible with diving and remotely operated underwater vehicles (ROV) to document and assess the status of shipwrecks. The Coast Guard is also the responsible authority for oil remediation in case of an acute oil spill in Swedish waters.
- Chalmers University of Technology develops the probabilistic risk assessment tool VRAKA.

The project can be a good example of cooperation between national stakeholders and making good use of a state's resources.

In Finland, the Finnish Border Guard is the responsible authority during an oil and/or chemical spill in aquatic environments. In the case of an oil leakage from a wreck, it is their responsibility to close the leak and recover the spilled oil. The Finnish Environment Institute (Syke) is responsible for monitoring and remediating wrecks that pose a risk of environmental damage, as well as organizing the care of animals affected by an oil or other chemical spill. The Finnish Heritage Agency is the authority in Finland that has the mandate to follow up archaeological wrecks and build monitoring systems to protect them. The Finnish Border Guard is also a partner in this protection work. Additionally, all war wrecks have been protected by the War Museum together with the Finnish Navy and Border Guard.

Starting from 2023, the amendment (963/2022) to the Environmental Protection Act (547/2014) clarified the responsibilities around shipwrecks (see 3.2.1). The current responsibilities of Finnish authorities in relation to potentially polluting shipwrecks are as follows:

- The Ministry of the Environment has the responsibility for the guidance, monitoring, and development of activities under the Environmental Protection Act (Environmental Protection Act (527/2014), Sec. 21). According to Section 2, Paragraph 4 of the Government Decree on the Ministry of the Environment (1286/2015, amendment 1176/2020), the tasks of the Ministry of the Environment include organization of the prevention of oil spills and other environmental damages, as well as compensation for environmental damages. Section 187 of the Environmental Protection Act (527/2014) obligates the Defence Forces to provide assistance, if necessary, in the task of monitoring and remediating wrecks that pose a risk of environmental damage. The Finnish Navy keeps the preparedness and technology for subsea operations and provides training for its personnel. Several oil removal operations have been conducted in cooperation between SYKE, the navy, and the Border Guard;
- The Finnish Border Guard, as a competent oil combating authority, has the responsibility for oil spill response. It also has a good possibility for surveying and has technology and trained personnel for a large variety of sub-sea operations;
- Traficom (Transport Safety Agency) coordinates new wrecks based on the Nairobi Convention. Traficom also assists operations if wrecks are situated close to shipping lanes or planned construction sites;
- The Finnish Environment Institute is responsible for monitoring and remediating wrecks that pose a risk of environmental damage, as well as organizing the care of animals affected by an oil or other chemical spill. (Environmental Protection Act Sec. 21 963/2022);
- The Finnish Meteorological Institute assists operations by delivering wind, wave, and current prognoses and modelling results; and
- The Finnish Heritage Agency has the responsibility for archaeological wrecks. Co-operation for monitoring and protection of wrecks is also the agency's priority. War wrecks are also protected by the War Museum.

2.2. International agreements

The United Nations Convention on the Law of the Seas (UN, 1982) includes the general obligation to protect and preserve the marine environment and the authority to act to reduce or control pollution, including the development of contingency plans. According to the Convention, nations also have a duty to “take all measures necessary to ensure that activities under their jurisdiction or control are conducted so as not to cause damage by pollution to other States and their environment, and that pollution arising from incidents or activities under their jurisdiction or control does not spread beyond the areas where they exercise sovereign rights in accordance with this Convention.”

The European Maritime Safety Agency (EMSA) works to provide technical and scientific advice in the field of maritime safety and prevention of pollution by ships and to provide support to, and facilitate cooperation between, the EU Member States and disseminate best practices.

2.2.1. Conventions for compensation of oil pollution damages

Compensation for pollution damage caused by spills from oil tankers is governed by an international regime under the auspices of the International Maritime Organization (IMO). The framework for the regime was originally the 1969 International Convention on Civil Liability for Oil Pollution Damage (1969 Civil Liability Convention) and the 1971 International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (1971 Fund Convention).

This regime was amended in 1992 by two Protocols. The amended Conventions are known as the 1992 Civil Liability Convention and the 1992 Fund Convention. These 1992 Conventions entered into force on 30 May 1996. The 1992 Fund Convention instituted the International Oil Pollution Compensation Fund 1992 (IOPC Fund 1992), a worldwide intergovernmental organization established with the purpose of administering the regime of compensation of oil damages[1].

The two Conventions can cover the compensation of costs incurred to minimize the potential risk posed by a shipwreck, but only in the case of recovery of persistent oil contained in a sunken vessel as cargo. The costs of any operations to remove the oil from the wrecks are admissible for compensation if they fit with the criteria laid down in the 1992 Civil Liability Convention and the 1992 Fund Convention. Additionally, the Bunker and HNS Conventions can cover the compensation of costs to minimize the potential risk posed by a shipwreck if it represents a “preventive measure”, the activities are reasonable from a technical point of view, and the balance of costs/benefits is adequate (Alcaro et al., 2007).

The International Convention on Civil Liability for Bunker Oil Pollution Damage was adopted in 2001, and the International Convention on Civil Liability for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS) was adopted in 1996.

2.2.2. The Nairobi Convention

The Nairobi International Convention on the Removal of Wrecks, 2007, was adopted by an international conference held in Kenya in 2007 and entered into force on 14 April 2015. The Convention provides the legal basis for States to remove, or have removed, shipwrecks that may have the potential to adversely affect the

[1] www.iopcfund.org/npdf/genE.pdf

safety of lives, goods, and property at sea, as well as the marine environment (IMO, 2007). The Convention introduces a definition for wrecks and its main focus is to resolve problems caused by wrecks in three basic cases:

- first, depending on its location, a wreck may constitute a hazard to navigation, potentially endangering other vessels and their crews;
- second, depending on the nature of the cargo, the potential for a wreck to cause substantial damage to the marine and coastal environments; and
- third, in an age where goods and services are becoming increasingly expensive, is the issue of the costs involved in the marking and removal of hazardous wrecks.

The convention provides a sound legal basis for coastal States to remove wrecks from their coastlines that pose a hazard to the safety of navigation, to the marine and coastal environments, or both. The treaty also covers the prevention, mitigation or elimination of hazards created by any object lost at sea from a ship (e.g., lost containers). It also covers a wide range of themes such as reporting, locating, and warnings, criteria for determining hazards caused by wrecks, measures to facilitate the removal of wrecks, liability of the owner for the costs of locating, marking, and removing ships and wrecks, and settlement of disputes.

The convention makes shipowners financially liable and requires them to take out insurance or provide other financial security to cover the costs of wreck removal. It also provides states with the right of direct action against insurers (IMO, 2007).

3. Wrecks in the Baltic Sea

3.1. General

The accessibility and accuracy of the wreck information vary among HELCOM contracting parties. Estonia, Finland, and Sweden have all collected a great deal of information on wrecked ships in their waters, together with some sort of prioritization of which wrecks constitute the largest risk to the environment. Poland, Denmark, and Germany also have registers of known wrecks, but the risk assessment and prioritization are yet to be made. In Latvia and Lithuania, the wreck issue has up till now been classified as of minor importance. However, the growing concern about the possible oil pollution has also raised interest there. Finally, in Russian territorial waters, there are a lot of wrecks having a high potential for oil pollution, but the interest from authorities seems to be low.

Usually, the existing wreck registers have been created and maintained due to safety reasons for the maritime traffic, to ensure adequate water depth is kept in shipping lanes. Besides official registries, there exist other sources of information, like databases and websites, that serve diving clubs and other enthusiasts. These registers and other sources can be used to identify and assist in the collection and completion of information that is needed to classify the wrecks that pose the highest environmental risk.

3.1.1. International wreck registers

Wreck Site.EU

The wreck site is the world's largest online wreck database. It has 206 780 wrecks, 176 360 positions, 73 530 images, 2575 maritime charts, 33 210 ship owners and builders amongst other data. Main sources of the information are based on the British Isles Hydrographic Service, United States Hydrographic Service, and practically all Hydrographic Services worldwide (Fig. 1).

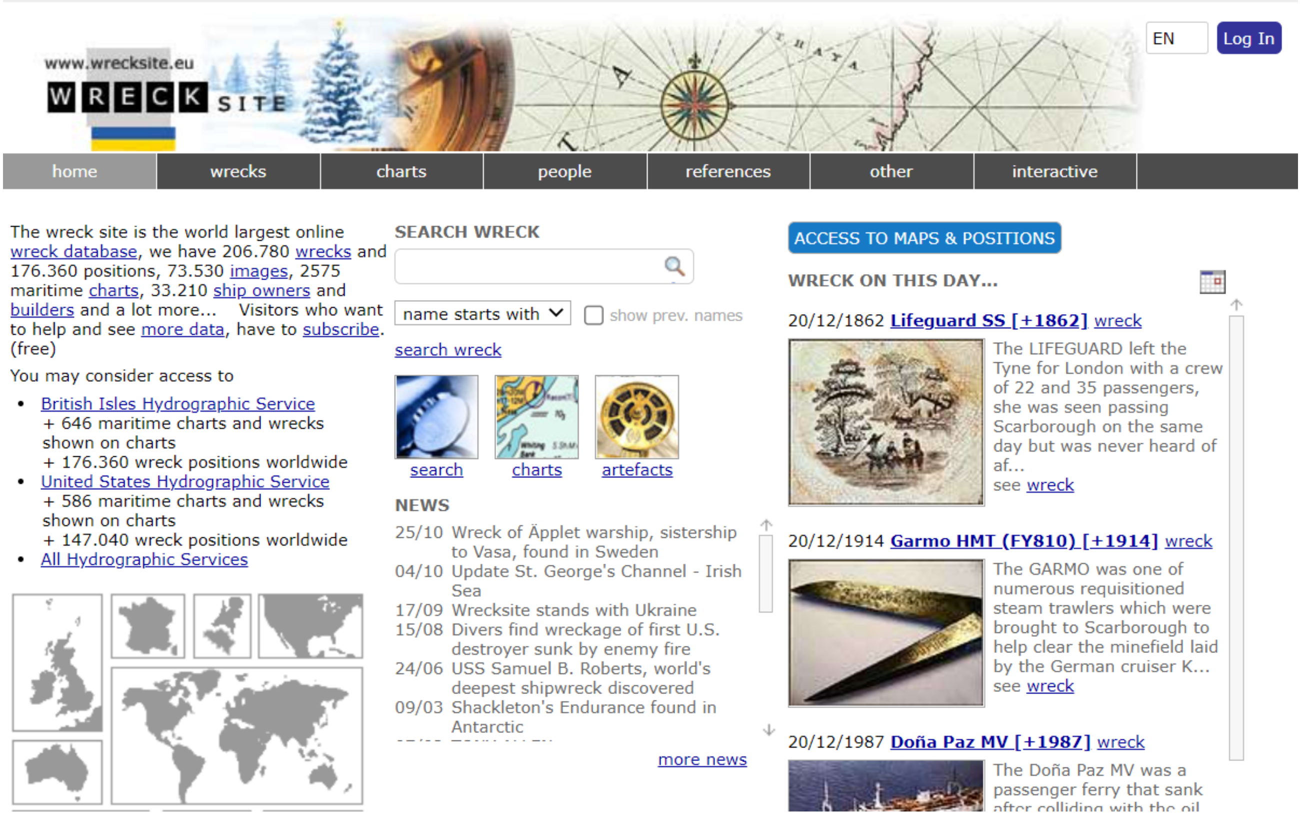


Figure 1. Homepage of the https://www.wrecksite.eu/Wrecksite.aspx.

Other wreck registers outside the Baltic Sea area

There are several wreck registers available around the world. Outside of the Baltic Sea region, perhaps the most well-known are:

- The NOAA Office of Coast Survey has more than 1000 maritime charts and 12 000 wrecks in US waters in their register (https://nauticalcharts.noaa.gov/).
- The Onroerend erfgoed has a database of hundreds of wrecks in Belgian territorial waters, all in very much detail with true maritime charts (https://www.maritieme-archeologie.be/).
- The website of a diving club off Dunkirk is covering all the wrecks in their geographic area and beyond. Many ships that sank during WWII are covered here in detail, including information for divers (http://dkepaves.free.fr/).
- The website from the Flemish Hydrographic Office has an online wreck database that can be navigated on a chart (https://www.agentschapmdk.be/nl/vlaamse-hydrografie/wrakkendatabank.htm).
- Uboat.net shows all the German U-boats from both World Wars, their commanding officers and operations, including all Allied ships attacked, technological information, and much more (https://uboat.net/).
- Wikipedia also has a list of shipwrecks classified by nation (https://en.wikipedia.org/wiki/List_of_shipwrecks_of_Europe).

3.2. Finland

3.2.1. Authorities and wrecks

Until 2018, the Finnish Environment Institute (SYKE) and the Ministry of the Environment had the responsibility for the prevention of oil leakage from wrecks. At the beginning of 2019, this responsibility was transferred to the Finnish Border Guard under the Ministry of the Interior. However, the duties of the Finnish Border Guard do not include monitoring or any pre-salvage surveys of wrecks. The amendment (963/2022) to the Environmental Protection Act (547/2014) at the beginning of 2023 clarified SYKE's statutory duties on this matter. According to the amendment, SYKE is "responsible for monitoring and remediation of wrecks that pose a risk of environmental damage, unless otherwise provided by law, and for organizing the care of animals contaminated as a result of oil or other chemical spills." The amendment (963/2022) also states that “The Finnish Defence Forces are obliged to provide assistance, if necessary, in the task related to the monitoring and remediation of wrecks that pose a risk of environmental damage, as stipulated in Section 21, subsection 4 of this law.”

SYKE is the leading institution in a cooperation between the Finnish Navy and the Border Guard in the work of monitoring and remediation of wrecks. When trying to identify a wreck or the origin of a mysterious oil spill, SYKE has been working closely with the Finnish Navy and the Border Guard, which have provided ships, divers, and equipment for on-site investigations and oil removal. SYKE has co-financed part of the equipment and diving gear used by the Navy and/or the Border Guard. Over the years, SYKE has also acquired important equipment for itself, necessary for research and surveillance of wrecks. The above-mentioned authorities have conducted several oil removal operations from wrecks in cooperation.

In a legal sense, wrecks can be divided into two categories in terms of the responsibilities related to these authorities:

category 1; the so-called new wrecks to which the Nairobi convention can be applied.

category 2; so-called old wrecks that are younger than archaeologically significant sites according to the Antiquities Act (wrecks over 100 years old), but which have sunk before the entry into force of the Nairobi Convention.

In this assessment, wrecks have been interpreted as sunken ships, whose method of propulsion or cargo has been based on oil, or that may contain significant amounts of other hazardous substances. In 1999, SYKE ordered a study from the Technical Research Centre of Finland with the aim of analysing the environmental risks of reported oil spills from shipwrecks, to develop a policy for the Finnish oil combating authorities (Rytkönen, 1999). It was emphasized in the study that due to the topography of the Finnish coastline, together with the sensitivity of the Baltic Sea, even small oil spills could result in serious negative consequences for the environment. The coastline is made up of many islands, and the seaways are often narrow and shallow. The Gulf of Finland is 400 km long. The mean depth is 37 meters, and the width varies between 58 and 135 km. An oil spill of only 200 tons of heavy fuel oil in 1984 affected an area of 2000 km^2, which included 200 islands and smaller shoals. The oil spill had a significant impact on the local sea bird population (Svensson, 2010; Mykkänen & Rytkönen, 1999). The report stated that shipwrecks with corroded fuel tanks could constitute a large threat to the environment and that the fuel oil can persist rather intact for a long time in the fuel tanks of shipwrecks.

3.2.2. Databases of shipwrecks

The Finnish Environment Institute (SYKE) has its own database of shipwrecks and has been collecting data on wrecks in Finland's water areas since 1987. The SYKE wreck register contains more than 1000 wrecks. Wrecks have been added after being discovered, confirmed by divers in connection with bathymetric surveys and cartography studies by the Finnish Maritime Administration, or through continuous surveys of the sea floor by side-scan sonar of the Finnish Border Guard. Wrecks have also been discovered during pipe- and cable-laying operations in the Baltic Sea.

In the SYKE wreck register, each object has a maximum amount of 73 describing titles/columns. Usually, only a few of these columns have been defined, and there are a lot of uncertainties to evaluate, for example, the amount of oil onboard and the actual status of the wreck. In addition, the number of known disappeared vessels in the area is high, so there are probably wrecks that are still to be detected. The exact location and the amount of oil remaining in the wrecks are unclear for many of the cases. For example, there are many wrecks from WWII situated in the eastern Gulf of Finland with unknown locations and possible amounts of oil on board (Jolma, 2009).

SYKE has made an updated version of the wreck register and merged it into a relevant GIS-based database. The first version of this new shipwreck register was published in February 2024 in the Border Guard's MERT system (Marine Environment Response Tool), which is an environmental damage response information system introduced in 2022. The material in this register is intended only for use by the authorities involved in environmental damage control.

The information on the wrecks added to the register has been updated, checked, and supplemented using the old wreck data from the Finnish Environment Institute. The work of updating the information of the wrecks in the register has also utilized literature, archives, and the wreck registers of the National Board of Antiquities and Baltic Sea countries. The aim is also to review the risk categories of the wrecks in the near future and add them to the register. The wreck information will be gradually transferred to the MERT system a few times a year.

The register information includes as comprehensively as possible the technical details of the wreck, its location, and the environmental risks it poses. In addition to the register information, an appendix has been created for each wreck, which includes a more detailed description of the ship's history and current situation. The appendix also includes pictures if possible. The wreck register will require regular updating and maintenance. In particular, the information on the highest risk wrecks should be monitored regularly and supplemented with, for example, ship drawings, 3D materials, and the results of water and sediment samples.

In addition, the Finnish Heritage Agency maintains an internet service where you can find information about relics in mainland Finland, including shipwrecks. Additionally, certain voluntary (recreational) diving associations with skilful crews have collected data on wrecks, especially related to WWI and WWII warships and submarines.

3.2.3. Risk analyses and prioritization

The Finnish 2005 Action Plan for the Protection of the Baltic Sea and Inland Watercourses provides the following statement, “Surveys of wrecks in Finnish waters should be conducted wherever there are risks of oil leakages. Oil must be safely removed from wrecks where risks are serious” (Finnish Ministry of the Environment, 2005, p.36). Most of the identified wrecks have been assessed and classified according to their potential environmental hazards. Several different methods have been used to assess the wrecks, and currently, a new risk assessment model is being implemented. Based on the risk assessments, SYKE has created prioritization lists of risk wrecks. Together with other Finnish authorities, SYKE also maintains a 'Top 5' list of high-risk wrecks, which is partially compiled based on these risk assessments. The existing risk assessment models are introduced in the following paragraphs.

In the past years, the risk classification of the wreck register has applied the system developed in Sweden, namely the VRAKA risk assessment tool (Landquist et al., 2016a and 2016b). According to this assessment model, there are a couple of dozen objects classified as high-risk wrecks in the SYKE wreck register, from which a priority list has been formed (Table 1). The priority list also serves as a work list in Finland, as it presents the wrecks that should be focused on.

Table 1. An old draft proposal for the prioritized wrecks in Finland. Some of the wrecks (Aluksen nimi - vessel name, Tyyppi -type of ship in Finnish) have already been the focus of oil removal operations or are now listed as non-hazardous wrecks.

Tyyppi	AluksenNimi	Ex nimi	Bunk+AB483+AB1:A+AB1:AB1079
MA	BEATRIS	Arild -73	14.0 tdo
MA	CERES		85engl.tn
HA	EIRA	Theodore Laurent	440m.tons
hävittäjä 7 lk	GNEVNYJ		540/548 tn
HA			140 tn
hinaaja/jäänmurtaja	HINDENBURG		
panssarilaiva	ILMARINEN		93 tn
MA	IRMA	Veslemöy-61,KariK.56	19.5tdo
miinalaiva	KÖNIGIN LUISE		katkennut – vain paravaani poistetaan
sukellusvene	M 98		17 t
sukellusvene	P 1 Pravda		93 tn
HA	PARK VICTORY		saneerattu
MA	RIEGEL	Twee Gebroeders-50	25t, tarkennetaan 2021
sukellusvene	S 5		n.200t
sukellusvene	S 7		100 t
sukellusvene	S 9 tai S 12		100 tn
sukellusvene	S 9 tai S 12		100 tn
sukellusvene	Shch 304 Komsomolets	Makrel	24.6 t
sukellusvene	Shch 305, Lin		58 tn
sukellusvene	Shch 308, Syomga		58 tn
sukellusvene	Shch 311, Kumzha		58 tn
sukellusvene	Shch 317		58 t
sukellusvene	Shch 322		58 t
sukellusvene	Shch 324		58 t
hinaaja	SIMSON	Terma -71	27.5tof, pyritään tarkentamaan 2021
hävittäjä	SMETLIVY		540t, katkennut useisiin osiin
hävittäjä	SUROVYJ		500t
MA	SVANSJÖ	Marga -63	15.0tdo
miinanraivaaja	T-206, Verp		96 tn
MA	TRANSLUBECA		137 tn
hävittäjä	Z 35, Bäthke		täysin hajonnut
hävittäjä	Z 36, Häusen		835 (tod n. 500 tn)
sukellusvene	M-103		17 t
miinanraivaaja	T-203, Patron		96 tn

The VRAKA risk model and the method ORRA (see chapters 4.3 and 4.5) have also been tested in the two-year EU-BONUS project (2014-2016) "SWERA", which was implemented in cooperation between Finland, Sweden, and Estonia.

After updating the SYKE's wreck register in 2024, the plan is to update the risk assessment model of the wrecks, too. The assessment model aims to be unified between Finland and Estonia, and the collaboration with Estonian actors has begun. The assessment matrix used in Estonia's risk wreck assessments will be applied in the assessments of the potentially polluting wrecks in Finland. Initially, the assessment matrix has been prepared based on the risk wreck assessment models of both the United States NOAA (National Oceanic and Atmospheric Administration) and the EU DEEPP (Development of European guidelines for Potentially Polluting shipwrecks) and adapted to Estonian conditions in the Baltic Sea. Therefore, it is reasonable to apply this risk assessment model in other countries in the Baltic Sea region, including Finland.

Using the assessment matrix, the wrecks are scored based on various factors, and according to the total score, they can be classified into low, medium, and high-risk categories. The matrix considers several factors, including the wreck's distance from shore, its age, the amount and quality of oil, munitions aboard, and the presence of ghost nets.

The scores are classified as follows: High risk wrecks: a value more than 60, Medium risk wrecks: a risk value between 25–59, and Low risk wrecks: a risk value below 25.

A risk level of 15 is assigned if a risk exists, but the information is insufficient to complete the matrix, or if the ship did not use liquid fuel, but it has munitions or ghost nets. The update of the risk categories of the wrecks in the register is intended to be completed in spring 2025.

Since a large part of the risk wrecks are warships, special attention needs to be given to the danger to humans that might be caused by explosives and ammunition when initiating any remediation work. The surrounding area of these wrecks must first be cleared to ensure safe working conditions. In this case, the deactivation of explosives and the risk analysis of the target before any oil removal operation are of key importance.

3.2.4. Other sources of wreck information in Finland

Wreck data received in connection with underwater inspections

Finnish Transport Agency and Meritaito Ltd. conducted surveys in 2000 – 2012 within Finnish territorial waters for ECDIS (electronic chart display and information system) purposes. During these surveys, 271 wrecks were found and later identified by divers. All survey data were provided to SYKE in Excel and in ESRI Shape format with geographic information. Data includes reports and images of all discovered objects, including coordinates of the wreck positions (Figs. 2 and 3).

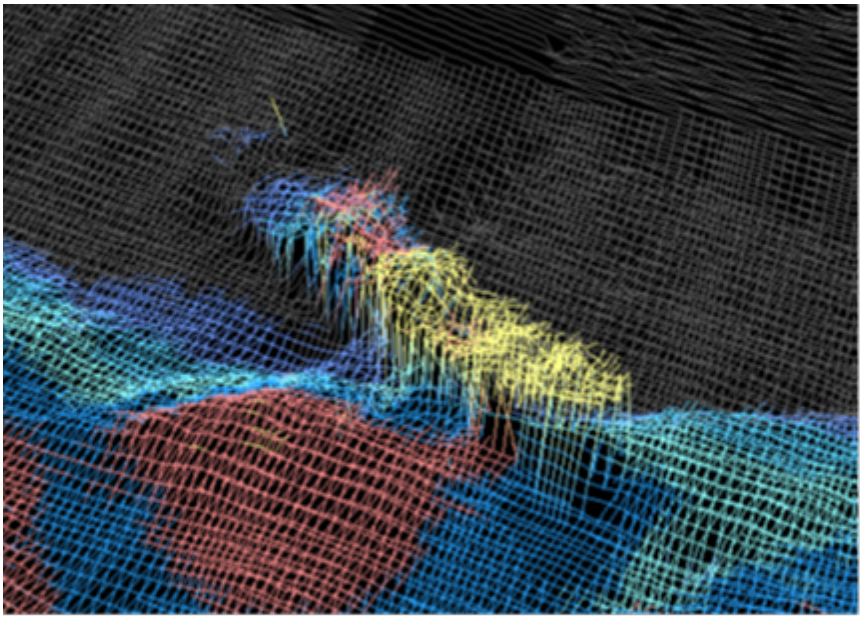


Figure 2. Example of wreck data received from the Finnish Transport Agency. The wreck is MS Ulf Jahrl, which wrecked on 29 January 1924, in the Gulf of Finland after hitting a mine. Ship length is 67 m, width is 9 m, and she is resting at a water depth of 55 m to 63 m.

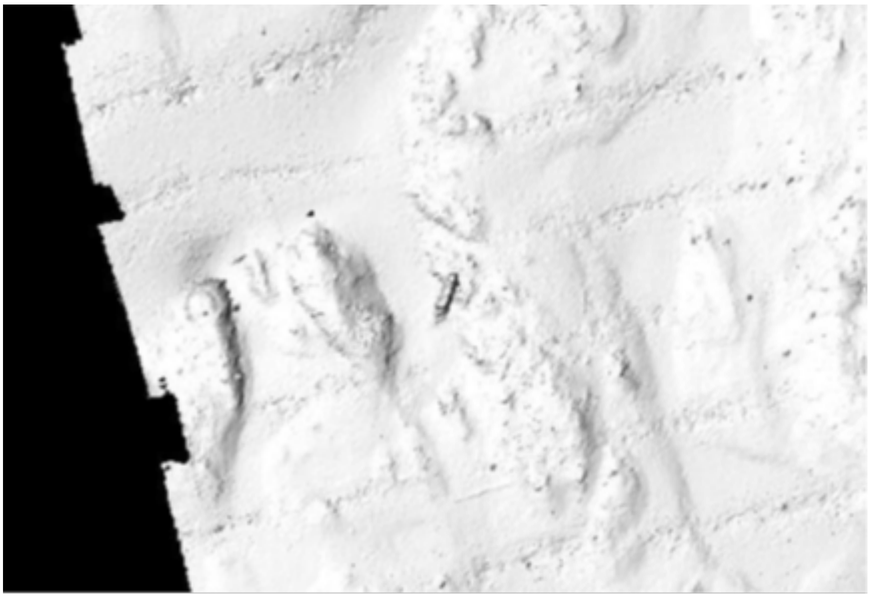


Figure 3. The image shows the location of MS Ulf Jahrl, with the wreck visible in the middle of the image. Confirmation of the wreck's identity through diving was performed in 2007.

Wreck information stored in hylyt.net

Hylyt.net[2] is an open shipwreck and wreck discoveries internet database, which covers the Finnish coastal and inland waters. It includes some 2358 wrecks. The aim of the service is to gather private persons' personal archives and discoveries of shipwrecks into one place to be used by all interested in maritime history and

[2] http://www.hylyt.net/

marine archaeology. The site has been running since 1999. Interactivity of the web page enables all interested parties to participate in updating and supplementing the information with their own wreck data. It also has a database search function and a map-based service (Fig. 4).

Figure 4. Example of the hylyt.net webpage.

The Finnish Heritage Agency

The Finnish Heritage Agency maintains an internet service where information can be found about relics in Mainland Finland. The register contains information about 1400 shipwrecks. Åland Islands are not included in the register. The relics can be searched by the name of municipality or by the name of item, as well as by type, age, or genre. The Finnish Law of Antiquities protects both terrestrial and underwater antiquities. Old shipwrecks are protected based on age. A wreck or part of a wreck that can be assumed to have sunk more than 100 years ago is equal to an antiquity. Such a discovery of a wreck must be reported to the Finnish Museum Agency without delay. If it is obvious that the owner has abandoned the wreck or a part of the wreck, it belongs to the state along with its belongings. This has a special influence on certain wrecks which may have pollution risks for the environment, i.e., especially warships from the First World War. Even if the majority of those ships were steamers using coal for propulsion, there were ships using oil for propulsion, such as submarines, for example. Old wrecks with their armaments (shells, explosives, mines, etc.) also pose a risk to the environment after corrosion has deteriorated the munitions, with the following release into the sea.

Recreational divers

There are a couple of skilful diving associations acting in the Baltic Sea area, which have very good data on specific wrecks, usually from WWI or WWII. Badewanne[3] is one of the most advanced of those associations, which have good-quality video and photos describing the targets. Badewanne has detected several old war wrecks and has then shared the data with authorities and relevant bodies. They usually also have the ability to

[3] www.badewanne.fi

dive deeper than the military or Coast Guard divers, thus new findings deeper than 65 meters have been identified and are well documented.

Another group of divers is "divers of the dark"[4] which have experience in both cave diving and wreck diving. Both diving associations have made presentations at diving conferences and shared their information among experts and professional divers.

3.2.5. Past oil removal operations – selected cases

Oil removal from S/S PARK VICTORY

Oil removal from the wreck of Park Victory was conducted during the years 1994 – 2000. The location of the wreck, offshore in open water, made it a challenge, and salvaging works often had to be interrupted due to bad weather, e.g., heavy winds and wave conditions. The American 9000 DWT freighter (Victory type) S/S Park Victory was built in 1945 (Fig. 5). The ship was loaded with coal when it sank in 1947 after being hit by a blizzard on her way from Newport, USA, to Helsinki, Finland. The ship broke in half and is now located at a depth of about 30-40 meters outside the island of Utö. Already in 1985, divers informed about the oil onboard, and oil leakage was detected in August 1994. At the time, about 35 litres per day leaked from the wreck. After two days, the holes were plugged by divers, but this was only a temporary solution. About 20 m^3 of oil from the settling tanks was then removed the same year. The volume of bunker fuel inside the wreck was estimated to be 600 tons. The poor condition of the wreck was an obvious threat to the environment (Svensson, 2010).

Figure 5. Typical Victory-class ship (SYKE, 2009).

S/S Park Victory differs from the ship in the picture by having a different kind of anti-aircraft defence platform. The wreck is broken in two at the front of the hatch of hold three, and the prow has moved 10,5 m to the right. Ice packs have knocked the foremast partially over the hatch of hold one. The left side of the bridge is also damaged by ice, and the left side mast is broken off. It has been moved outside the wreck. Figure 6 (sonar view) shows the wreck before the salvage operations.

[4] www.diversofthedark.com

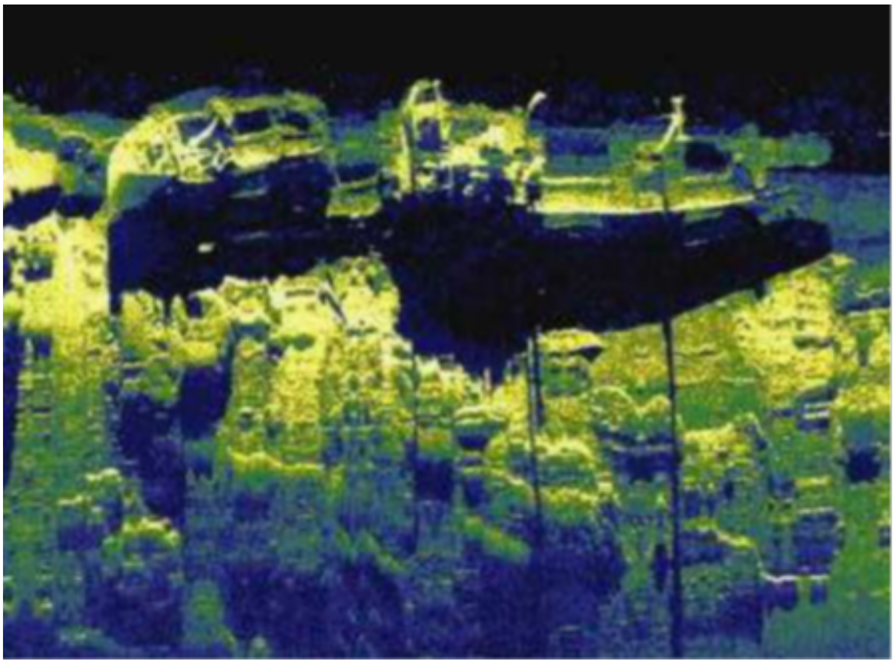


Figure 6. Sonar view of the S/S PARK VICTORY (Finnish Border Guard).

About 100 tons of oil had already been removed from the settling tanks prior to 1998. About 20 tons had been removed from the bottom tanks under hold three, and about 50 tons from the tanks under hold two. There was still oil in the bottom tanks, but the coal cargo situated in the cargo holds on top of the tanks had prevented its removal. The coal was therefore removed in the summers of 1997 and 1998 in order to be able to continue with the oil removal. Estimates of the amount of oil still left in the wreck varied. In 1998, the Finnish Ministry of the Environment authorized SYKE to continue with the oil removal operation of the wreck. The wreck was first cleared of debris, and some additional cargo was removed. Holes were then drilled into the fuel tanks in the double bottom, and suction connectors installed in the holes. More holes were drilled after removing the coal in the cargo holds. Removal of coal was necessary on the right front and back areas of hold three, and on the right side of hold four. In the drilled area, there was oil in three tanks under hold two, and in the right tank under hold three. The tank under hold five was found to be empty. After drilling holes into the fuel tanks, it was possible to pump oil from them, but only after heating the oil first. This was performed by injecting steam for some time into the tanks to lower the viscosity of the oil. During the oil removal operation in the years 1994 – 2000, a total of 410 m^3 of oil was removed from the wreck (Table 2).

Table 2. The annual amount of oil removed from the wreck Park Victory (SYKE, 2009)

Year	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**Total**
Volume (m^3)	20	80	0	20	50	95	145	410

The total amount of working hours during this period was more than 2 900, with approximately 1 200 diving hours. A ROV was used for a total of 1689 hours. The removal of the cargo took 547 hours of this amount. The oil removal costs, in year 2000 monetary terms, were approximately 52 marks per litre (860€/ton).

Oil removal from M/S ESTONIA

The passenger and car ferry Estonia sank in the Northern Baltic Proper on 28 September 1994. The Swedish government investigated the situation of the wreck and decided on 15 December 1994 that the wreck of Estonia would be covered to ensure the peace of the grave (Jolma & Mykkänen, 1996). Estonia is situated in international waters, but Finland is responsible for the oil combating and other oil pollution control in that area (the Baltic Sea is divided between the littoral states into such response regions). The problem was that covering the wreck with stone or concrete would prevent an oil removal operation, or at least make it difficult, but it would not prevent leakages when the bunker tanks finally corrode and start to leak their contents. The issue was discussed between representatives of Finnish, Swedish, and Estonian authorities in the spring of 1995. It was agreed that Sweden would include the removal of the oil as an option in the tender for covering the wreck.

The total amount of oil on board at the time of the wreckage was estimated to be 418 m^3, of which 302 m^3 was heavy fuel oil. The oil was located in thirteen tanks in the double bottom and in two deep tanks situated on the tank deck. These two tanks were attainable through the double bottom only and contained heavy fuel oil.

Oil removal began on 9 April 1996 and was finalized on 20 June 1996. Light oil (diesel) was removed from eight of the fifteen tanks under the operation. It was estimated that those tanks would contain 98 m^3 of light oil. The heavy fuel oil was removed using a total of eight hot-taps through the hull. Fuel oil residues were discovered during the work in the double bottom tanks, which also had to be removed. The work then had to be put on pause for some time due to several reasons, for example, the drilling tools had to be modified, and the work ROV experienced some trouble. After recommencing the work, the oil in the double bottom tanks was removed, about 30 m^3 of heavy fuel oil. In addition, another tank next to it was controlled for oil, but it was found empty; a settling tank and a day tank were emptied of light oil, although it was thought to be empty. After that, the equipment for drilling into the four double-bottom tanks containing heavy fuel oil arrived, and operating could start on this part of the oil removal operation. On all tanks, double bottom drills were installed on base plates on the bottom of the wreck. They were attached to docking stabs in the valve plate by a robot. The drills' bodies were tightened against the tank top with a bolt drill operated by the ROV. Thus, the body formed a protective piping through the double bottom. Next, the bolt drill, the ROV drilled a hole 76 mm in diameter in the tank top. The drill was withdrawn and replaced by a Taifun suction hose whose steam pipe was pushed into the tank. Then heating of the tank started, followed by pumping of the now pumpable heavy fuel oil.

When oil removal was completed on 20 June, thirteen of the originally intended fifteen oil tanks and two other tanks were emptied as far as possible. Altogether 230-250 m^3 of various oils were removed. In addition, the oil recovery vessel Hylje collected about eight m^3 of oil from the surface (Jolma & Mykkänen, 1996).

Other selected oil removal operations

During the last 30 years, Finland (SYKE together with the Finnish Navy and the Border Guard) has conducted numerous wreck surveys and oil removal operations. Even though the previously described operations on Park Victory and Estonia are the largest, other cases are worth mentioning.

M/S Coolaroo was a 5600 DWT freighter, built in 1956 in Gothenburg, Sweden (Fig. 7). She sank in 1961 outside Helsinki after leaving the Port of Helsinki with full bunker tanks. Based on the estimation of the amount of oil onboard she was classified as a Category 1 wreck, thus having a significant risk for oil pollution. Site surveys were performed at the site in 2001 – 2005, leading to the assessment that all tanks were empty. The wreck was covered by debris, gravel, and wooden items; thus, it took a lot of manpower and mammoth dredging to get access to the fuel tanks and investigate them for the presence of oil.

Figure 7. M/S Coolaroo (courtesy SYKE).

M/S Brita Dan sank in 1964 outside the city of Rauma and later began to leak oil. SYKE then, in 2003, conducted an oil removal operation which resulted in 20 m^3 of oil being removed from the wreck. The ship was a small coastal freighter, and it was assumed the fuel tanks were empty after the operation was finished.

In 2007, the old fuel barge Sisko, which sank during WWII outside the port of Hanko, was subject to an oil removal operation in shallow water (30-35 m). SYKE with the Finnish Navy drilled a series of holes close to the keel of the capsized barge and emptied the wreck. The total amount of oil and oily water (a mix of oil and water) removed from the wreck was close to 700 m^3.

In 2008, an inspection was conducted of a smaller coastal freighter M/A Jut'n Feldman. The ship sank outside Helsinki in 1953. The wreck is situated at a water depth of 45 m. The inspection was followed by an oil removal operation in 2010. The ship's single fuel tank was emptied of 4.5 m^3 of oil.

In 2018, the Finnish Government decided to allocate 69 million euros in funding between 2019 to 2023, to enhance water protection. As a part of the "Water Protection Program" around four million euros was allocated to reduce the environmental risks of shipwrecks. Within the frame of this program, SYKE arranged training courses for the specialists of the Navy and Finnish Border Guard to survey wrecks and to conduct oil removal operations. SYKE's surveying vessel ARANDA was equipped with modern surveying tools, such as side sweep sonar, bottom profilers, and a modern multibeam echo sounder to be used for wreck surveying. In addition, ARANDA, as a research vessel, has her own laboratory for analyses of various samples. Thus, the new surveying tools combined with the sample taking and analysis tools made it suitable for various wreck surveying tasks.

During this program, several surveying operations were carried out to study the conditions of selected priority wrecks. Additionally, a total of five wrecks were selected for oil removal operations.

Veli chain dredger

The first wreck selected for an oil removal operation within the governmental Water Protection Program was the chain dredger Veli (Fig. 8). The ship lost her stability during towing, capsized, and sank. The wreck is situated in rather shallow water, which reduced the difficulty of the work, as light from the surface helps with the visibility. The operation was carried out as a training exercise for the Navy divers.

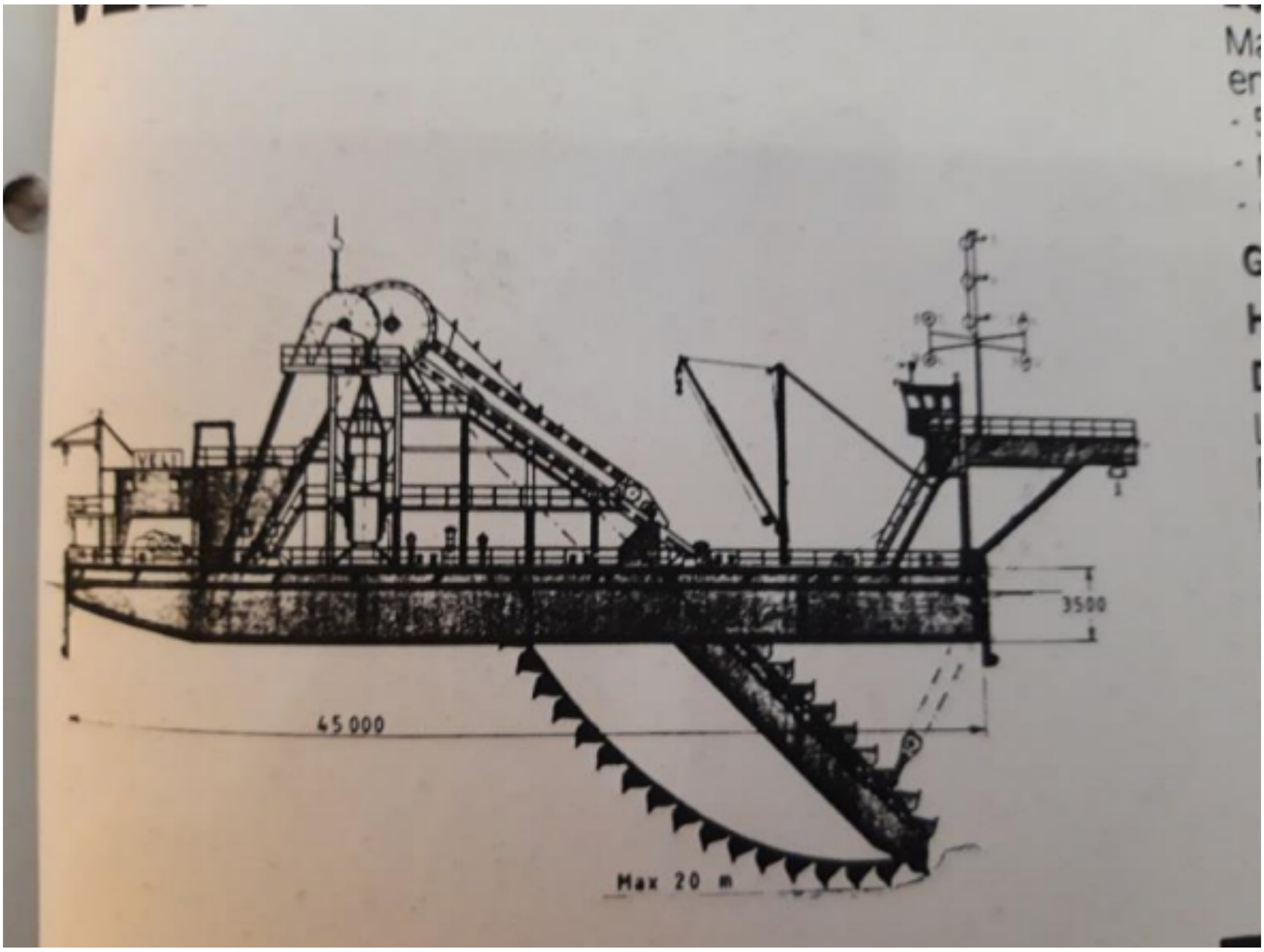


Figure 8. Veli Chain dredger. As almost all original drawings were lost, only sketches were left to illustrate the wreck (SYKE).

Before the operation, the wreck and surrounding area were surveyed using photogrammetry, which resulted in a 3D-model of the wreck (Fig. 9). Old inaccurate drawings of the vessel were then verified using this 3D-model. The locations of the fuel tanks could be found, and the operation planned, for example, places for the penetration points at the fuel tanks. The oil removal operation was carried out in autumn 2019, and the oil in the wreck was pumped using the Taifun-type suction system.

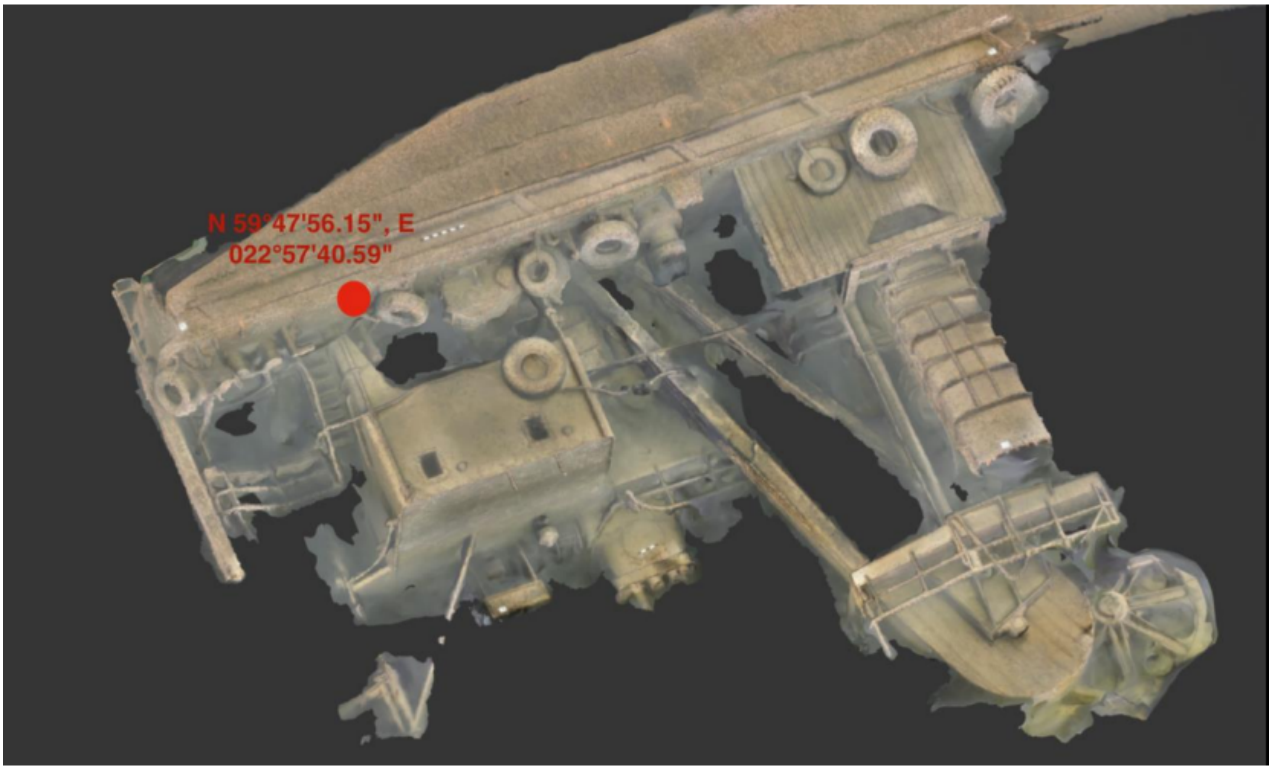


Figure 9. The 3D image of the VELI Chain dredger based on the photogrammetric model (photo: Jorma Rytkönen).

Hanna Marjut and Fortuna

During two weeks in August of 2020, the wrecks Hanna Marjut (Fig. 10) and Fortuna (Fig. 11), situated in the Archipelago Sea[1], were inspected and followed by an oil removal operation by the Finnish naval ship Hylje together with navy divers. The operation was coordinated by SYKE. Both wrecks are located close to each other, thus it was time- and cost-effective to perform the oil removal operation on both wrecks close together in time. The location of the wrecks is in the vicinity of shipping lanes and in the middle of the ecologically sensitive Archipelago Sea. Both objects were identified as high-priority wrecks, due to their situation in this sensitive sea area. Hanna Marjut, wrecked in 1985 with a full load of sugar beets at position (WGS84): 60° 04.910 N, 21° 02.864 E. The ship had a size of 499 grt, length 81.8 m, and breadth 9.6 m. Fortuna sank in 1987 also with a full load of sugar beets at position 60° 05 132N 21° 02 428 E. The size of the ship was 487 grt, length 52 m and breadth 8.9 m. The preliminary estimation of fuel oil onboard Hanna Marjut was around 10 m^3 of oil in a fuel tank located behind the cargo section under the superstructure. The tank had a capacity of 15 m^3. Fortuna was expected to have, based on the preliminary archive surveys, around 8-10 m^3 of diesel oil in fuel tanks situated on both sides of the bridge/machine room section of the stern.

Figure 10. Archive photo of Hanna Marjut.

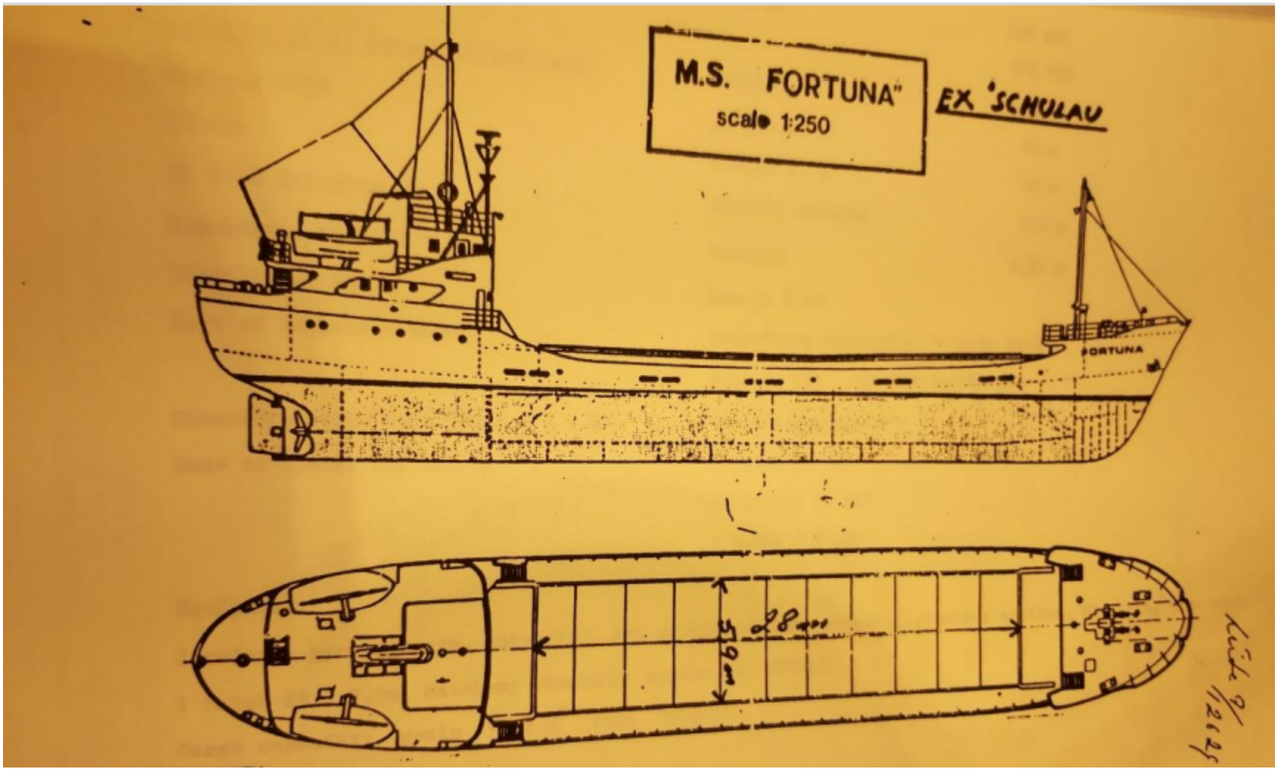


Figure 11. Archive photo of the GA plan of the MS Fortuna layout.

The oil removal operations on the ships were possible due to previous surveys of the wrecks. At the end of 2019, the wrecks were surveyed with SSBES (Sub Bottom Echo sounding System), MBES (Multibeam Echosounder System), and SSSS (Side Scan Sonar System) using SYKE's research vessel Aranda. In addition, a sea current profilometer was also installed close to the wrecks during the winter to measure the water currents in the area. Background samples were also taken from water and sediment in the vicinity of the wrecks for the detection of possible oil leakage from the wrecks. Knowing the water currents was important for the planned oil removal operation, in order to know the direction of a possible oil leak during the operation. The direction of the current was also an important fact when planning the positions for the sampling of sediment and water.

In spring 2020, using divers, 3D models of the wrecks and the surrounding areas were performed using photogrammetry (Fig. 12). A final survey was performed during the summer to continue the background sampling and create new MBES images of the wrecks (Fig. 13).

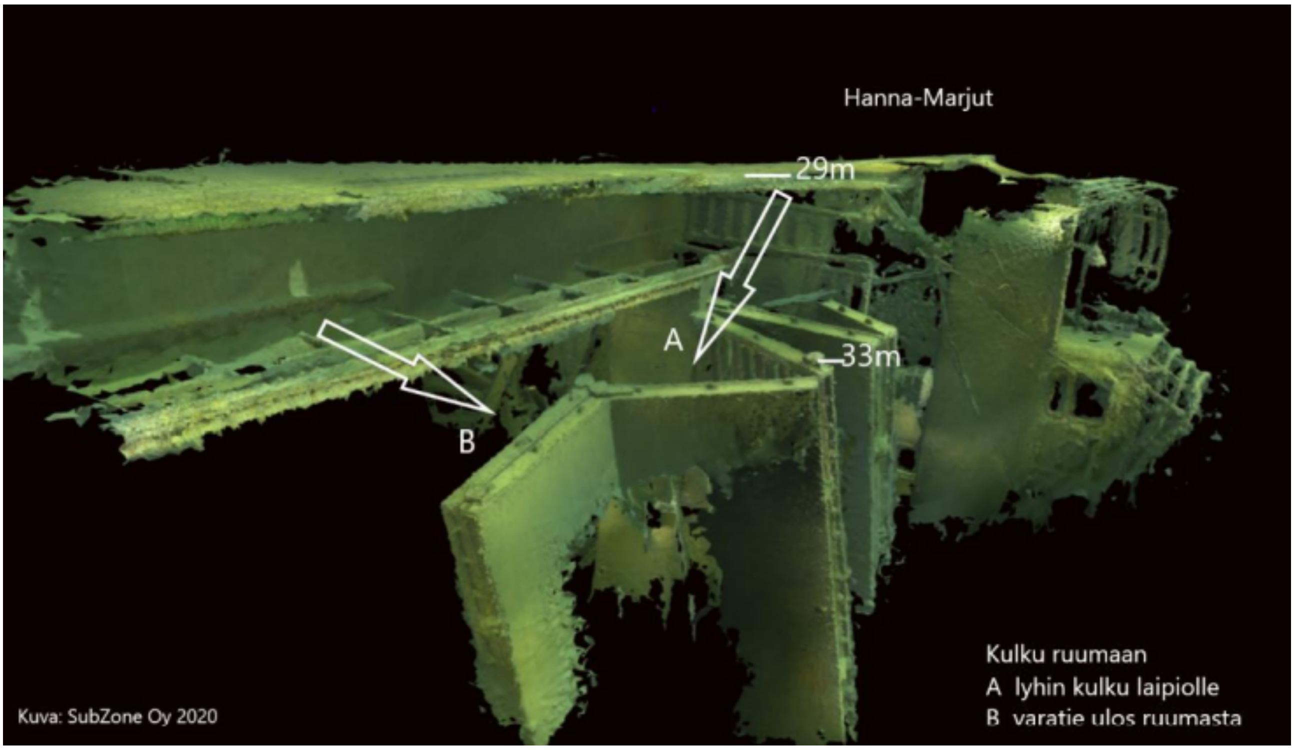


Figure 12. Details from the 3D image of the Hanna Marjut wreck. The image was then used by the divers to reach the cargo hold and fuel tank behind the end wall of the hold during the oil removal operation. Image by SubZone Ltd.

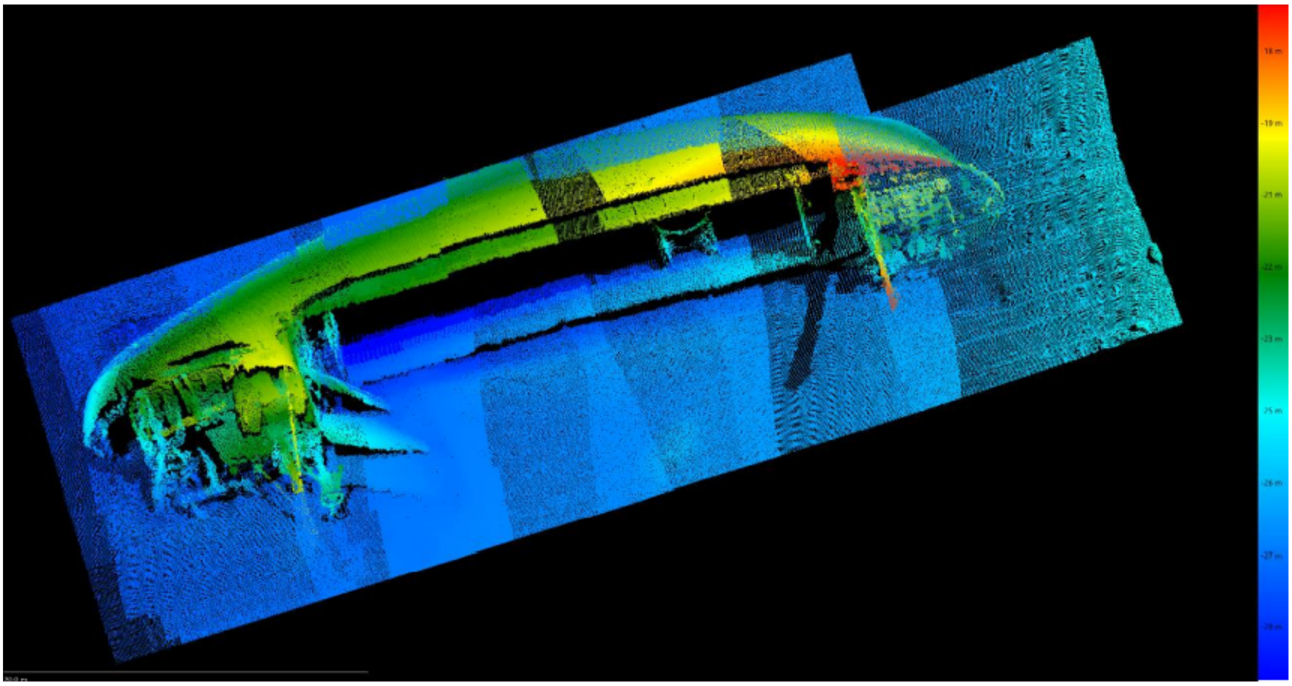


Figure 13. Multibeam image of the wreck Fortuna. Image by Jorma Rytkönen.

The oil removal operation in August 2020 lasted less than two weeks due to the well-made surveys prior to the operation itself. Due to the shallow water depth, the oil removal was carried out by Finnish naval divers from the naval oil recovery vessel Hylje. The sampling program prior to the work, during the work, and after the oil removal operation showed only minor contamination of oil. Thus, the operation itself caused no oil increase in the marine environment. However, during the oil removal from Fortuna, a small amount of diesel was accidentally released from the cargo hold at the bow section of the wreck. The origin of this small leak was a pool of free-floating oil inside the cargo hold, outside of the fuel tanks. The oil was collected using floating adsorption booms that were placed around the recovery vessel Hylje. A total of 3.5 m^3 of the oil was trapped inside the cargo hold, which originally leaked out through the damaged fuel tank through the vents after the sinking. More than 20 tons of oil and oily water were collected during the oil recovery operation. A report of the operation, including results of the sampling prior to the operation, is available (in Finnish) by request to SYKE.

Beatris

Beatris was a small coastal freighter that sank in 1981 close to the Finnish small city of Kustavi in the Archipelago Sea (Fig. 14). The wreck site was first surveyed by divers and later by Aranda's surveying equipment. The oil removal operation was conducted in October 2021 by a naval oil recovery vessel and divers. The water depth at the wreck site was 30 m, which enabled the use of divers.

Figure 14. Beatris disappeared/sank in November 1981 (archive photo).

At the time of the wreckage Beatris had a full cargo of gravel, which still was covering almost the whole cargo hold (Fig. 15). Based on the available archive drawings the ship's fuel tanks were bottom tanks under the cargo hold, thus the naval support vessel had to have special mammoth suction device to first remove the cargo in order for the divers to access the bottom tanks. During the operation, however, no oil was detected in the bottom tanks, and one of the hatches into the tanks was found open. The operation then concentrated on the end of the cargo hold, close to the bridge/superstructure of the vessel, as it was possible that some oil could be left in the tanks closer to the bow section. The aim has been to return to this wreck site, remove part of the gravel at this part of the cargo hold with the mammoth pump, and inspect the remaining tanks for the presence of oil as well.

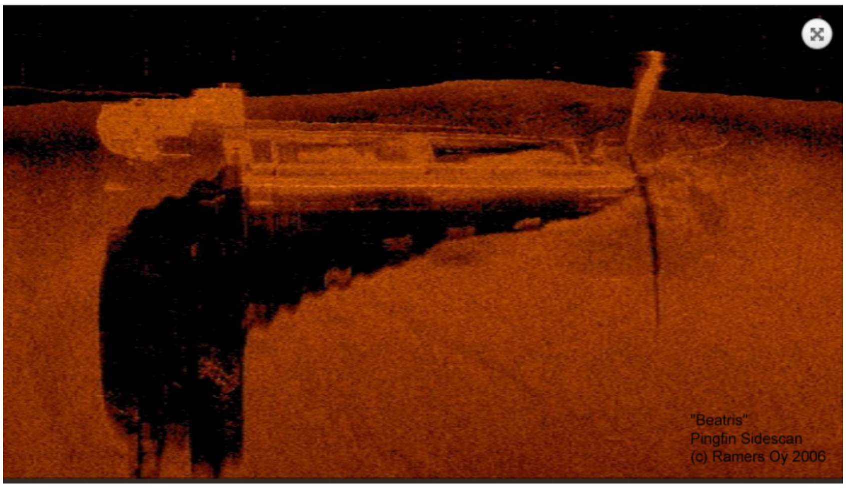


Figure 15. Older side scan sonar image of the Beatris. Note the cargo holds filled with gravel (photo: Ramers Oy, 2006).

Simson

Simson was towing a barge loaded with limestone (Fig. 16). Heavy seas and a heavily loaded barge slowed down the steaming and made steering difficult. On 20 September 1978, due to a strong side wind, both tug and barge hit a shallow southwest of the island of Utö. Subsequently, Simson sprang a leak and sank at a water depth of 60-68 m at approximately N 59° 40.450’, E 021° 29.550'.

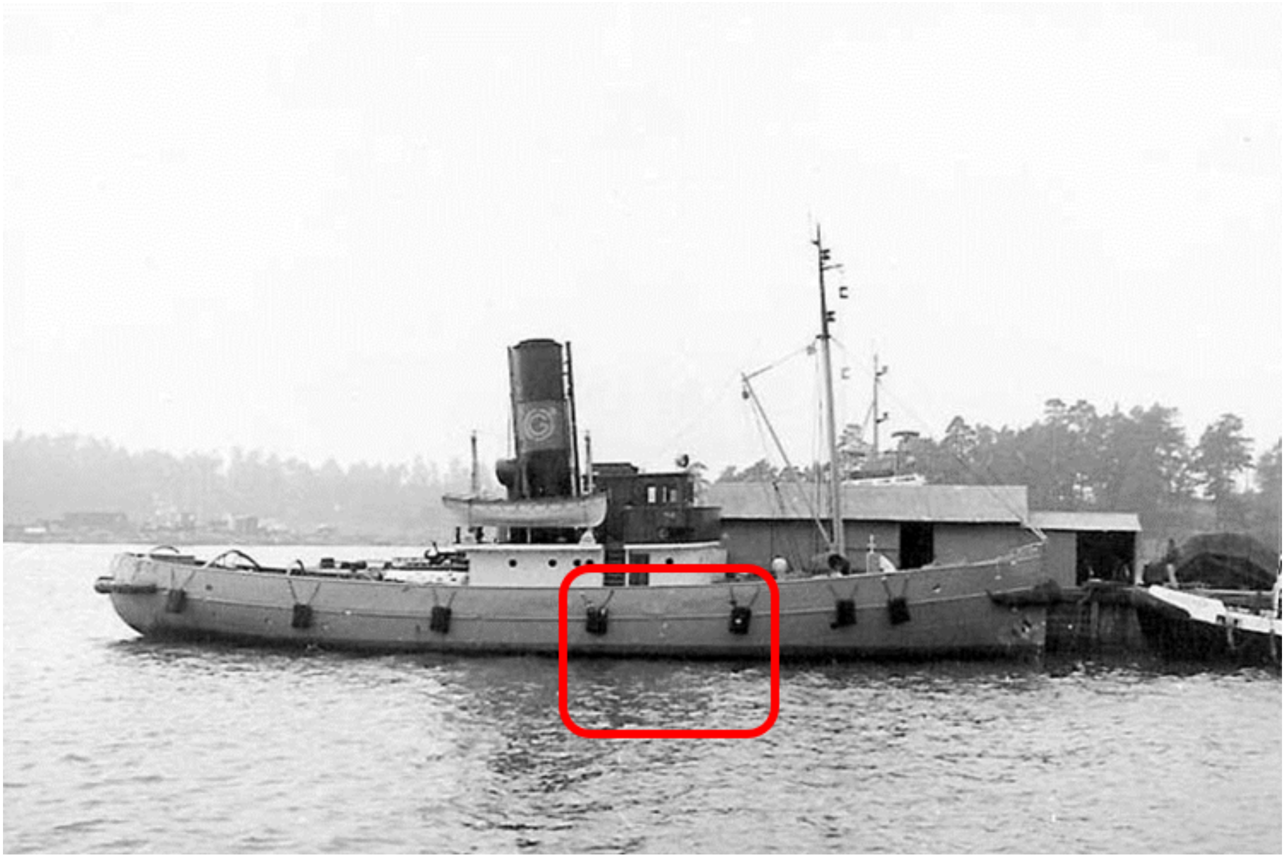


Figure 16. The tug Simson. The red square corresponds to the estimated position of the fuel tanks (archive photo modified by SYKE).

The engine room had two diesel engines with a small day tank midships, under the funnel and cabins. The bunker tanks are positioned on both sides of the engine room, slightly towards the bow section from the midship. The estimated amount of diesel fuel onboard at the time of the wreckage was 25 tons.

Initial surveys were performed by the SYKE’s ship Aranda, using hydroacoustic systems supported by ROV surveys. A 3D-model was prepared using photogrammetry to determine the positions of the fuel tanks. The result of the surveys showed that the wreck is buried four to five meters into the sea floor, which is made up of clay. To perform an oil removal operation on the wreck would require first carrying out a dredging operation at a depth of 65 m around the wreck to be able to access the fuel tanks. In addition, the 3D-model made it possible to detect damages to the fuel tanks’ air hoses, indicating that at least part of the diesel fuel had been released during the wreckage. Therefore, the planned oil removal operation was cancelled.

Ilmarinen

The coastal defence ship Ilmarinen (Fig. 17) sank in 1941, and its wreck has remained on the seabed for over 80 years. When Ilmarinen struck a sea mine off the shore of Utö on 13 September 1941, 271 marines were killed in the accident. The current estimate is that the tanks hold a total of 100 m^3 of light fuel oil. At the moment, the wreck is leaking a couple of drops per minute. The wreck is covered by a fairly thick layer of corrosion. One risk of the riveted hull is that it could split, which could result in a larger oil spill. This poses a significant risk to marine life and the environment. The Archipelago Sea National Park is near the wreck, and prevailing winds and currents would carry a potential oil spill towards the national park. Thus, Ilmarinen is planned to be the next oil removal operation. The sanctity of the grave is one important consideration when planning the investigations and the upcoming operation.

Figure 17. The photograph shows the battleship Ilmarinen on 18 August 1941, less than a month before its sinking (Photo by Vilho Heinämies, SA-kuva).

The operation was initially meant to be carried out entirely commercially. However, no suitable proposal was found to perform the work during the procurement process. Therefore, it has been decided that the operation will be carried out by the authorities instead. The goal is to extract the oil from the sunken vessel by 2026.

In the summer of 2023, initial surveys were conducted during a research expedition on the marine research vessel Aranda of the Finnish Environment Institute (SYKE). The aim was to determine the current condition of the Ilmarinen wreck and its suitability as a pilot site for commercial wreck remediation. The condition of the wreck's hull was examined using multibeam sonar and ROV imaging. Additionally, water and sediment samples were taken from the sinking site. Based on the data and drawings collected during the research expedition, SYKE created a 3D-model of the wreck. The investigation of the wreck continued in August 2024. The aim of the expedition was to investigate the condition of the vessel and the location of the fuel tanks. The results helped to shed light on how best to remove the fuel safely. The current state of the wreck was examined with the help of a remotely operated vehicle (ROV) and divers. ROV imaging was used to map out the locations of tanks containing oil, which will facilitate a potential oil extraction operation in the future. Imaging was also used to examine the condition of the hull of the wreck and the damage to it. The investigation also made use of remotely controlled imaging devices, hydroacoustic equipment, and ultrasound measurements.

3.3. Sweden

3.3.1. Database of wrecks and identification of potentially hazardous shipwrecks

A database of wrecked ships and known positions of wrecks has for decades been kept by the Swedish National Maritime and Transport Museums. This directory is now integrated into FMIS (Informationssystemet över fornminnen) information system for objects of historic interest (relics). This information about Swedish wrecks has been searchable on their webpage since 2008[5]. The following attributes can be found in the database:

1. Id
2. Last name
3. Earlier name
4. Flag state
5. Type of ship
6. Type of propulsion
7. Gross tonnage (BRT)
8. Dead weight tonnage (DWT)
9. Displacement
10. Year of construction
11. Warf/Place of construction
12. Type of bunker
13. Bunker capacity
14. Bunker consumption
15. Normal maximum speed
16. Armament
17. Cargo at wreckage
18. Owner of the ship
19. Owner of the wreck
20. Owner of cargo
21. Source of information
22. Pos Latitude Y
23. Pos Longitude X
24. Reference system
25. Positioning system / Information system
26. Land of origin

[5] https://app.raa.se/open/fornsok/

27. Region
28. Closest community
29. Length
30. Width
31. Year of wreckage
32. Height over the seafloor
33. Depth of object
34. Cause of wreckage
35. Last port of departure
36. Destination
37. Distance from departure port
38. Consumed bunker
39. Damage to the hull, status after wreckage
40. Source wreckage
41. Identified by NN
42. Submitted wreck observations
43. Report of leakage
44. Engagements on the wreck
45. Degradation status, corrosion factor
46. Last hull paint
47. Vulnerability
48. Class of risk (High, moderate, low)
49. Environmental consequences
50. Investigation permits

In 2006, a report was published within the framework of the EU project Forum Skagerrak II. It comprises the results from an inventory of potential hazardous shipwrecks along the Swedish west coast. 261 wrecks were identified as potentially hazardous. This is the first official report in Sweden that focuses on environmental issues from shipwrecks. Data was collected from databases such as governmental archives, private registers, and archives. Furthermore, diving clubs, diving forums, and fishermen were contacted during the project (Lindström, 2006). The year after, in 2007, the Swedish Agency for Public Management published a report on the legal rights and obligations for stakeholders to take control of, remediate, and move shipwrecks without an identified owner. The agency suggested that actions should be taken in three steps: 1. to perform an inventory of shipwrecks that are a hazard to the environment, 2. to perform in situ inspections of wrecks that constitute the highest risk, and 3. to develop and finance a program for oil removal operations on these wrecks. In 2011, the Swedish Maritime Administration (SMA) received a governmental remit to perform an inventory of potentially polluting shipwrecks in Swedish waters. In 2014, this was followed by another assignment, to develop a method for in situ investigations of hazardous shipwrecks and an assessment of potential environmental effects of shipwrecks, and finally to give suggestions for future actions.

SMA started with a database, mostly made up of objects from the FMIS database. In total 17 000 objects were included in the database. Firstly, a set of criteria for wrecks that can constitute a hazard to the environment was decided. These were:

- The wreck needed to have a registered tonnage of at least 100 gross tons.
- It needed to have been wrecked after the year 1900.
- The ship was propelled by oil, diesel, or similar, and still had fuel as bunker at the time of the wreckage.
- Ships that, according to information, had environmentally hazardous cargo were included even if they did not fulfil the criteria above
- Discharge or leakage of the hazardous products could cause environmental harm to the Swedish area of interest.

In total 17 000 objects were reduced to about 2700 objects after a first scan using the above criteria. In a second round, during a more detailed study of the available information on the objects, the list was reduced to about 316 wrecks. In the final round, after additional gathering of information, the list was reduced to 31 wrecks. The wrecks were classified to have a high probability of still containing oil, and external factors could affect the wreck, with a higher probability compared to others, resulting in a release of oil into the marine environment that could affect Swedish waters (Fig. 18).

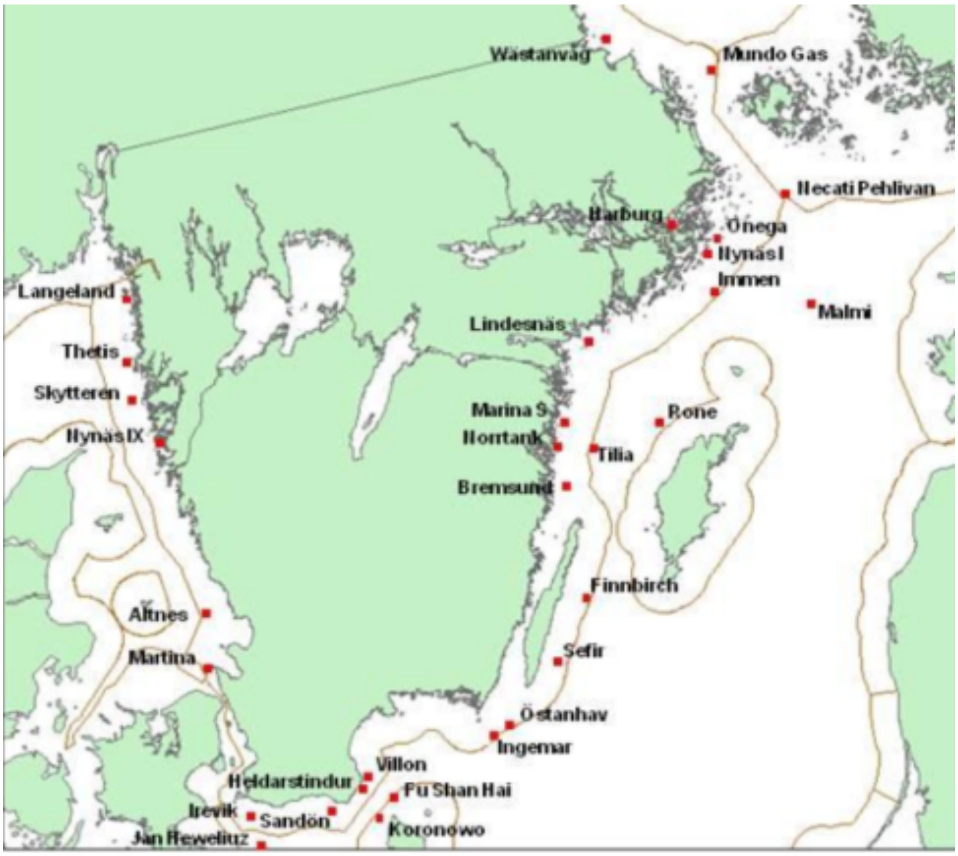


Figure 18. Overview of the position of the 31 shipwrecks that in 2011 were classified as environmentally hazardous in Swedish waters (SMA, 2011).

Finally, the Swedish Maritime Administration suggested in its report that the Swedish Agency for Marine and Water Management (SwAM) could be a suitable national authority responsible for handling a program for oil removal operations on these identified wrecks. In 2018, the Swedish government issued a 10-year program to reduce the risk of hazardous shipwrecks in Swedish waters. The funding is 2,5-4 million euros annually, and SwAM is the responsible agency for the work, which includes inspection and recovery of oil and ghost nets from prioritized shipwrecks. However, several other national authorities are included in the work:

- Chalmers University of Technology develops the probabilistic risk assessment tool VRAKA
- The Swedish Maritime Administration performs hydrographic surveys to examine the status and position of the shipwrecks.
- Swedish National Maritime Museums and the Swedish National Archives contribute with historical information regarding the ship and the wreckage.

- The Swedish Coast Guard and the Swedish Armed Forces (the Navy) dive and film the shipwrecks with remotely operated underwater vehicles (ROV) to investigate if they pose a threat to the environment. The Coast Guard also performs remediation operations in the event of an acute oil spill.
- SwAM coordinates the investigations and the recovery of hazardous substances and ghost nets. Competent and experienced contractors, with whom SwAM has framework agreements, carry out the work. SwAM also assists in developing new methods for the remediation of shipwrecks.

3.3.2. Risk analyses and prioritization for in situ investigations and oil removal operations, using the VRAKA model

In conjunction with the governmental remits to SMA, Chalmers University of Technology developed a risk analysis method for potentially polluting shipwrecks, called VRAKA. The VRAKA model is comprised of two main parts: (1) a tool for estimating the probability of discharge of hazardous substances from a shipwreck, and (2) approaches for estimating the consequences of such a discharge. The VRAKA model takes into account parameters affecting a shipwreck, e.g., corrosion and various human activities, which can result in a leakage of polluting substances. The analysis of the probability of a discharge of oil from a wreck is combined with a consequence analysis, including oil spill trajectory modelling and sensitivity of receptors that can be affected by the spill. Given the substantial uncertainties associated with risk analysis of shipwrecks, primarily due to a lack of data, the VRAKA model includes a comprehensive uncertainty analysis.

In the end, applying VRAKA to a number of different shipwrecks will allow for prioritization among the wrecks, i.e., to decide which wrecks pose the largest threat to the marine environment, and how certain the information about the wrecks is. It is also possible to tell where the most significant uncertainties in the analysis originate from, implying that it is possible to complement the analysis in a later stage if more data on the wreck is gathered. A more detailed description of the model and its use for wreck risk assessment can be found in Landquist (2016).

3.3.3. Past oil removal operations

Some of the 31 most environmentally hazardous shipwrecks in Swedish waters, described above, have been examined during the governmental remits and after SwAM became the responsible authority for the Swedish wreck program. In situ investigations are often carried out using multibeam sonar and/or photogrammetry. Several oil removal operations have been carried out since 2018. The plan is to remediate between one and three wrecks annually.

As part of the program is also to investigate the presence and environmental effects of dumped chemical warfare agents (CWA), as several wrecks with CWA are situated west of the island of Måseskär in Skagerrak. Another dump site is in the Gotland Deep in the Baltic Sea. Several exploratory fishing and sediment sampling have been performed in the Skagerrak wreck area over the years, degradation products of CWA have been found in both fish, crustaceans and sediment. The Baltic Sea dump site was studied in 2019 with the following results:

Exploratory fishing was performed near positions of mustard gas bombs in the Gotland Deep. Cod and flounder were caught and analysed, alongside sediment samples. Degradation products of CWAs were detected in two of the six pooled samples of cod caught in the area. The products found in cod were Clark I/II and Triphenyl arsine, products often included in mustard gas. All sediment samples contained products of CWAs, degradation products from Clark I/II, arsine oil and Adamsite. The quantities were measurable but below the limit of quantification. The results indicate that the area close to the dumped material is contaminated by the contents of the dumped CWAs. Fish in the area also contain, to a smaller extent, degradation products of CWAs. A more detailed presentation of the results can be found here.

As of 2024, oil removal operations have been carried out on ten wrecks in Swedish waters. In total, about 770 m^3 of oil and oily water and 16,8 tons of lost fishing gear have been removed from the wrecks. Updates of additional oil removal operations will be added to the SwAM webpage regarding wrecks[6]. In situ investigations have been carried out on these wrecks, but also on several others, for input to the risk assessment. The following is a brief presentation of the wrecks already handled in the program. During 2024, the shipwrecks Malmi, northeast of the island of Gotska Sandön, and Harburg, in the inlet to Stockholm, were subject to oil removal operations.

Thetis

The former fishing vessel Thetis sank in 1985 outside the island of Smögen (Fig. 19). Due to the fact that Thetis was one of the identified high-priority wrecks, it was selected as the first wreck for the program. She is lying at a depth of 30 m and is located near a sensitive archipelago, both in terms of the marine environment and recreation areas (beaches). SwAM led the work to recover oil and ghost nets from the shipwreck. The oil removal work was carried out in autumn 2017 together with the company Marine Works AB (Fig. 20). The initiative was possible with financial support from the Swedish Environmental Protection Agency. In total, 730 litres of oil were pumped up from the shipwreck and sent to the recycling company Ragn-Sells AB for destruction. Ghost nets around the wreck were also removed as a part of the project, about 12 tons were recovered. The cost of recovering oil and purse seine from Thetis amounted to SEK 5.7 million (around € 513 000).

[6] https://www.havochvatten.se/en/facts-and-leisure/environmental-impact/shipwrecks.html

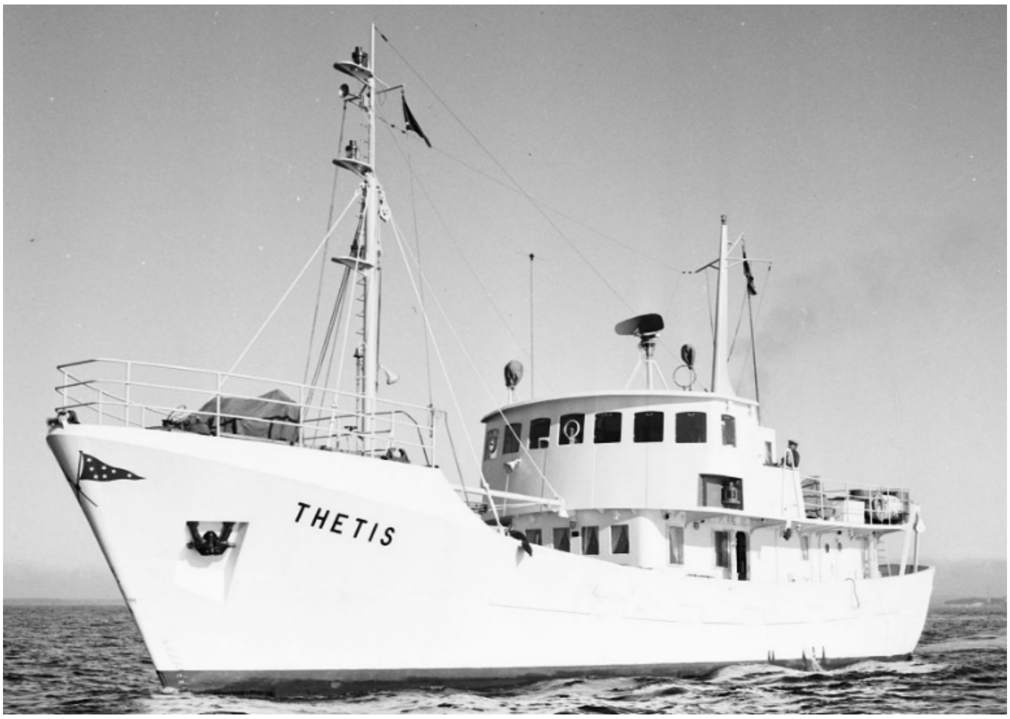


Figure 19. Fishing trawler Thetis. Photo by Varvshistoriska föreningen Karlskrona.

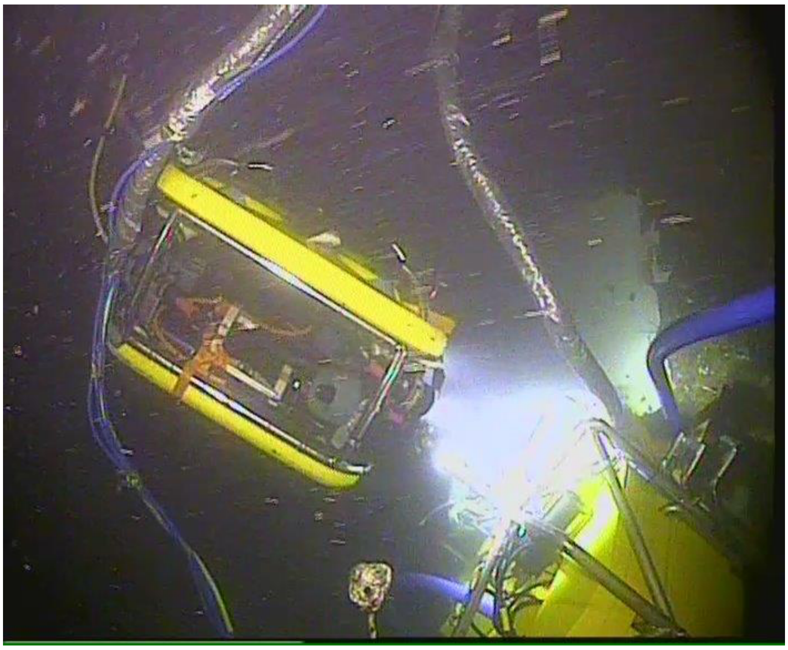


Figure 20. ROV used in the Thetis oil removal operation together with the Miko Marine Moskito system. Photo: Marine Works Ab.

Sandön and Hoheneichen

Both shipwrecks are located close to each other, about 12 to 22 kilometres straight south of the coast of Kåseberga (south of Sweden) at a depth of 18 to 30 meters with the keel pointing upwards. Since they were on the Swedish wreck priority list and also close to a nature reserve area, they were selected for a detailed investigation and oil removal operation in November 2018. Several holes were drilled in the hull at the location of the fuel and ballast tanks according to the drawings. Despite this, there was no oil detected in the wrecks, which indicates that the oil has leaked out over the years (Fig. 21). The recovery operation on the two shipwrecks Sandön and Hoheneichen amounted to a cost of SEK 5 912 000 (around € 532 000).

Figure 21. The hull of the shipwreck Sandön, notice the drilled hole in the middle of the photo. Photo: Marine Works AB/Secure Rescue & Safety AB.

Lindesnäs

The ship Lindesnäs wrecked in a snowstorm in 1957 on its way between Nynäshamn and Norrköping. It was loaded with 1 732 m^3 of kerosene. Lindesnäs was built in 1949 at AB Lindholmen's shipyard in Gothenburg. The wreck is lying on its port side at a depth of about 70 meters in an area where the sea-floor sediment consists of compact clay. The vessel weighed 1,265 gross tons and was just over 67 meters long.

During August and September 2019, SwAM led the work of investigating and removing oil from Lindesnäs, together with the Danish company JD-Contractor A/S, one of the seven companies SwAM at the time had a framework agreement with for removing oil from wrecks. The oil removal operation was performed using divers. Kerosene was found in four cargo tanks, and fuel oil was found in two bunker tanks and in the machine room. In total, 299 m^3 of oil was removed from the wreck. During the operation, the hull was penetrated in a controlled environment to avoid oil leakage. Thereafter, work began on emptying the tanks by pumping the oil from the wreck (consisting of kerosene and diesel) to a product tanker, due to the low flash point of kerosene (Fig. 22). The oil was then transported to shore for recycling and the amount that could not be recycled was sent for incineration. The project also included the removal of the ghost nets.

The recovery of the ghost net and the oil removal operation had a total cost of around € 2 million.

Figure 22. The fleet used for the oil removal operation (photo SwAM).

Finnbirch

The 156 m long and 22.7 m wide ro-ro vessel Finnbirch was built in 1978 by the Hyundai Heavy Industries shipyard in South Korea (Fig. 23). The ship was wrecked in 2006 due to a load shift of the cargo in severe weather. Two crew members died in connection with the accident. The wreck is today situated with the port side facing the sea floor at a depth of 83 meters, east of the Swedish island of Öland.

During the autumn of 2019, after the wreck suddenly started to leak oil, and during the summer of 2020, two oil recovery operations were conducted by SwAM. During the first operation, the diesel oil seeping from the leak in the hull was removed, and in the second operation, heavy fuel oil from two bottom fuel tanks was removed. During the operations, 60 m^3 of diesel and 88.2 m^3 of heavy fuel oil (HFO) have been recovered from the wreck, in total 148.2 m^3 (148 200 litres). In the operation, a specially constructed pump, dealing with the pumping of high viscosity substances, and heating using steam were used. When the pump and steam were used in combination, the contractor was able to salvage all of the hazardous oil from the two bunker tanks.

In total, the cost of the oil recovery operations amounted to approximately € 2.16 million.

Figure 23. Archive photo of Finnbirch.

Skytteren

The ship Skytteren sank on 1 April 1942, about ten kilometres from the Swedish west coast near the city of Lysekil. The water depth in the area is 72 meters. According to SwAM´s environmental risk assessment, Skytteren was ranked as number one on the list of the 30 most environmentally hazardous wrecks. A maximum volume of 400 m^3 of oil was estimated to remain in the wreck.
The ship was built in 1899-1900 for the shipping company White Star Line in Belfast and was named Suevic. After a number of years as a passenger vessel, she was sold to a Norwegian company, renamed to Skytteren and converted to a whaling mothership. During the invasion of Norway in 1940, Skytteren was held in arrest as a kvarstad vessel in the port of Gothenburg, Sweden[7]. On April 1, 1942, Skytteren and about ten other ships made an attempt to break through the German blockade and reach the allies in Great Britain with a cargo consisting of Swedish steel and ball bearings. The ship was shot at and damaged by the Germans. To avoid the valuable cargo being seized by the Germans, the captain chose to scuttle her.

Skytteren was first investigated in 2005 by the Swedish Coast Guard using ROV, the results presenting a general understanding of the general corrosion of the hull. In 2018, further studies of the general degradation of the wreck were performed by the Swedish Navy, using divers and a support vessel equipped with a diving wet bell. In addition, several ghost nets were found on the wreck during the investigation. Further investigations were performed in 2020, using an ROV with a high-quality camera. Photogrammetry was used to produce a 3D digital image and a digital elevation model (DEM) on the wreck (Fig. 24). This data was then used, in detail, to study the extent of degradation of the wreck, and also later during the inspection for presence of oil in, as well as in the

[7] https://en.wikipedia.org/wiki/Kvarstad_vessels

salvage operation of the oil. The results showed that even though the wreck was degraded with heavy corrosion in some places, it couldn't be excluded that the ship still contained oil. The stern is in worse condition than the rest of the wreck. There are several holes due to corrosion, but also a 4.2-meter-long crack in the hull. In this area, the hull has a depression with a difference of 90 centimetres compared to the rest of the hull. The bilge keel was also carefully examined, as this area is particularly interesting. Since the wreck lies on the side, the bilge keel is the highest point of the wreck, and therefore, where the oil may have accumulated if leaked from the bunker tanks. No holes or damage to the hull were discovered in this area.

Therefore, a third survey was conducted during February-March 2021 with the aim of discerning if, and where, the oil in the wreck was located. Divers performed about 60 penetrations of the hull at three different depths horizontally along the hull side. Where oil was found, a probe was inserted to enable a calculation of the lowest volume of oil in the tank in question. The penetration holes were re-sealed immediately after the examination of the tanks. Oil was found in five bunker tanks, in the machine room, and in the boiler room.

Finally, an oil removal operation of the oil in the areas of the wreck was performed from September 2021 to April 2022. This complex undertaking involved skilled divers and an ROV. During the operation, it was realized that the wreck contained a particularly viscous type of oil or that the oil, over time, had fractionated so that some parts were highly viscous. This oil then obstructed the pump responsible for transporting the oil to the tanks aboard the work vessel. This type of oil necessitated the deployment of specialized equipment, to heat the oil inside the wreck's tanks, rendering it less viscous and using a stronger pump, specifically a screw pump.

These altered operational conditions and non-favourable weather conditions resulted in an extended period before the work could be completed. Consequently, the project experienced delays and had to be temporarily halted during the winter months. It wasn't until April 2022 that weather conditions permitted the resumption of work. Following approximately six days of intensive diving operations, the salvage work could be completed. During the operation, divers penetrated the hull of the wreck at areas containing the oil, extracting it and using the pump to transport it to the work vessel at the surface. In total, 175 000 litres of oil and oil mixed with water were successfully pumped from the wreck. Additionally, the salvage team successfully cleared the wreck of six ghost nets, measuring a combined length of 120-180 meters, from the wreck.

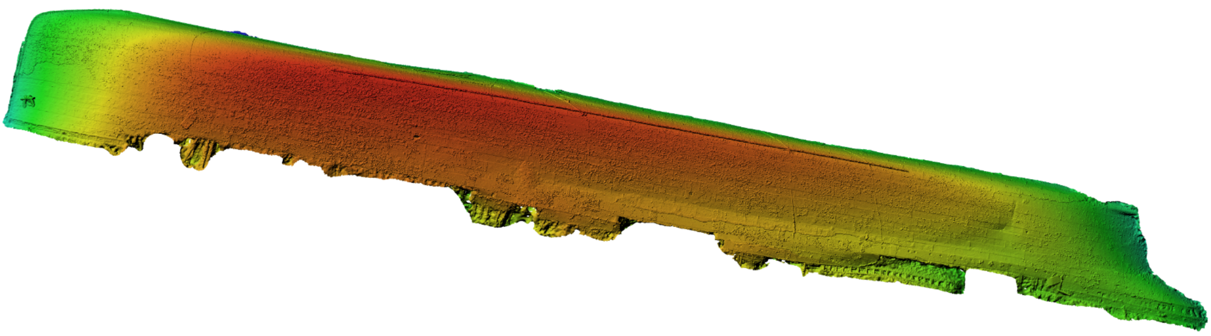


Figure 24. DEM of the wreck Skytteren (Ocean Discovery, 2020).

Rone

On 19 February 1981, the ship Rone was en route between Nynäshamn and the island of Gotland. The wind at the time was northeast, 10-15 meters per second, with moderate visibility. Reports from the wreckage describe the reason for the accident as water suddenly seeping into the pump room, which caused the ship to become too heavy in the bow and then sink. At the time of the sinking, Rone had a cargo of 209 m^3 of heavy fuel oil and approximately 0.4 m^3 of diesel for propulsion. There was no information about oil leaks during the sinking or from the years after the accident. The wreck lies today at a depth of 98 meters, about 15 nautical miles west of Visby, Gotland.

During an inspection by an ROV in 2017, the wreck was found to be in good condition. There was low corrosion on the wreck, and paint remained on the hull. There were also no visible holes or cracks that could be detected during the inspection.

In the fall of 2022, SwAM, with a contractor, began performing a detailed investigation and oil recovery operation from Rone. The technically complicated operation was carried out using an ROV and a remote-controlled robotic drill. All of the cargo tanks were inspected for oil presence. Oil was found in two of the cargo tanks. In total, 13 m^3 of pure oil and 57 m^3 of oil mixed with water (a total of 70,000 litres) could in the end be removed from the wreck. The wreck turned out to be more degraded than what could be seen in the inspection carried out in 2017. During the work, it was found that in some places on the wreck, especially the ventilation piping to the oil tanks, there were holes that were only covered with layers of paint. There was also an inward bend in the hull at tank pair five, which was found to have cracks, from which oil likely had leaked over the years.

3.4. Estonia

3.4.1. Authorities and wrecks

The responsibility for managing wrecks is divided between different Estonian authorities, depending on the status of the wreck. Modern wrecks that wrecked in recent years and that pose a threat to the safety of navigation fall under the responsibility of the Estonian Transport Administration. Historic wrecks and underwater cultural heritage (UCH) in general fall under the Estonian National Heritage Board, and marine oil spill response is the responsibility of the Estonian Navy. In addition, the Ministry of Climate (formerly the Ministry of Environment) is involved in managing potentially polluting wrecks.

In 2016, the Estonian Ministry of Climate commissioned a desk-based assessment of wrecks in the Maritime Administration’s wreck database (see below). The assessment was updated in 2021. Some of the positions of identified wrecks were updated, threat assessments were revised in the light of new information, and new wrecks that had been found were added to the register and assessed. In 2020, the Estonian National Heritage Board (NHB) procured another desk-based assessment to assess sunken vessels from the 20th century that included both known wrecks and those that have not yet been found. From 2018 to 2023, the Ministry of Climate commissioned environmental assessments of the following wrecks: Soviet submarine Sch-408, German torpedo boat T-18, Soviet destroyer Smelõi, Soviet cargo ship Ruhnu, and British light cruiser HMS Cassandra. In addition, in 2023, the Estonian Environmental Investment Centre completed a project funded by Nordic Environment Finance Corporation where three potentially polluting wrecks were assessed - German torpedo boat S31 (WWI), German torpedo boat T-22 (WWII) and German minesweeper M37 (WWII).

3.4.2. Wreck database

The most comprehensive wreck database in Estonia is the Transport Administration, Department of Hydrography's Hydrographic Information System (HIS), which contains all known wrecks in Estonian waters (including the EEZ). This database is constantly updated as new wrecks are found and new information (e.g., identity, history) about a wreck becomes available. The database is accessible to everyone on the internet.

The National Heritage Board (NHB) has two databases of wrecks. One is specifically for cultural heritage, which also includes underwater cultural heritage. The other database, called the wreck register, is dedicated only to wrecks. The latter includes wrecks that have not been found and wrecks with confirmed locations, and is based on archival research. The register[8] was developed within the framework of a three-year project "Shipwreck Heritage: Digitizing and Opening Access to Maritime History Sources" (SHIPWHER). The project was launched in 2010 and was carried out in collaboration between the Estonian NHB, the National Archives of Estonia, the Estonian Maritime Museum, and the Swedish National Maritime Museums. The project was financed by the European Regional Development Fund via the Central Baltic INTERREG IVA program. The register contains information on more than one thousand shipwrecks, mainly in Estonian waters. The information was collected by accessing various historical archives, through fieldwork, but also from newspaper articles published in the Netherlands, Tallinn, and Riga. Information in national archives mainly originates from the Estonian Historical Archives of the National Archives, State Archives, and Tallinn City Archives. Information from international archives was mainly collected from the National Archives of Sweden, the National Archives of the Netherlands, Lübeck City Archives, and the Amsterdam City Archives. In addition to this central database, information about shipwrecks in Estonia can be found on webpages intended for recreational divers and diving tourism. The database[1] currently (March, 2025) contains 705 objects (wrecks).

There are additional sources for information about shipwrecks in Estonian waters, for example, diving clubs and recreational divers who present their findings on webpages. These webpages mostly contain information about wrecks already included in the other databases, like HIS or NHB's wreck registry, but they contain photographic material as well as other details. In some cases, observations have been made over several years or even decades, which provides a possibility to follow the change of condition of a shipwreck.

Identification of environmentally hazardous shipwrecks

During a desk-based study commissioned by the Estonian Ministry of Environment (now Ministry of Climate), 65 wrecks (Fig. 25) were identified as potentially environmentally hazardous. Available data regarding the wrecks included basic information on the ship and historical records about the wreckage and other relevant information. However, due to a large number of unidentified objects (232) and a lack of in situ investigations, the total number of hazardous shipwrecks in Estonian waters may increase or decrease, as more wrecks are investigated. The Estonian wreck register mainly contains basic information about the wrecks. Information like the amount of oil onboard at the time of the wreckage or potentially hazardous cargo is scarce. Pärt (2015) carried out a detailed study of wrecks in Estonian waters and initially identified around 25 wrecks that were classified as potentially polluting. These are presented in detail in Pärt et al. (2015) and in Figure 25.

[8] http://register.muinas.ee/?menuID=en_wreckregistry&page=1&_nocache=1408705748
[1] https://his.vta.ee:8443/HIS/Avalik?REQUEST=Main&WIDTH=1920&HEIGHT=919

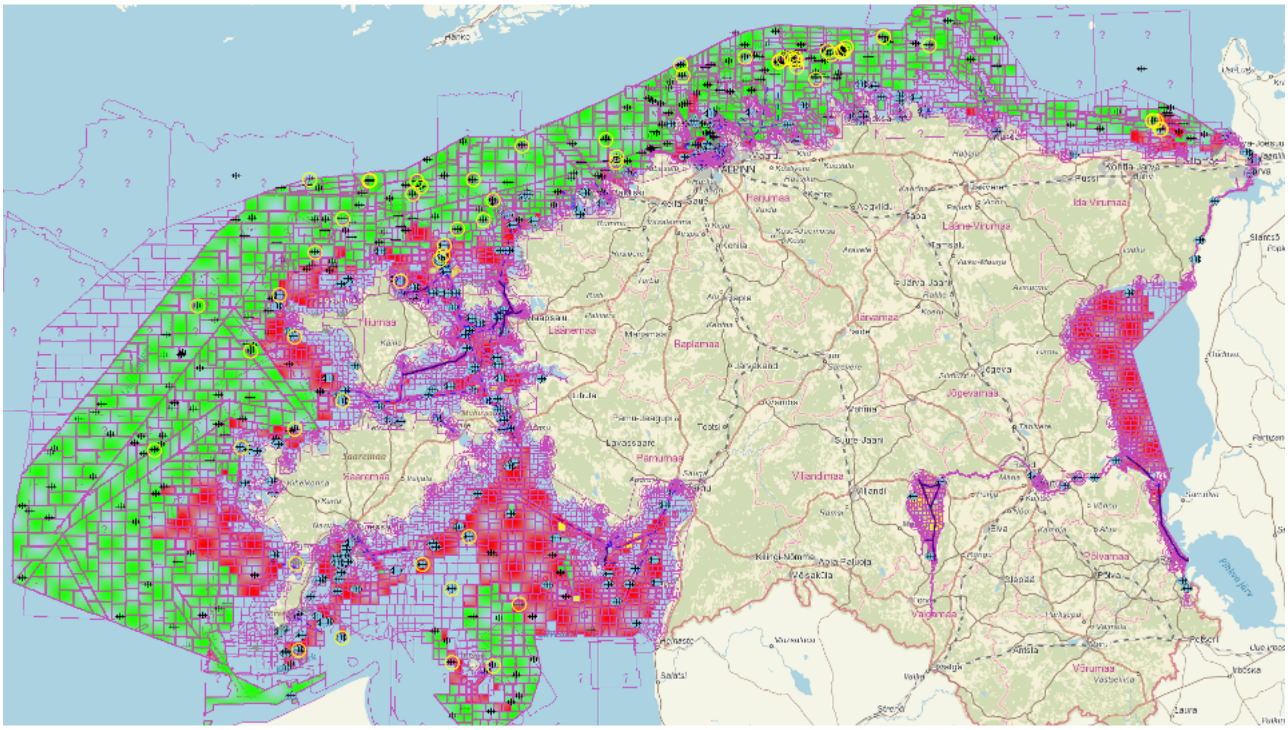


Figure 25. Positions of the 65 identified potentially environmentally hazardous shipwrecks and identified potentially polluting shipwrecks in Estonian waters. Image from the Estonian Transport Administration HIS database.

Furthermore, WWII ships sunk on 28-29 August 1941 during the Russian evacuation from Tallinn to Leningrad (Saint Petersburg) are of special concern regarding environmental risk. 183 ships participated in the evacuation of Tallinn in four divisions, where each division included destroyers, other warships, and transport ships. According to another source, 197 warships, transport, and auxiliary vessels participated in the operation, of which 53 were sunk. These wrecks remain to be assessed.

3.4.3. Past oil removal operations

Runner IV

The ship Runner IV was sailing in an ice channel as part of a convoy in March 2006, when the icebreaker at the front of the convoy stopped, requiring all other vessels to stop as well. However, the vessel Svjatoi Apostol Andrey, positioned directly after Runner IV in the convoy, could not stop in time. It hit Runner, causing severe damage and finally the sinking of Runner IV. Surveillance flights and satellite images detected oil leakage in the area after the incident. Estonian and Finnish oil combating authorities started oil recovery operations in these ice conditions, and the operation ran between 15 and 18 March and again later in April. The oil had dispersed over an area of 500 km^2, and only a few tens of tons of oil could be collected. During these operations, oil was observed to drift westwards (Fig. 26). Later surveys confirmed additional oil leakage from the wreck and further oil removal operations were performed (Wang et al., 2008).

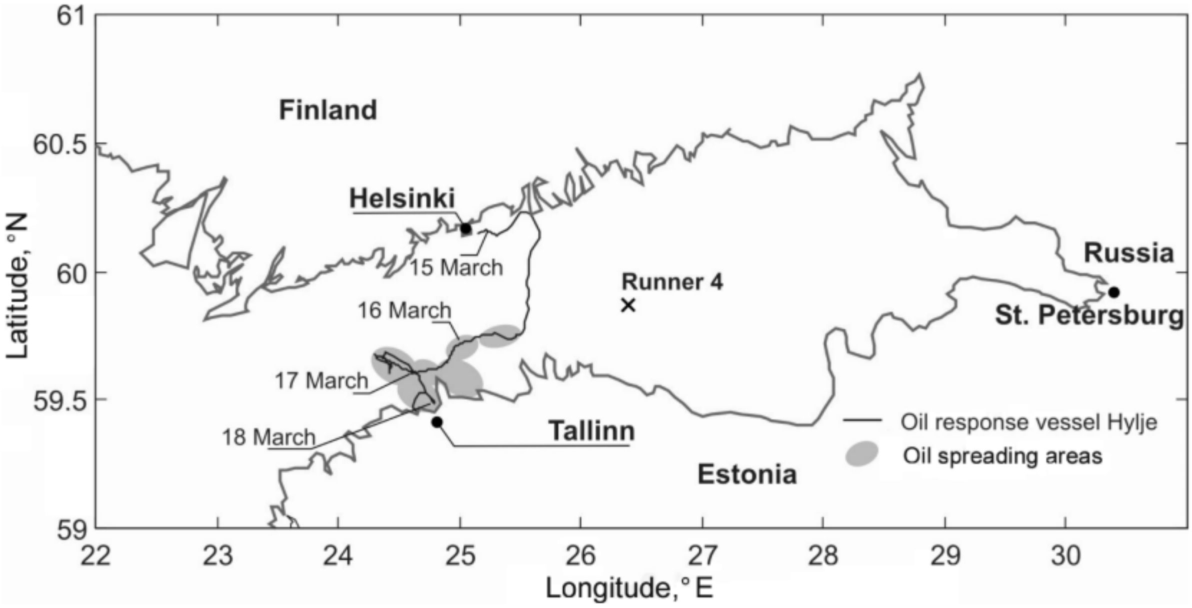


Figure 26. Map showing the wreck site, the shaded area are the areas affected by the oil and the line is the path of oil recovery vessel Hylje (Wang et al., 2008).

The oil removal operation of the wreck was carried out in November 2006 using ROV and hot-tapping techniques. The great water depth of 80 meters was the main reason to use the advanced ROV technology (Fig. 27). The work was conducted during approximately ten days, with the results of around 100 m^3 of oily water being removed from the wreck. It was estimated that the amount of oil in this mixture was roughly 80 m^3.

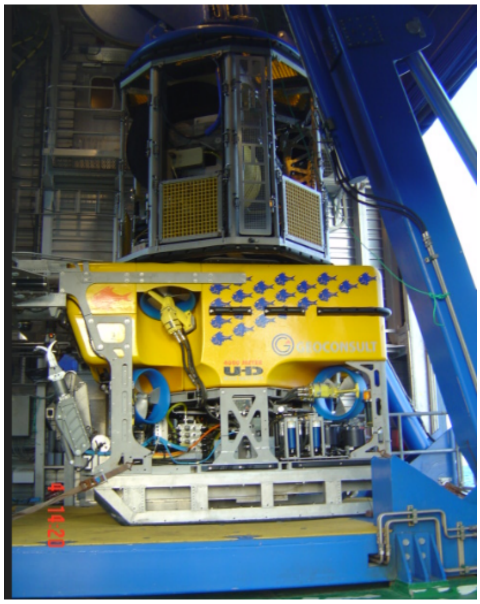


Figure 27. Left. Photo of the hot-tapping system used, where base plates are attached to the wreck as a main instrument for oil removal. Right. ROV used in the operation (photo: SYKE).

Torpedo boat T-30

The T-30 (German Torpedo boat from WWII, Fig. 28) started leaking oil in 2020, and oil was removed by the diving company Tuukritööd OÜ, on commission of the Estonian authorities. The pollution was discovered at Narva Bay on 23 April 2020, and samples taken indicated that a fuel mixture had been discharged into the sea. The source of the leak was identified as the German torpedo boat T-30, which sank in August 1944 together with two other similar ships, the T-22 and T-32.

Figure 28. Torpedo boat T-30 was one of fifteen Type 39 torpedo boats built for the German Navy during WWII. The vessels had an overall length of 102.5 meters (Mätik, 2020).

Investigations of the wreck site showed that an oil removal operation would be difficult due to the fact that the wreck is surrounded by munitions. The visibility to the wreck was also very low, especially close to the sea floor, resulting in a delay of the start of the salvage operation. Estonian authorities had positioned barriers and absorbing oil booms around the wreck site to collect the leaked oil. It was estimated that in a worst-case scenario, up to 370 tons of oil could be contained inside the wreck[9]. On the other hand, the ship was wrecked on 18 August 1944 after hitting several mines. This information possibly contradicts that such a large amount of oil would still be contained in the wreck.

A commercial diving company was contracted to identify the leak and remove the oil. A hole was drilled through the hull, and the remaining oil was removed. About a month later, another leak appeared, then another hole was drilled, and more oil was removed (Fig. 29). After the second operation, no more leaks have been discovered, though that does not mean that no more oil remains in the wreck.

[9] https://news.err.ee/1094829/gallery-oil-spill-from-wwii-wreckage-cleaned-up-in-narva-bay

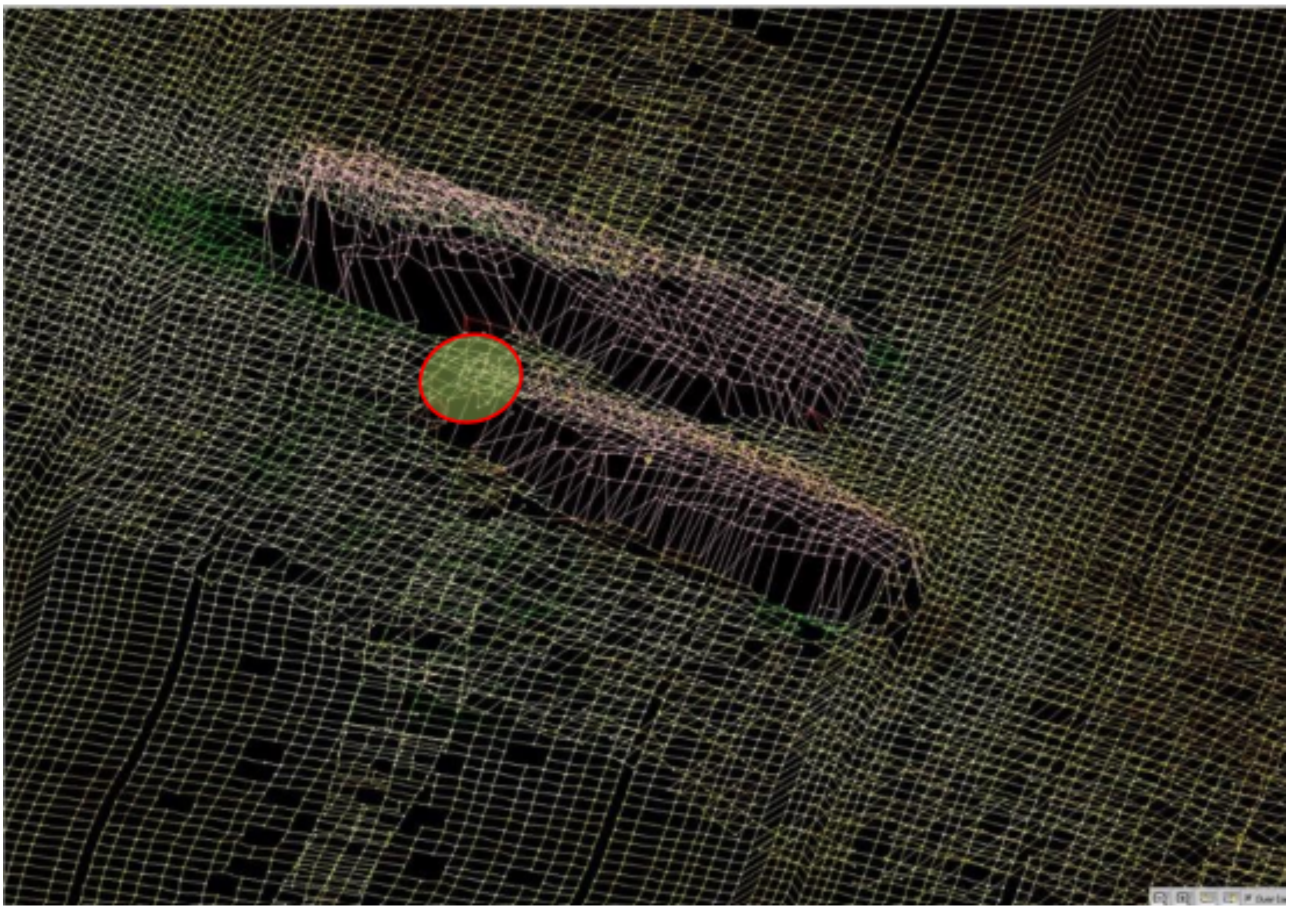


Figure 29. The figure shows that the wreck of T-30 is in two parts. The circle refers to the origin of the detected oil leak (Mätik, 2020).

Volare

Volare, an ore carrier type vessel, was grounded in 1980, southwest of Saaremaa Island in a water depth of 4-5 m. In the years after the grounding, the wreck was on fire several times and was subject to metal scrappers. Today, all metal over the water line has been removed, leaving only the hull and part of the engine remaining inside the wreck (Fig. 30). After the wreckage, constant leakage of oil was detected to originate from the wreck, especially during heavy weather with stronger winds. Therefore, a thorough study was carried out to evaluate the volume of oil still contained in the wreck and the level of contamination around the wreck site (Kõuts et al., 2015). Results showed that the main source of the oil leakage was a remaining high-viscosity layer of heavy fuel oil still contained in the wreck. Therefore, an operation was carried out to remove all the remaining oil, oily metal fragments from the ship, as well as oily sediment. A work which has now been concluded.

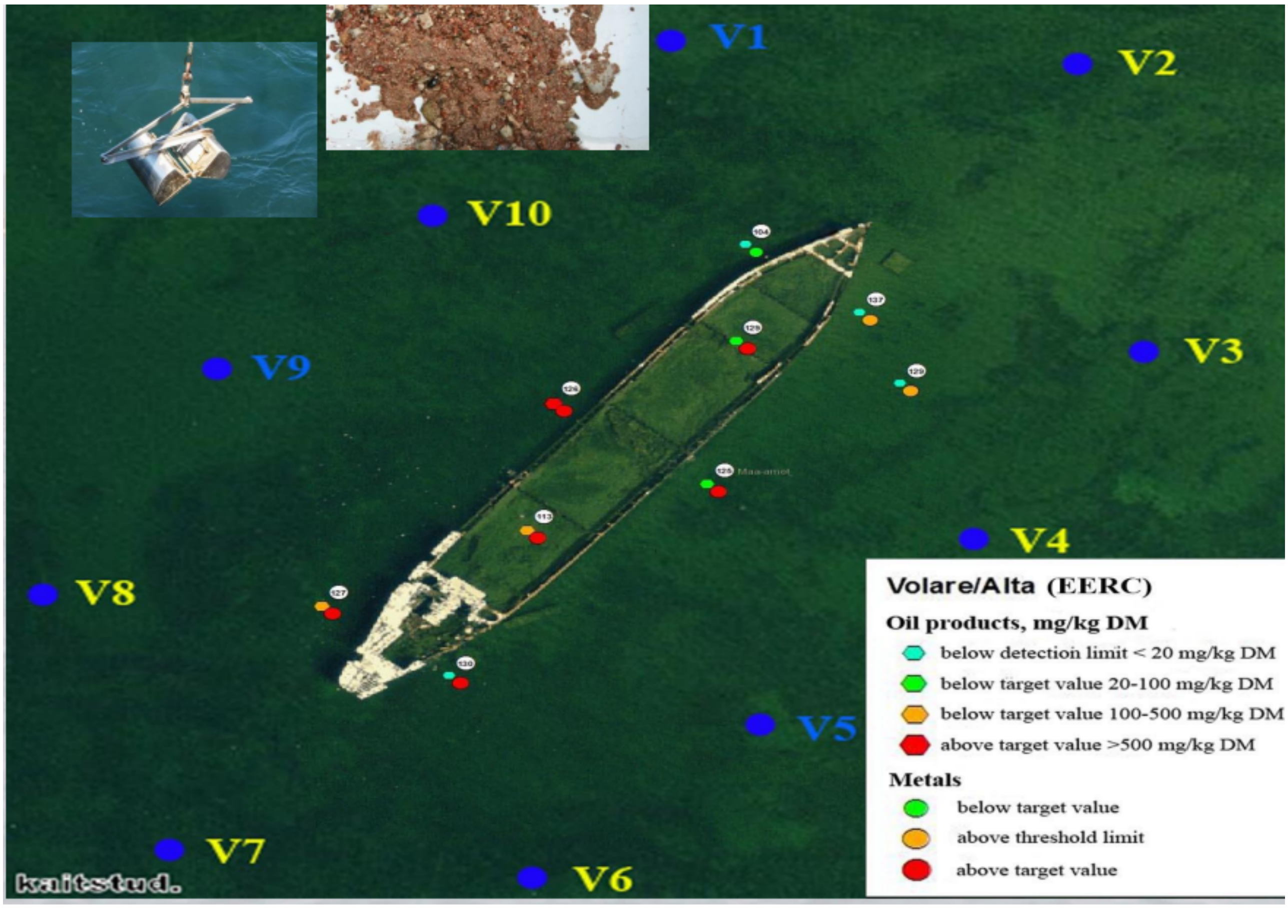


Figure 30. The wreck of Volare prior to the salvage operation. The figure also presents the sampling stations for hydrocarbons and heavy metals in the sediment around the wreck (Kõuts et al., 2015).

3.5. Poland

Work related to the management of hazardous materials dumped or included in shipwrecks in Polish maritime areas is carried out by various national authorities, scientific institutions, and private entities. Due to the fact that the competence in this area is divided among various national authorities and scientific institutes, which has hampered coordinated action by all stakeholders, an inter-ministerial committee has been established to initiate a planned and holistic approach to the issue.

According to the UNESCO Convention for the Protection of Underwater Cultural Heritage, ratified by Poland in 2021, wrecks older than 100 years with cultural or historical value are subject to monument protection. Younger wrecks of historical or cultural significance are protected by the 2003 Act on the protection and maintenance of historical monuments. All activities on protected wrecks require a permit from the Director of the Maritime Office in Szczecin, issued in consultation with the West Pomeranian Voivodeship Conservator of Monuments in Szczecin, or a permit from the Director of the Maritime Office in Gdynia, issued in consultation with the Pomeranian Voivodeship Conservator of Monuments in Gdańsk. In 2005, the competence of the Pomeranian Voivodeship Conservator of Monuments concerning the coordination of activities on archaeological sites and historic wrecks was taken over by the Director of the National Maritime Museum in Gdańsk.

Another factor to be considered is that some of the wrecks in Polish waters are considered war graves and therefore have special protection from human activities. These are WWII wrecks that still have a large number of victims inside the wrecks, e.g., Wilhelm Gustloff 10 000 victims, Goya about 5 000 victims, Steube about 6 000 victims, and the Karlsruhe – about 1000 victims. Thus, great consideration needs to be taken before initiating a detailed and intrusive operation on these shipwrecks.

3.5.1. Wreck database

The official wreck database in Poland is managed by the National Hydrographic Service, which consists of the Hydrographic Office of the Polish Navy (HOPN) in cooperation with the Maritime Administration. According to Polish law, all stakeholders conducting hydrographic surveys in Polish sea areas (internal waters, territorial sea, and EEZ) must provide the HOPN with the collected data, including information on detected underwater objects. Fulfilling the obligations of the HOPN maintains the official hydrographic data resource. This resource includes an underwater objects database and a bathymetric database. At the end of 2024, the database of underwater objects contained 580 wrecks (Fig. 31). It includes only basic information such as the known position, dimensions, water depth at the position of the wreck, and a short description prepared by the hydrographer who detected the object. The database also contains data obtained from surveys carried out by hydrographic survey vessels of the Polish Navy and research vessels of external entities (maritime offices, scientific centres, commercial surveyors, diving companies). It should be noted that the objects contained in the databases are classified in terms of whether they pose a threat to the safety of navigation and not their military nature or possible risk to the marine environment. If, during the in situ investigation of the object, information is obtained regarding the presence of hazardous materials, this data is included in the database.

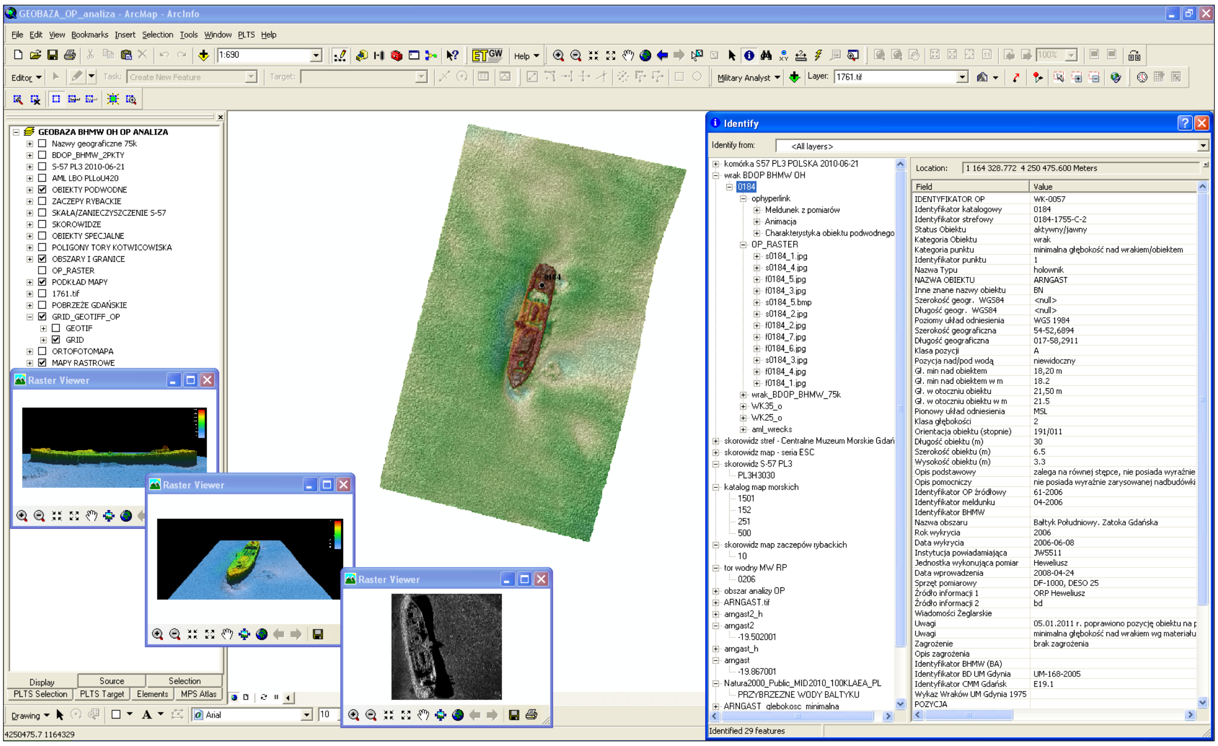


Figure 31. Example of information about a wreck in the underwater objects database (HOPN).

The number of wrecks and underwater objects is constantly changing. Today, only about 37 % of the Polish maritime areas have been surveyed with modern hydrographic techniques. Hence, it is highly probable that the number of wrecks is much higher in reality (Fig. 32).

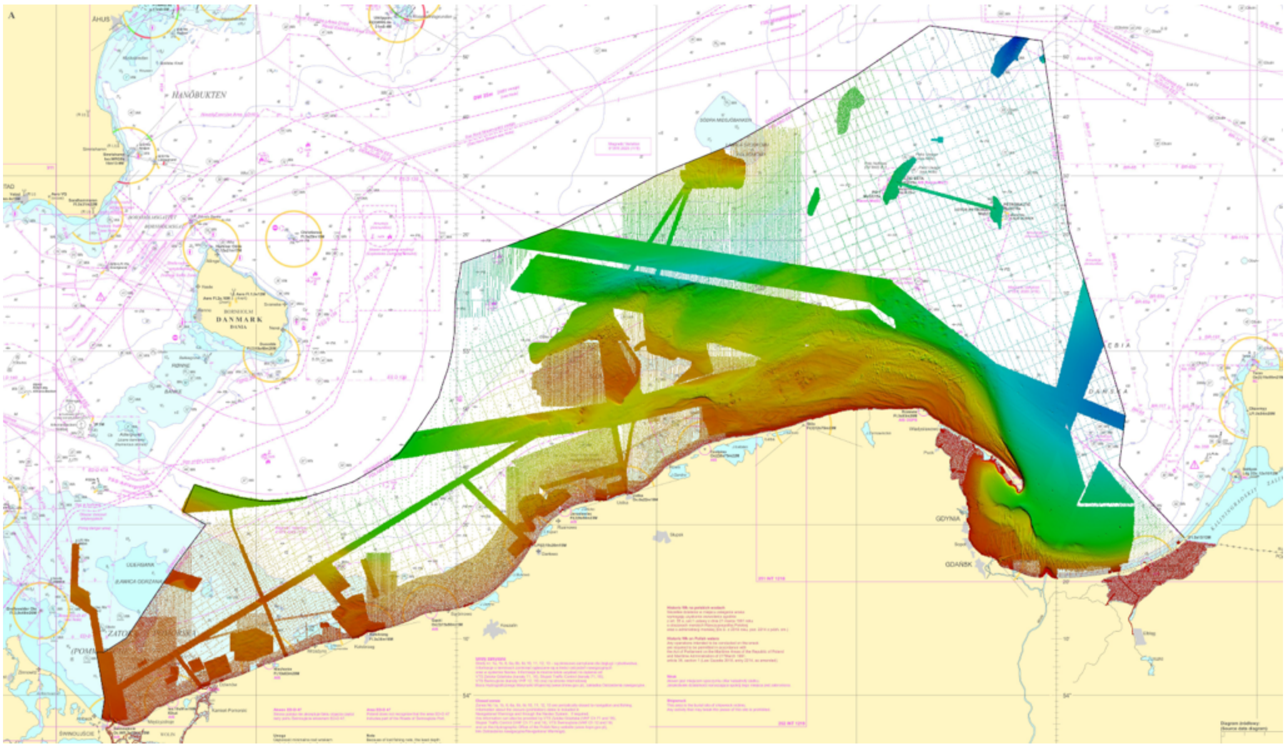


Figure 32. Polish Maritime Areas seafloor coverage (HOPN).

Current bathymetric data, as well as positions of wrecks in Polish maritime areas, can be found in the National SIPAM (Spatial Information System of the Maritime Administration) portal, which was implemented in 2020 by the Maritime Administration. The portal is available online[10]. It presents marine spatial data and provides data, metadata, and reference documents for download. The HOPN is responsible for updating bathymetric, contour, and wreck layers.

In connection with Poland's ratification of the UNESCO 2001 Convention, in 2021, the Minister of Culture, National Heritage and Sport entrusted the National Maritime Museum in Gdańsk to maintain a database of underwater cultural heritage objects. The database contains information on over 130 archaeological sites. The verification of an additional 280 wrecks is planned (as of December 2024). This information was gathered through access to various historical archives, underwater research, but also through reports from fishermen, divers and discoveries made during survey. In addition to basic information on the location and state of preservation of objects, the database contains data on possible hazards to humans, e.g. about the presence of ammunition on the wrecks.

[10] https://sipam.gov.pl

3.5.2. Current work

The inter-ministerial committee, described above, held several meetings in 2021 and conducted an analysis of the available bathymetric data, applicable legal regulations, and conclusions from scientific studies on hazardous materials on the seabed carried out in Poland and abroad.

After its consideration, the Committee developed the following recommendations to the Council of Ministers:

- Establish a new committee dedicated to dumped hazardous materials, to coordinate the long-term perspective cooperation of ministries whose competences include activities related to identification, monitoring, and neutralization of threats caused by dumped hazardous materials;
- secure sufficient funding to support the Committee's work and carry out operations to investigate and neutralize the dumped hazardous materials, constituting the greatest hazard to the marine environment;
- evaluate existing regulations in terms of adequacy and recommend, according to identified needs regarding the issue of dumped hazardous materials, possible new proposals for additional legislation to address any emerging issues related to the neutralization of threats caused by hazardous materials deposited in the maritime areas of the Republic of Poland.

The report on the Committee's work was adopted by the Council of Ministers of the Republic of Poland in 2022. Following this decision, the Inter-Ministerial Committee on hazardous materials deposited in the maritime areas of the Republic of Poland has been established with the following tasks:

- to coordinate cooperation between public administrations in the field of dumped hazardous materials;
- to recommend activities to identify hazardous material on the sea floor;
- to recommend actions aimed at adapting monitoring and methods for remediation of the identified threats;
- to evaluate existing regulations in terms of their adequacy to the changing state of affairs and prepare recommendations for possible changes in these regulations.

Considering the potential environmental threat posed by war wrecks, which may contain not only unexploded ordnance, but also oil, Poland intends to perform additional investigations of two wrecks located in the Gdańsk Bay, Franken and Stuttgart. The aim of these additional studies will be to develop an appropriate method to neutralize the environmental hazard they pose.

Franken

Franken is situated in the Gdańsk Bay (54° 32’ 19,452” N; 18° 57’ 57,024” E) (Fig. 33). It was a German petroleum supply ship, bunkering large naval ships, for example, battle ships and destroyers. The ship was 178 m long, and its width was 22.1 m (Fig. 34). It was sunk by a Russian aeroplane in April 1945. According to historical documents, it may have had up to 3136 m^3 of various petroleum products on board when it sank.

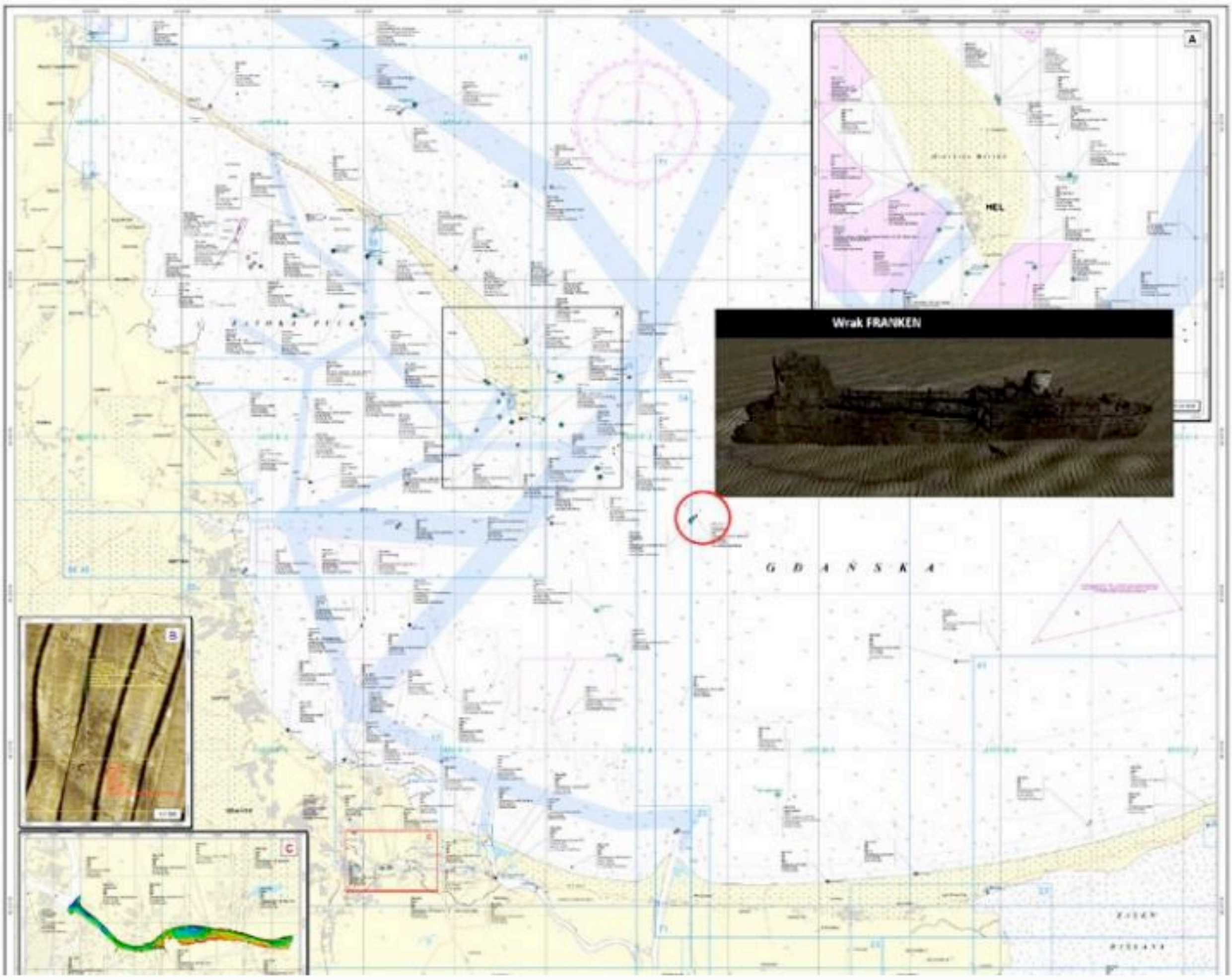


Figure 33. Identified shipwrecks in Gdańsk Bay. The red circle shows the position of the wreck Franken (HOPN).

Sonar and bathymetric studies have shown that the ship is broken into two sections, probably during the wreckage. This was later confirmed by testimonies of witnesses to the sinking, which stated that the ship broke into two sections minutes after the attack. The main part of the wreck, including the stern, the midship (where the oil tanks were located), together with the forecastle, approximately 130 m in length, is today located approximately 420 m away from the bow, which is 50 m in length. A potential large oil leakage from the wreck, and the wreck's location in the middle of Gdańsk Bay, could impact a large area with a negative impact on the coastal ecosystem of the Gdańsk Bay. For this reason, it is essential to investigate what volumes of fuel are still contained in the wreck and the possibilities for oil removal.

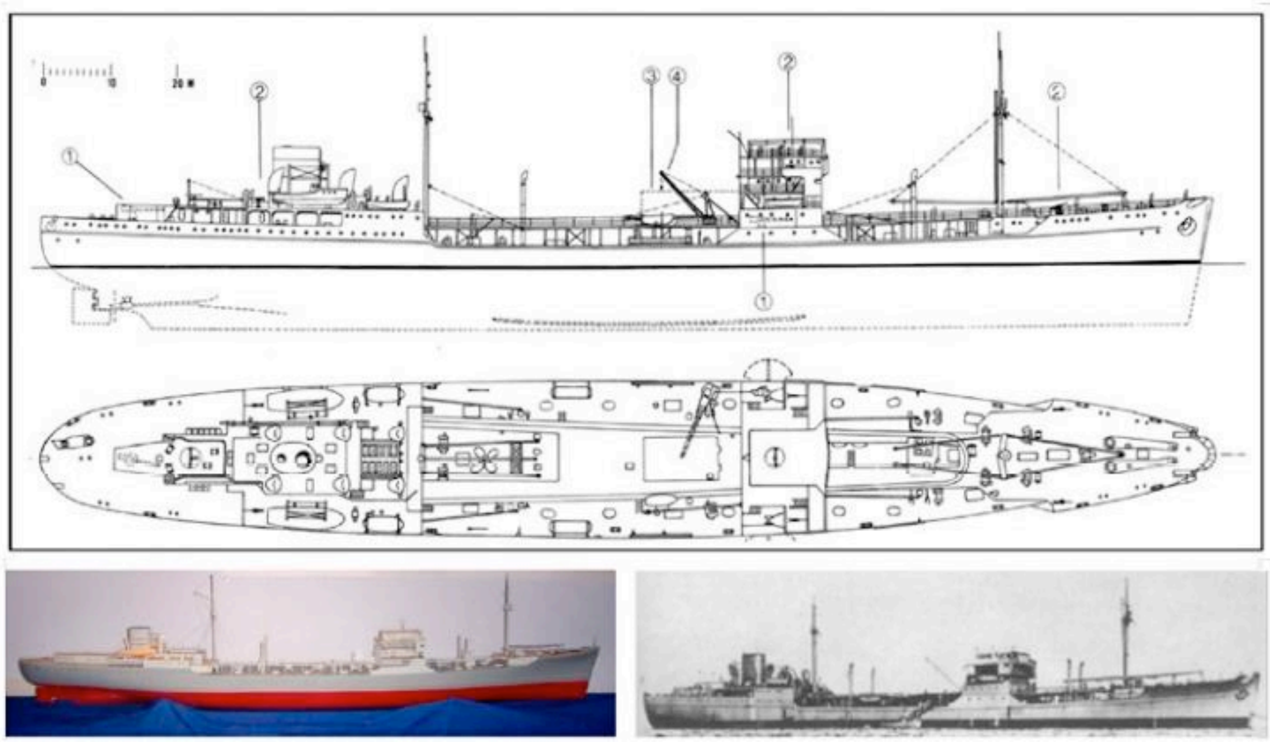


Figure 34. Drawings and pictures of T/S Franken (Hac, 2018).

Stuttgart

S/S Stuttgart was a hospital ship, built in 1923, which was sunk in 1943 by American planes in Gdańsk Bay (Fig. 35). The ship was 171,6 m in length and 19,8 m in width, with a displacement of 13387 GRT. Several studies have shown that oil leakage from the wreck has contaminated the surrounding sediments. The studies included geological analysis of the sea floor in the area, as well as chemical analyses and zoobenthos sampling of the sediment. Results show a severe contamination of the sea floor in the vicinity of the wreck.

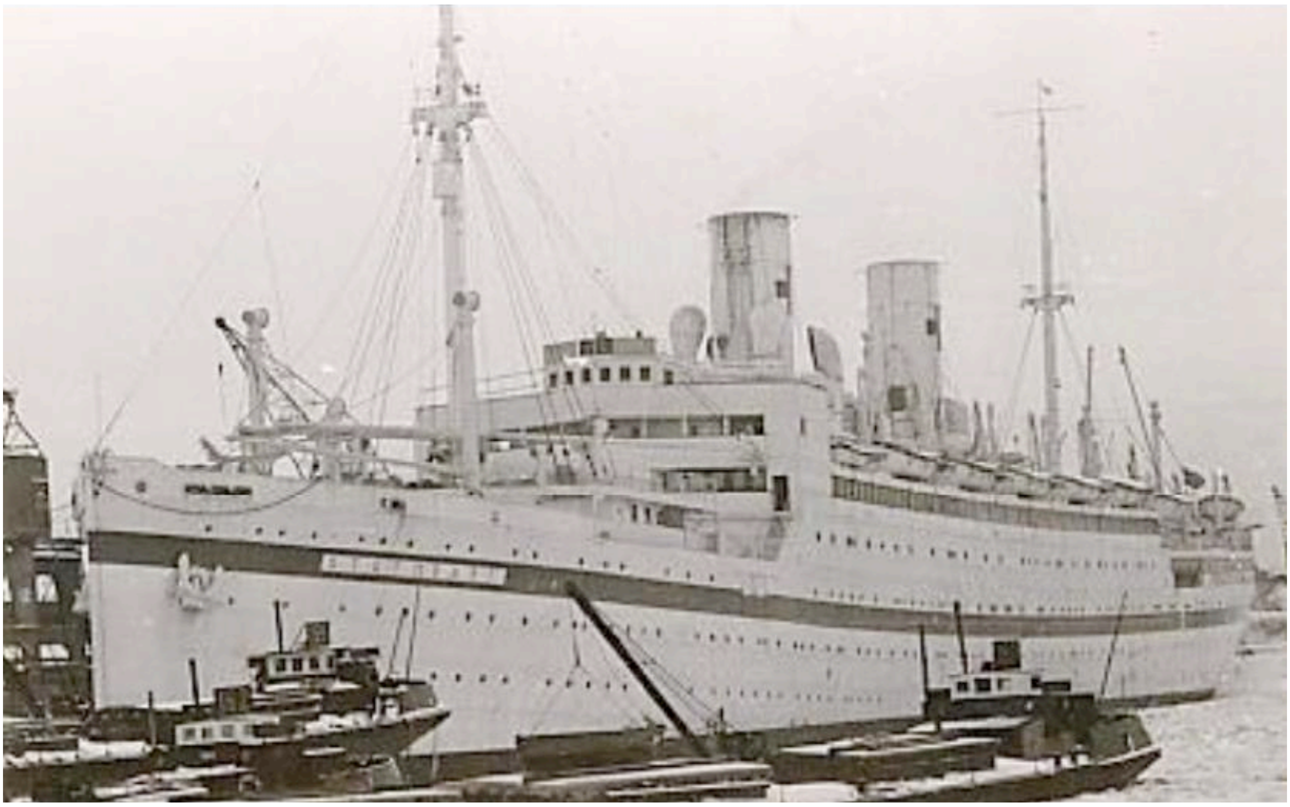


Figure 35. S/S Stuttgart as a hospital ship (Hac. B. 2014).

3.5.3. Past investigations of shipwrecks

In Poland, no oil removal operations have been performed. However, since the 1990's several projects have been carried out to perform in situ investigations of wrecks. For example, U-boot 272 and a mine supply vessel in Puck Bay, the wreck of Bürgermeister Petersen, and several investigations on the large wrecks of the ships Franken and Stuttgart. These investigations were mostly performed by the Maritime Institute in Gdansk. Future work should be directed to developing methods for risk assessments and more systematic investigations. Besides the investigation of the wrecks, generally accepted methods for oil removal were described. They are a valuable tool for risk assessment methods and for management. Another stakeholder engaged in past works is the Institute of Oceanology, Polish Academy of Science. In recent years, the focus of its scientific investigations and projects has shifted towards investigations of dumped chemical and conventional munitions.

3.6. Denmark

3.6.1. Databases of shipwrecks

The Department, Safety of Navigation under the Ministry of Societal Resilience and Preparedness records all wrecks within the Danish EEZ and has a shipwreck database. The purpose of the database is primarily for the safety of navigation, and it includes information such as ship type, ownership, and cargo. This register includes wrecks in Danish waters, including Danish EEZ, and a small number of wrecks just outside the EEZ. It does not include wrecks in waters around the Faroe Islands. However, wrecks in Greenland have been registered since 2023. There are 3250 (as of November 2024) wrecks in this register (Fig. 36) and 90 % of the shipwrecks recorded by The Department, Safety of Navigation under the Ministry of Societal Resilience and Preparedness prior to 2000 only include information about the clearance depth above the wreck, the best-known position and water depth at the position.

However, in a report in 2024, Andresen (2022) describes a database called Fund og fortidsminder platform, by The Agency for Culture and Palaces. This database includes historical and archaeological objects on land and at sea in Denmark. In the marine areas, there are some 14083 objects, of which 10127 are classified as shipwrecks. 46 % of the wrecks in the database are dated from the year 1900 to the present day.

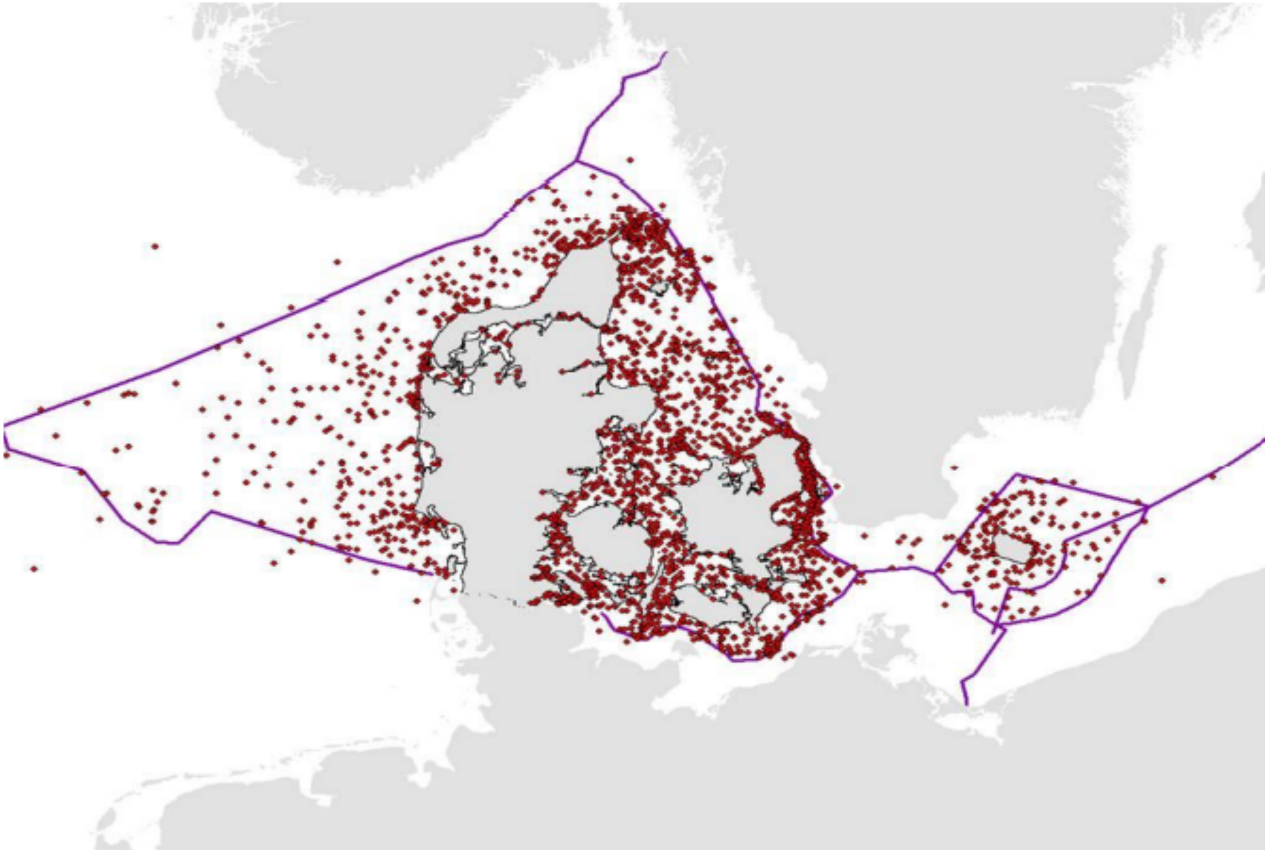


Figure 36. Locations of wrecks in the Danish EEZ area.

3.6.2. Risk assessment

The process for risk assessment and case handling within the Department of Safety of Navigation under the Ministry of Societal Resilience and Preparedness is methodically carried out within the scope of assessing whether the wreck has any impact on the navigational safety in the adjacent waters.

1. Initial Notification

Upon receiving a report about a wreck, the Department of Safety of Navigation acknowledges the notification and opens a case file. Relevant authorities, including the Fisheries Agency, Environmental Protection Agency, Coastal Directorate, and Maritime Assistance Service (MAS), are informed to ensure the wreck is reviewed under their respective legal frameworks.

2. Consultations and Preliminary Assessments

The department conducts a nautical risk assessment to evaluate if the wreck poses a significant danger or major inconvenience to maritime traffic or fishing activities, in accordance with applicable laws. As part of the consultation, specific agencies, like the Fisheries Agency, may be asked to assess the wreck's impact within their domain. For instance, they might be asked if the wreck hinders fishing and to propose potential mitigation measures.

3. Concluding the Case

Once all consultations and assessments are complete, the department decides if the wreck must be removed or mitigated. If the wreck is deemed non-hazardous, the case is closed. Relevant authorities are notified, and the case is finalized. If the wreck poses a risk for navigation, the responsible parties may be instructed to address the issue under applicable legal mandates.

Throughout the process, stakeholders, including the owner and relevant authorities, are kept informed at various stages:

- Initial acknowledgement and request for information.

- Notifications regarding new cases and sharing details of the wreck.

- Formal hearing requests to gather opinions from agencies like the Fisheries Agency.

- Notification of case closure with conclusions shared with all parties.

This process ensures that the risks associated with the navigational safety of wrecks are methodically evaluated and appropriately managed while complying with legal obligations.

In addition, in a report by Andresen (2022), a method for the environmental risk assessment of shipwrecks in Danish waters is suggested. This includes assessing wrecks that can contain both oil and munitions. Firstly, an initial screening of wrecks for potential hazards is proposed. This is based on the location of the wreck, occurrence of the wreck in multiple databases, year of wreckage, relation to war, cargo that includes potentially dangerous goods and/warfare agents, and current condition of the wreck that influences the probability of a leakage. After this screening, the wrecks can be divided into three categories: 1/ wrecks without risk, 2/ wrecks without munitions but that may contain large volumes of bunker oil or wrecks associated with war but not a naval vessel, and 3/ wrecks that contain munitions.

In a second stage, it is suggested to use the risk assessment tools developed in the DAIMON and North Sea Wrecks projects, the Decision Support System (DSS) including VRAKA, and the WRECKNS tool. Both tools include the use of several parameters, such as environmental parameters, historical information, in situ investigations of the wreck, and various human activities in the area. The tools then provide the assessor with results that can be used to identify wrecks that constitute the greatest risks and, in the end, prioritize between wrecks. In addition, in a last stage, it is suggested that cumulative effects in a water body be considered. This is often difficult to assess, however, it is regularly performed within the Danish national monitoring program (NOVANA).

The risks from wrecks should then be incorporated in the modelling scheme for the relevant stressors in an area and contribute to the final assessment of wrecks that should be prioritized.

3.6.3. Past oil removal operations

Fu Shan Hai

Fu Shan Hai was a bulk carrier constructed in 1994. During a voyage in 2003, it collided with another vessel and wrecked close to the island of Bornholm in the Southern Baltic. When sinking, the ship went down with its prow into the seabed and broke mid-ship. Figure 37 shows the wreck on the sea floor prior to the oil removal operation. At the day of wreckage, the ship was carrying close to 1825 tons of oil, roughly 1500 tons of which were recovered during the clean-up operations: at the wreck site 891 $m^3$by Danish recovery ships 248 m^3, by Swedish recovery ships 280 m^3, oil recovered from the Danish coast line 10 m^3 and from the Swedish coastline 79 m^3. Unofficial data also state that some oil was detected on the coastline of Kaliningrad, Russia (discussion with M. Durkin of the Kaliningrad Port Authority in 2004). The total amount of 1825 tons of oil included 1680 tons of heavy fuel oil (IFO 380), 110 tons of diesel oil, and 35 tons of lubrication oil. After the wreckage, oil was occasionally detected on the water surface. Later, during inspections by divers, the origins of the leakages were detected (Fig. 38). The expected amount of oil remaining in the ship was 335 tons. An oil removal operation on the wreck was conducted from 24 July to 11 September 2013.

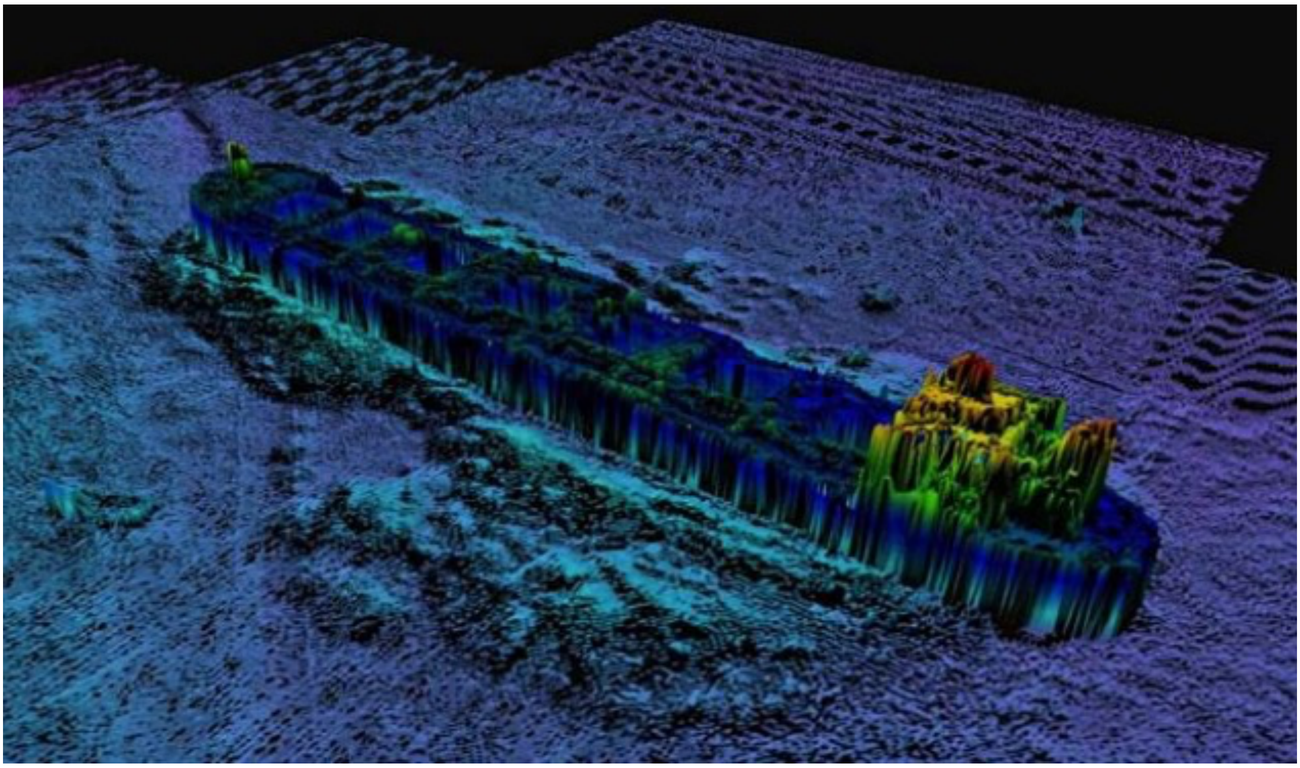


Figure 37. Multibeam image of the wreck of Fu Shan Hai (Danish Navy, 2013).

The investigation of the wreck was made by divers and ROVs. The oil removal operation was then conducted according to the following steps. Firstly, 50 mm holes were drilled in the hull for inspection in areas where oil could have assembled or in bunker tanks (Mortensen & Rasmussen, 2013). If the tank was empty, the hole was sealed with a wooden plug. If oil was detected, a base plate was mounted over the hole into the tank or space. A special ball valve was then mounted to the base plate, enabling drilling through the hull using a 6” cup drill. The cup drill was removed, and a pump was mounted on the top of the valve system, connected to hoses. The heating system on the deck of the support vessel was turned on, and the oil in the tanks was heated from +4 °C to +70 °C through the venting pipes. The amount of steam that could be generated was 4250 m^3/hour. Finally, the oil and oily water were pumped to recovery tanks onboard the supply vessel (Fig. 39). More details regarding the salvage work can be found in reports by the Danish Navy (2013) and Mortensen & Rasmussen (2013).

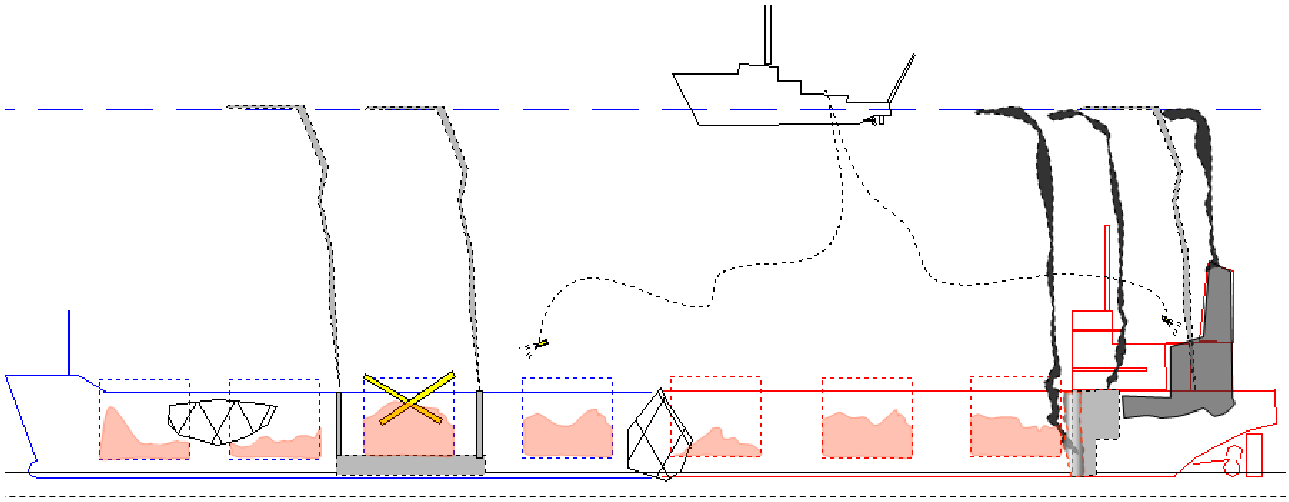


Figure 38. The image illustrates the positions of the oil leakages detected during the investigation of Fu Shan Hai after the wreckage (Danish Navy, 2013).

The duration of the oil removal operation was roughly 50 days. During the operation, more than 620 m^3 of oily water was recovered and 251 m^3 of oil of different origins. The large amount of oily water is a result of the hot tapping method, using steam or hot water, that was used to heat the viscous and sticky oil in the tanks in order to pump it up to the recovery ship at the surface.

Figure 39. The image shows the different vessels involved in the oil removal operation (Danish Navy, 2013).

3.7. Germany

3.7.1 Authorities and wrecks

The legal classification of wrecks in Germany depends on the differentiation between historic wrecks, mainly warships from the two World Wars, which are to be salvaged due to potential environmental risks, and modern wrecks, which are salvaged as part of acute hazard prevention measures. In the case of historic wrecks, environmental permitting requirements must be observed, involving different responsible authorities. For ships that wreck more recently, the competent hazard prevention authority issues a removal order and then enforces it.

The handling of shipwrecks according to different German legislation can be divided into four parts: a) environmental law, b) traffic and traffic route law, c) property law (ownership rights), and d) cultural heritage protection law.

a) Environmental law and permitting requirements

In terms of environmental law, the German legal situation is based on the implementation of the Marine Strategy Framework Directive (2008/56/EC) and the Water Framework Directive (2000/60/EC). Key legal bases include:

Federal Water Resources Act (Wasserhaushaltsgesetz, WHG), with section 44 WHG: Measures to prevent dangers to water bodies, including pollution from wrecks, and section 56 WHG: Specific provisions for the Exclusive Economic Zone (EEZ), particularly for preventing pollutant discharges.

Circular Economy Act (Kreislaufwirtschaftsgesetz, KrWG), which includes obligation to disposal of waste from wrecks, such as heavy oil, in an environmentally sound manner and legal basis for managing hazardous waste arising from wreck salvage operations.

Federal Nature Conservation Act (Bundesnaturschutzgesetz, BnatSchG) with section 34 BnatSchG: Compatibility assessments for projects in Natura 2000 areas (FFH and bird protection areas), including wreck salvage projects.

b) Traffic and traffic route law

Maritime Tasks Act (Seeaufgabengesetz, SeeAufG) with § 3 SeeAufG: Measures to eliminate hazards, including the elimination of disruptions to the safety and ease of traffic on maritime waterways, if the hazard is directly related to shipping and § 1 No. 9a SeeAufgG: Maritime survey service.

Federal Waterways Act (Bundeswasserstraßengesetz, WaStrG) with section 8 (5): Measures for the maintenance of sea waterways within the territorial sea. This only includes the maintenance of the navigability of the shipping lanes marked by the Federal Waterways and Shipping Administration (WSV), insofar as this is economically justifiable. Sections 24 ff WaStrG: River police measures in the territorial sea. Authorities of the Federal Waterways and Shipping Administration (WSV) have the task of taking measures to avert dangers that are necessary to maintain the federal waterways in a condition required for navigation.

c) Ownership rights of wrecks

Under German law, warships are considered state property. They retain their ownership status even after sinking unless explicitly abandoned. This aligns with international legal practice. Warship wrecks are classified as public property used for administrative purposes and are subject to the general property law provisions of the German Civil Code (Bürgerliches Gesetzbuch, BGB). Loss of ownership through abandonment (Section 959 BGB) is possible but uncommon. Ownership claims by the German Reich over sunken ships continue to exist and can be asserted by the Federal Republic of Germany.

Private shipwrecks may be considered ownerless if it can be proven that the owner no longer claims salvage rights. Germany has ratified the Nairobi International Convention on the Removal of Wrecks and the Salvage Convention, incorporating their provisions into national law. Relevant regulations are embedded in the German Commercial Code (Handelsgesetzbuch, HGB) and the Maritime Tasks Act (Seeaufgabengesetz, SeeAufgG), particularly Sections 574 et seq. HGB. These sections address the salvage of private ships as well as the prevention or mitigation of environmental damage during salvage operations.

d) Cultural heritage protection

According to the UNESCO Convention on the Protection of the Underwater Cultural Heritage, wrecks older than 100 years with cultural or historical significance are subject to monument protection in Germany. This is regulated by state monument protection laws, as cultural heritage protection is a state matter.

Responsible authorities

The responsibilities for shipwrecks in Germany are distributed among various levels of governmental institutions, which address both navigational safety and environmental protection. Key actors include:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), which coordinates the legal implementation of international agreements on environmental protection and is responsible for the respective strategic planning and legislation.

German Environment Agency (UBA), which compiles and assesses federal and state monitoring data on pollutants and other stressors and leads working groups within the Federal/State Working Group on the North and Baltic Seas (BLANO) and regional sea conventions (HELCOM and OSPAR) for the implementation of the Marine Strategy Framework Directive (MSFD).

The Federal Maritime and Hydrographic Agency (BSH) is, according to the Maritime Tasks Act (Section 1, No. 9a SeeAufgG), responsible for hydrographic surveys in German coastal waters and the EEZ. As a marine geodata service, the hydrographic survey provides up-to-date information on water depths, which is particularly important for the safety of shipping off the German coasts. The topographical survey of the seabed and tidal flats includes the investigation and localization of obstacles, in particular wrecks. The survey area covers an area of around 57,000 km^2.

The Federal Waterways and Shipping Administration (WSV) is, in accordance with the Federal Waterways Act, responsible for the condition of a federal waterway required for navigation and for keeping the shipping lanes safe and clear. It is required to act in case shipwrecks pose a threat to the safety and ease of navigation or if the wrecks are associated with an impairment of the traffic route function of the federal waterways.

The Federal Office for Central Services and Unresolved Property Issues (BADV) is responsible for former movable assets of the German Reich in the EEZ, while the Institute for Federal Real Estate (BimA) is responsible for former movable assets of the German Reich within the 12-nautical-mile zone.

In addition, there are the responsible hazard prevention authorities of the federal states.

Management of wrecks: acute hazard response

Wrecks that pose an immediate threat to navigation or the environment after the wreckage falls under the jurisdiction of the responsible state or federal hazard prevention authorities. These authorities can issue orders for removal and, if necessary, conduct the removal through substitute performance. As a rule, the state authorities of the corresponding coastal states (e.g., Lower Saxony, Schleswig-Holstein, Mecklenburg-Western Pomerania) are responsible, unless there is subsidiary federal responsibility. The hazard prevention authorities of the states cooperate closely with federal authorities such as the Federal Waterways and Shipping Administration (Wasserstraßen- und Schifffahrtsverwaltung, WSV).

The Central Command for Maritime Emergencies (CCME, Havariekommando) in Cuxhaven plays a key role in this collaboration. The CCME, established in 2003 as a joint institution of the federal government and the five coastal states, ensures unified maritime emergency management in the North Sea and Baltic Sea. It consolidates responsibilities for planning, preparation, training, and implementation of measures for combating pollution incidents, fire-fighting, providing assistance, and addressing hazard-related salvage operations during complex maritime emergencies, especially when state resources are insufficient.

Additionally, the Federal Coast Guard (Küstenwache), comprising units from various federal authorities (e.g., Federal Police, Customs, Federal Waterways and Shipping Administration), plays a significant role in hazard response. Its responsibilities include surveillance, control, and operational measures related to environmental protection and maritime safety.

3.7.2 Wreck databases

The BSH maintains a database of underwater obstacles (DUWHAS – German Underwater Obstacle Information System), which includes approximately 3,000 registered positions (Fig. 40). The database primarily contains navigational safety issues but also information on shipwrecks and other underwater obstacles that could pose navigation hazards, such as large stones, containers, and munitions remnants.

Figure 40. Red dots present the positions of underwater obstacles included in the DUWHAS database.

The underwater obstacle database contains information describing objects on the seabed. The position, minimum depth, general condition, and surrounding conditions of objects are documented. An average of 200 objects is analysed each year. Depending on the hazard, repeat surveys are carried out to record changes in the shallowest depth and the condition due to currents and sediment displacement.

Various hydrographic survey methods are used for locating and assessing wrecks. Side-scan and multi-beam sonars are employed to determine the position, shape, and condition of objects. Diver inspections can provide additional detail and verify minimum depth using depth gauges. Remote-operated vehicles (ROVs) are deployed as needed to evaluate objects and their surroundings. Any apparent environmental pollution risks identified during routine investigations are documented in reports. These reports can be made available to relevant authorities, who then decide on appropriate actions to address potential environmental hazards.

3.7.3 Risk assessment of wrecks – future prospects

Germany is participating in the EU Interreg South Baltic Project BALTWRECK to develop a standardized system for risk assessment of hazardous wrecks. Partners such as north.io and the Chalmers University of Technology in Gothenburg, known for the Swedish VRAKA model, are working on adapting this system for the southern Baltic Sea. Criteria include remaining oil volumes in the wreck, corrosion status, amounts of munitions, and proximity to sensitive marine areas.

3.8. Lithuania

At the time of writing this assessment document, no data on the wrecks in the Lithuanian waters have been delivered to EG Submerged. However, Lithuanian delegates have informed that they have seven wrecks in their heritage list.

The Maritime Safety Administration of Lithuania is the institution capable of conducting wreck surveys, since it is the institution that possesses hydrographical survey vessels. Surveys are carried out only in the fairways and not in the whole territorial sea. Wrecks discovered in these areas are of interest due to possible obstruction to navigation. In addition, the survey information is submitted to the University of Klaipeda to be included in their work with wrecks of historical value (Svensson, 2010).

According to the Lithuanian Transport Safety Administration, oil sheen has sometimes been detected close to some of the wrecks, but the sampling results have not indicated hydrocarbons exceeding the national limit values.

Lithuania is currently participating in the EU Interreg South Baltic Project BALTWRECK “Preventing massive marine waters chemical pollution from the leaking wrecks and munition/weapon dumps in the South Baltic”. Within the BALTWRECK project, Lithuania is represented by Klaipeda University Marine Research Institute and the Nature Research Center. Lithuanian partners of the project will contribute to:

- Thorough examination of a two wreck sites in the Lithuanian territorial sea (Submarine W-19 and new shipwreck (231123) discovered in the area of Lithuania’s first planned offshore wind farm) using the toolbox of geophysical, chemical and biological methods and novel marine pollution diagnostic tools in close cooperation with project partners to evaluate the risk and real threat to the marine life;
- Application of XRF spectrometry method for the assessment of sediment pollution by hazardous metals in the vicinity of a wreck site;
- Application of eDNA metabarcoding approach for the biodiversity assessment and biomonitoring at the wreck area;
- Contribute to the development of the wreck management strategy.

3.9. Latvia

The information on various shipwrecks in Latvian waters is incorporated in the Latvian Maritime Spatial Plan[11] and is also published in the manual for seafarers “Pilot of Baltic Sea -Latvian Coast"[12].

The Maritime Code of Latvia[13] states that the Maritime Administration of Latvia shall register shipwrecks. This task for the Maritime Administration involves compiling information and identifying wrecks that pose a hazard to navigation. Then maps for seafarers are updated according to the acquired information.

The National Cultural Heritage Board of Latvia also collects information on shipwrecks, as objects of national underwater heritage. Their register contains data on more than 300 shipwrecks. However, the register is not public to protect the wrecks from looting and damage by the activity. In Latvia, the issue of wreck looting and damage is considered of the same importance as the potential for pollution or other risks from wrecks. Regulations are in force for designing prohibited areas around potentially dangerous wrecks and for limitations of diving activities in these areas[14]. In addition, there are unofficial data on wrecks, based on recreational divers in Latvian waters, available. This unofficial shipwreck register of Latvia, kept by the Private Diving and Scuba Diving association “Daivings”, contains around 200 wrecks in Latvian waters in the register[15]. Included are at least several wrecks from the First World War. They are mostly steamers, but some of these wrecks, however, pose an environmental risk due to the munitions onboard. One wreck from WWII is also worth a specific mention. The Moero, a German hospital or troop carrier ship, was sunk in 1944 by Soviet bombers while carrying evacuees from Estonia. Nearly 2 700 out of the 3 350 people onboard were killed. No position is registered for the ship; the approximate area is between Pāvilosta and Ventspils.

3.10. Russia

During the work of EG Submerged, there has been no participation from Russia. However, based on the past ship accidents and known data from both world wars, the existence of several shipwrecks is known both in the Russian waters of the Gulf of Finland and in the Kaliningrad area. Given the maritime history and especially WWII, quite a large number of wrecks must be expected in Kaliningrad waters. Part of the data may be found in German registers.

In Russia, war wrecks belong to the Russian army, and wrecks that are more than 100 years old have the status of archaeological objects. Only individual wrecks are documented and marked as monuments, unlike in Finland and Estonia, where all found wrecks that are that old are automatically marked in the register. Furthermore, the Russian army is not supervising or monitoring war wrecks, e.g., there are no diving permits needed and issued. One can freely dive the wrecks.

One event worth mentioning is the Russian forces' evacuation of Tallinn in August 1941. This resulted in more than 50 sunken Russian ships in the Juminda mine field on their way from Tallinn to the war harbour of

[11] https://drive.google.com/file/d/11ThySZ9MfnT3F8indvTugWCJnZsRrVp-/view
[12] https://www.lja.lv/en/ATONLV/getPilot
[13] https://likumi.lv/ta/en/en/id/76358
[14] https://likumi.lv/ta/id/221385-juras-vides-aizsardzibas-un-parvaldibas-likums
[15] https://daivings.lv/wp-content/uploads/2023/12/zemudens-karte.jpg

Kronstadt, Russia. More exact data on these shipwrecks might be found in the Estonian wreck register and is partly known to Russian divers.

In addition, Russian private divers describe some hazardous shipwrecks in Russian waters (Ivanov, 2022):

- Two German, two British, and three Russian destroyers in the Gulf of Finland, each carrying 300-500 tons of oil
- One German minesweeper is operating, and a couple of Russian patrol ships are. Each may have carried 100-400 tons of naphtha on board
- Eight diesel-powered submarines, each with 60-120 tons of diesel oil
- One Russian mine sweeper and two German gunboats, each with 30-100 tons of diesel
- Six German naval ferry barges and a mine sweeper, each with about 10 tons of diesel
- Three large diesel-powered cargo ships, each of which can hold hundreds of tons of fuel
- One diesel-powered bunker tanker, which possibly transported more than 1000 tons of naphtha, hundreds of tons of diesel, and dozens of tons of various lubricants, etc. in the tanks

According to these divers, this last-mentioned wreck has leaked oil several times, which was detected when private diving groups conducted surveys to investigate its condition. Figure 41 provides an illustration of the general position of some of the wrecks described above.

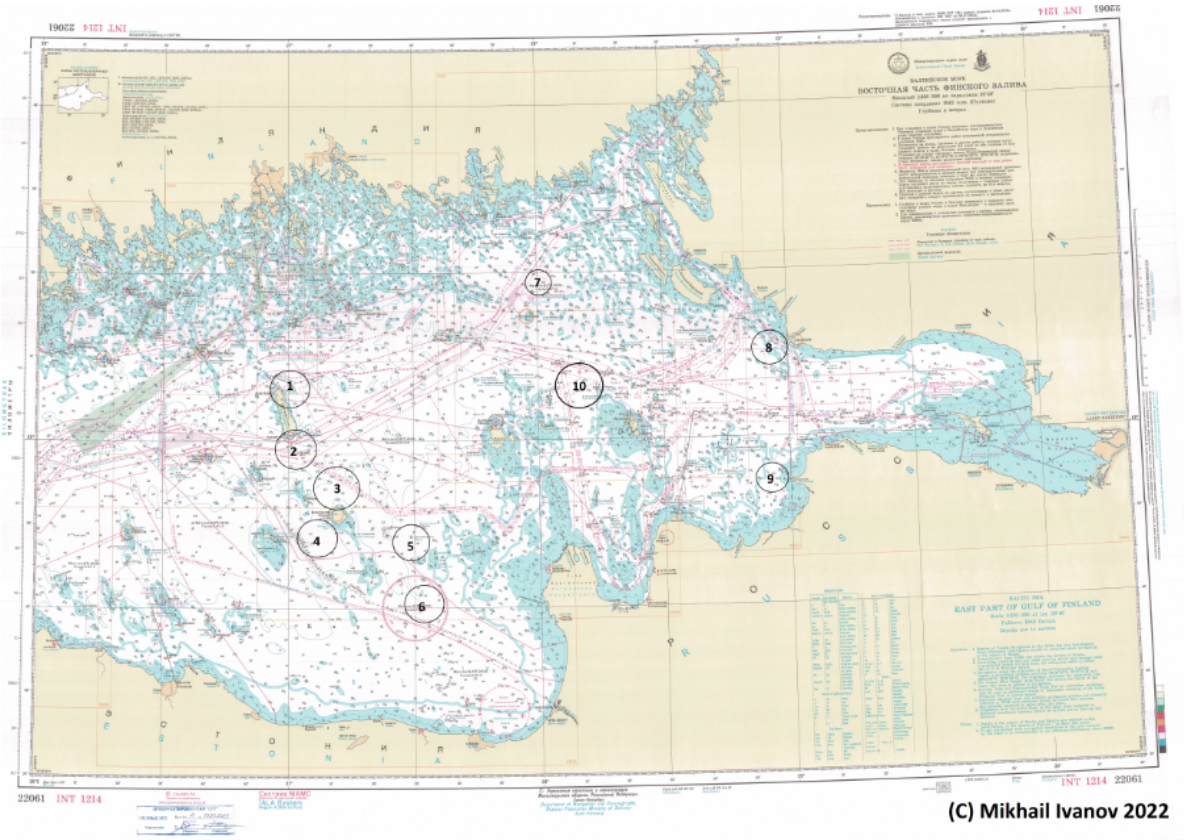


Figure 41. Shipwrecks with a probability of containing oil in the Russian territorial waters of the Gulf of Finland (Ivanov, 2022).

Most of the wrecks mentioned above and seen in Fig. 41 are located in the Suursaari-Tytärsaari-Lavansaari triangle, or in its immediate vicinity. But near the territorial waters of Finland, off Kotka north of Suursaari, there are also a few naval ferry barges and mine sweepers, and off Ulko-Tammio, a German destroyer and another naval ferry barge. The M98 submarine is also located close to the Gotland Island. In addition, close to the Estonian border in Narva bay, there are a lot of known wrecks, German destroyers, minesweepers, gunships, Russian submarines, and smaller German minesweepers. Russian and British fighters are found near St. Petersburg, east of the island of Seskar. This includes three wrecks, the motor ships Vtoraya Pyatiletka and Vyborg, and the tanker T-12, all of them sank on 29 August 1941. These three wrecks alone can have contained around 2 500 tons of oil.

As a conclusion, there might be potentially hazardous shipwrecks all over in Russian waters, as well as near the borders of both its neighbouring countries. The more than 30 wrecks mentioned above may have contained a total of around 843 tons of diesel and 5 870 tons of heavier oil fractions onboard as they wrecked or were sunk. How much is still left is unknown. There exists some data and unconfirmed stories related to the sinkings. However, in all of the cases, there remains a need to conduct individual in situ investigations of the wrecks to assess the damages, verify damaged sections with ship drawings, and estimate the volume of oil still on board the wreck.

No official work has been executed to remediate the wrecks in the Russian part of the Gulf of Finland. The wrecks are studied only from a historical perspective. There are diving teams such as UWEX[16] and URC-RGS[17], which are trying to raise the issue on their own. The URC-RGS team conducted research on the tanker described above, which is possibly the biggest threat in the area. The deck was photographed, water and sediment samples were taken in the vicinity of the wreck, and part of the hull of the ship was removed to analyse the corrosion rate.

[16] https://uwex.org/en/
[17] https://urc-rgs.ru/en

4. Risk assessment procedures for wrecks

4.1. General background and prioritization

4.1.1. Risk definition and general application on shipwrecks

A commonly used definition of risk is defined as a function of the probability of something occurring combined with the negative consequence of this probability (Kaplan & Garrick, 1981). When assessing the risk of a shipwreck to the marine environment, there is firstly one prerequisite that needs to be fulfilled. The wreck needs to contain a hazardous substance, either as cargo or bunker. If that is the case, one considers the probability of a hole or breach occurring in the hull of the ship, combined with the consequence of the hazardous substance leaking through this hole. Common hazardous materials that wrecks may contain are various oil products. However, a wreck can also include hazardous cargo.

Assessing the probability of a hole occurring in a wreck involves taking into account several factors. Corrosion is a factor where the rate of corrosion depends on, for example, salinity, oxygen content in the water and sediment, sea currents, but also biofouling on the hull. The number of years the wreck has been on the sea floor affects the degree of corrosion that has afflicted the wreck. Other factors that can result in a hole in a hull are human activities such as bottom trawling, military activity, ship traffic, and construction work in the area close to the wreck, but also non-human activities, e.g., storms or other extreme weather or underwater landslides (Landquist et al, 2016).

When the probability of a hole has been calculated or assessed, the next step is to assess the amount of hazardous substance that will be released from the wreck, and if this is released during a single event or continuously over a period of time. If assessing a possible worst-case scenario, one could assume that the entire amount of the hazardous substance is released during a single event.

By combining the probability of release with the amount of released hazardous substance and performing this for a number of shipwrecks in an area or country's water, it is possible to perform an initial prioritization of shipwrecks in the area. However, it is beneficial to also include the consequences of the spill in more detail, since the scale of an affected area and the receptors that are affected by a spill affect the total consequences and hence the total risk. This can be achieved by using oil spill trajectory modelling with the wreck as a source, for example, using the SeaTrackWeb tool[18] or the NEMO-Nordic model (Kärnä et al., 2019). To model where a release of the hazardous substance would end up. The final step is to assess the presence and sensitivity of receptors in the affected area, what kind of habitats are there, and how difficult oil clean-up operations would be. One option is to investigate if the area that would be affected is protected by the state or municipality in some way, e.g., as a marine protected area or as a nature reserve. In total, this could be a framework for assessing the risk to the marine environment from shipwrecks.

Several risk assessment projects on potentially polluting wrecks have been reported or are under development. The most used method so far in the Baltic Sea region may be the VRAKA method, developed during a five-year period in Sweden by Chalmers University of Technology (Landquist et al., 2016). It is described in detail in

[18] https://stw.smhi.se/

papers by Landquist (2016, 2017). It has been used to a varying degree in Sweden, Finland, and Poland. Other EU-related methods described here are the DEEPP project´s Risk Index Method. However, there is only limited information about its usage. Additional methods are the Finnish ORRA method, which was developed during the EU-funded SWERA project. It should be noted that the ORRA method is not a risk-type approach per se, but rather considers several factors to define how easy or difficult it may be to conduct an oil salvage operation from a wreck's fuel tanks in each specific case. Each case is different, and depending on the conditions, the most suitable salvage solutions for one wreck might differ compared to another (see Chapter ORRA -Oil Removal Risk Assessment Toolbox). The US NOAA developed a risk assessment method during the Remediation of Underwater Legacy Environmental Threats (RULET) project[19]. Poland has also developed their own risk model protocol, called Environmental Desk-Based Assessment (E-DBA), which seems to be the most appropriate to apply for the assessment of wrecks in Polish waters. It does not assess how the risk changes with time, which is possible using the VRAKA method, but it has a clear and simple structure. The E-BDA protocol provides an impartial risk assessment and provides the assessor with advice on the most appropriate management strategy. This minimises conflicts of interest with the maritime administration, who would be consulted throughout the assessment process (Hac & Sarna, 2021). A comparison of some of the known risk approaches is shown in Table 4.

Table 4. Comparison of risk assessment approaches for potentially polluting shipwrecks (NOAA 2013).

Project	Database	Trajectory Modelling	Engineering and Archaeological Assessment	Risk Model or Matrix	Mapping	Taking into account other hazards
NOAA Rulet	Extensive data on vessels, potential impacts to resources at risk	Trajectory, fate, and effects modelling	Comprehensive	Yes	Yes	Limited data on munitions, chemicals
VRAKA	Extensive data on vessels	Trajectory modelling	Limited	Yes	Yes	Limited data on other pollutants
DEEPP	Location, type, size, owner, age	None	Limited	Yes	Yes	MARPOL chemicals
Transport Canada	Location, type, size, owner, age	None	No	No	Yes	No
Kystverket	Extensive data on vessels	None	Limited	No	Yes	Chemicals

[19] https://sanctuaries.noaa.gov/protect/ppw/

SPREP	Location, type, size, owner, age	None	No	No	Yes	No
UK MCA	Extensive data on vessels	None	Limited	Yes	Yes	Munitions, chemicals
NMRI	No database	Trajectory modelling and fate modelling planned	No	Yes	No	No

4.2. NOOA's RULET approach

The NOAA RULET approach is a comprehensive full risk assessment and prioritization tool that was applied to 87 wrecks in waters of the USA during the project (NOAA, 2013). The only other known project that included a full risk assessment and prioritization is the Swedish VRAKA model, which has so far been applied to more than 40 different wrecks.
NOAA's Resources and Undersea Threats (RUST) database includes approximately 20 000 shipwrecks in US waters. Most are thought to have lost their cargoes long ago or only contain minor amounts of oil. However, it is known from recent experience that some wrecks can contain thousands of tons of oil. Due to the large number of wrecks, an initial screening method was used to reduce the number of potentially polluting wrecks that needed further and more detailed assessment. A similar approach was also used in Finland and Sweden to define "priority wrecks".

After an initial assessment of the large number of wrecks in the RUST database, 573 priority wrecks were identified. Basic screening parameters that were used were vessel age, vessel location, vessel construction, propulsion type, vessel type, and vessel size. A secondary screening was conducted using archival and historic records, and the number of wrecks could be further reduced to 288. In this phase, the age of the wrecks was connected to an assessment of corrosion rate, available records from the wreckage, data concerning the conditions of the wreck, and the possibilities for salvage of the oil in the wreck. A wreck´s risk factors were evaluated in NOAA's risk model using a ranking from low to moderate to high. The factors included in the analysis are as shown in Table 5.

Table 5. Factors included in the risk assessment method developed by NOAA.

Risk Factor	Information
A1 Total Oil Volume	The oil volume risk classifications refer to the volume of the most likely worst-case discharge
A2 Oil Type	The oil type(s) on board the wreck are classified only regarding persistence
B Wreck Clearance	This risk factor is based on historic records and does not take into account what a wreck site currently looks like

C1 Fire on board during wreckage	Any fire that is known to have occurred at the time of the wreckage and may have resulted in oil products being consumed or breaks in the hull or tanks
C2 Reported Oil on Water	This risk factor addresses reports of oil on the water at the time of the vessel casualty
D1 Nature of the Casualty	This risk factor addresses the mechanism by which the vessel sank
D2 Structural Break Up	This risk factor considers how many pieces the vessel broke into during the wreckage, or since sinking

Additionally, the analysis includes other factors that may affect the oil removal operation, such as

- orientation of the wreck,
- water depth,
- any visual or remote sensing confirmation performed,
- other hazardous cargo on board,
- munitions on board or in the vicinity of the wreck and
- archaeological status, any restriction by the military, and gravesite status.

Finally, using the data available from the screening phase, the most probable volume of oil that could be discharged from each of the selected priority wrecks was estimated. This amount of oil was then used as input for a hypothetical oil spill in the SIMAP model, the Integrated Oil Spill Impact Model, from each wreck. To determine the range and direction of the spill from a wreck site, historical wind speed and sea current velocity and direction data from the area were used. The SIMAP is a stochastic model package, detailed explained in http://asascience.com/software/simap/. The SIMAP and its usage for wreck studies are also described in (McKay, 2015). A detailed description of the parameters used in the risk assessment of the US wrecks is shown in NOAA (2013), and the results of the assessment of the 87 selected wrecks are summarised in Table 6.

Table 6. A summary of the risk assessed wrecks in US waters and the number of wrecks categorized as low, medium or high priority (NOAA, 2013).

Category rank	**Range of scored**	**Number of wrecks for worst case discharge**	**Number of wrecks for most probable discharge**
High priority	15-21	36	6
Medium priority	12-14	40	36
Low priority	7-11	11	45

4.3. VRAKA risk assessment model

The VRAKA risk assessment model was developed in Sweden by Chalmers University of Technology. It is a model that performs quantitative probabilistic risk assessment of shipwrecks and an uncertainty analysis of the results. The tool is divided into two main parts: a tool for estimating the probability of discharge of hazardous substances from a shipwreck, and approaches for estimating the consequences of a discharge. It can also be used to better understand the risk, for example, to assess which activities contribute the most to the probability of a hole occurring in a shipwreck.

The first part is performed using a fault tree analysis, taking into account several hazardous activities and site and wreck-specific properties. It is also possible to consider uncertainties (Fig. 42). A generic probability of an opening is the result of each of the identified activities and the provided estimates of how these probabilities are conditioned by different indicators. An assessor estimates site-specific and wreck-specific indicator values for the wreck in question, and the generic probabilities are updated using a Bayesian approach, regarding the site-specific and wreck-specific information about indicators. The assessor also estimates the annual rate of hazardous activities.

In the second part, the consequences of a spill from a shipwreck can be assessed at three levels of ambition or available resources (tiers). In the Tier 1 assessment, the probability of discharge is combined with the expected volume of hazardous substance still contained in the shipwreck to arrive at an annual expected amount of discharged substance, hence a risk value. In a Tier 2 assessment, a consequence matrix considers the distance to shore, the volume of released hazardous substance, and a simple assessment of the sensitivity of receptors, in addition to the Tier 1 factors. In Tier 3, the consequence is assessed in even greater detail, based on the estimated discharge of hazardous substances from the shipwreck into the marine environment, the type of end-point receptors, and the vulnerability of each receptor. This is done by modelling the load of hazardous substances to end-point receptors using the Seatrack Web tool developed by the Swedish Meteorological and Hydrological Institute and maps of sensitivity to oil spills in the Swedish Digital Environmental Atlas (Landquist et al, 2016).

The model is used within the Swedish national wreck program to prioritize in situ investigations and oil removal operations. The Tier 1 assessment is used as a crude prioritization to determine which wrecks should be subjected to more detailed in situ investigations. Finally, the Tier 3 assessment is applied to determine which wreck should be prioritized for the oil removal operation.

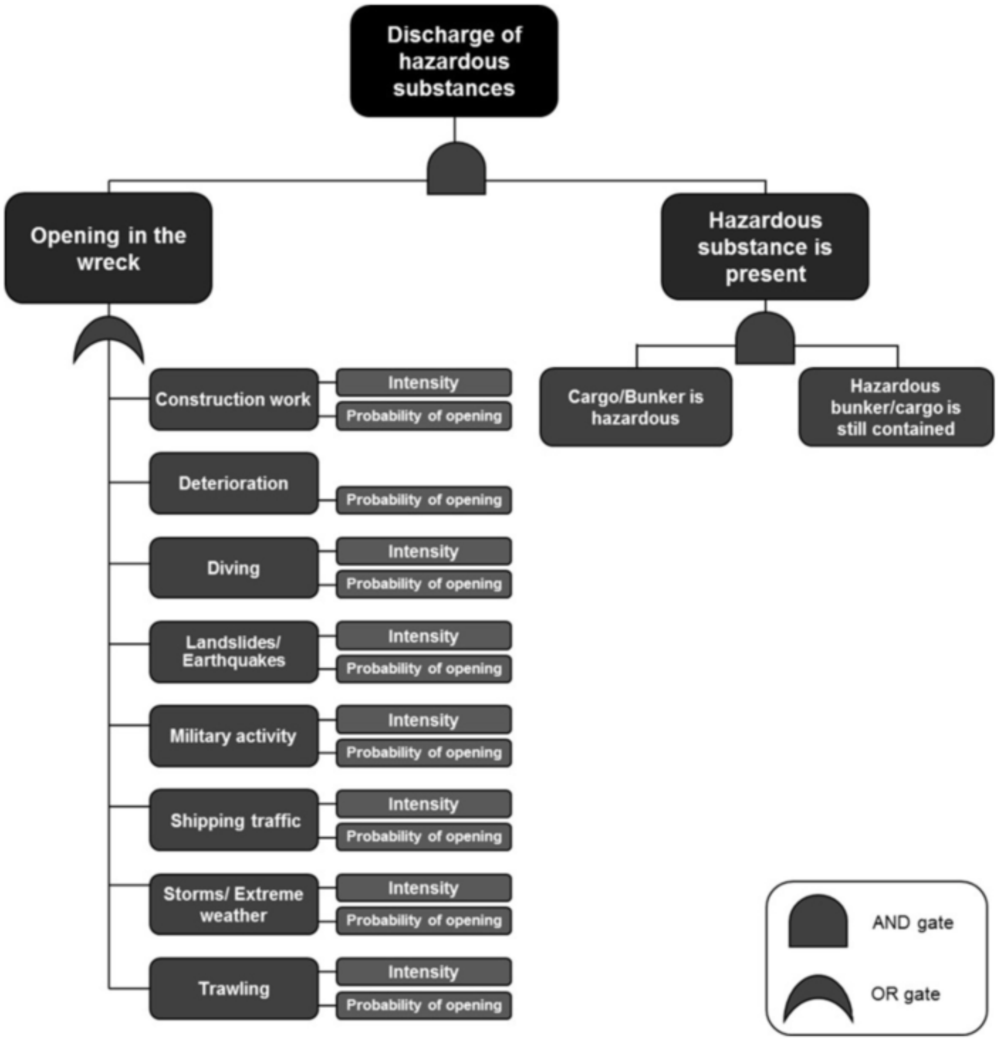


Figure 42. The fault tree used in the VRAKA model illustrates the various activities and site-specific and wreck-specific properties used to calculate the possibility of hazardous product leaking from the wreck (Landquist et al., 2016).

4.4. E-DBA risk approach

The Polish E-DBA (Environmental Desk-Based Assessment) is described in detail in Hac & Sarna (2021). It is based on a method developed by CEFAS (Centre for Environment, Fisheries and Aquaculture Science), UK in 2016 (Goodrir et al., 2019). It uses the OSCAR model (Oil Spill Contingency and Response) developed by Sintef, Norway, for oil spill modelling, combined with open-access global meteorology and ocean data, thus having a wide usage not dependent on the sea area in question. Figure 43 provides an overview of the assessment process for carrying out the environmental desk-based assessment (E-DBA) for wrecks (Hac & Sarna, 2021).

The E-DBA assesses the environmental risk of potentially polluting shipwrecks through a three-stage process:

1. Predicting the likelihood of a wreck releasing oil by using available historical information and survey data from the area in the vicinity of the wreck;
2. Modelling acute and chronic oil spill scenarios to determine the likelihood of sensitive ecological and socio-economic receptors getting exposed to the released oil

3. Determining the risk for each receptor based on the likelihood of exposure and potential impact

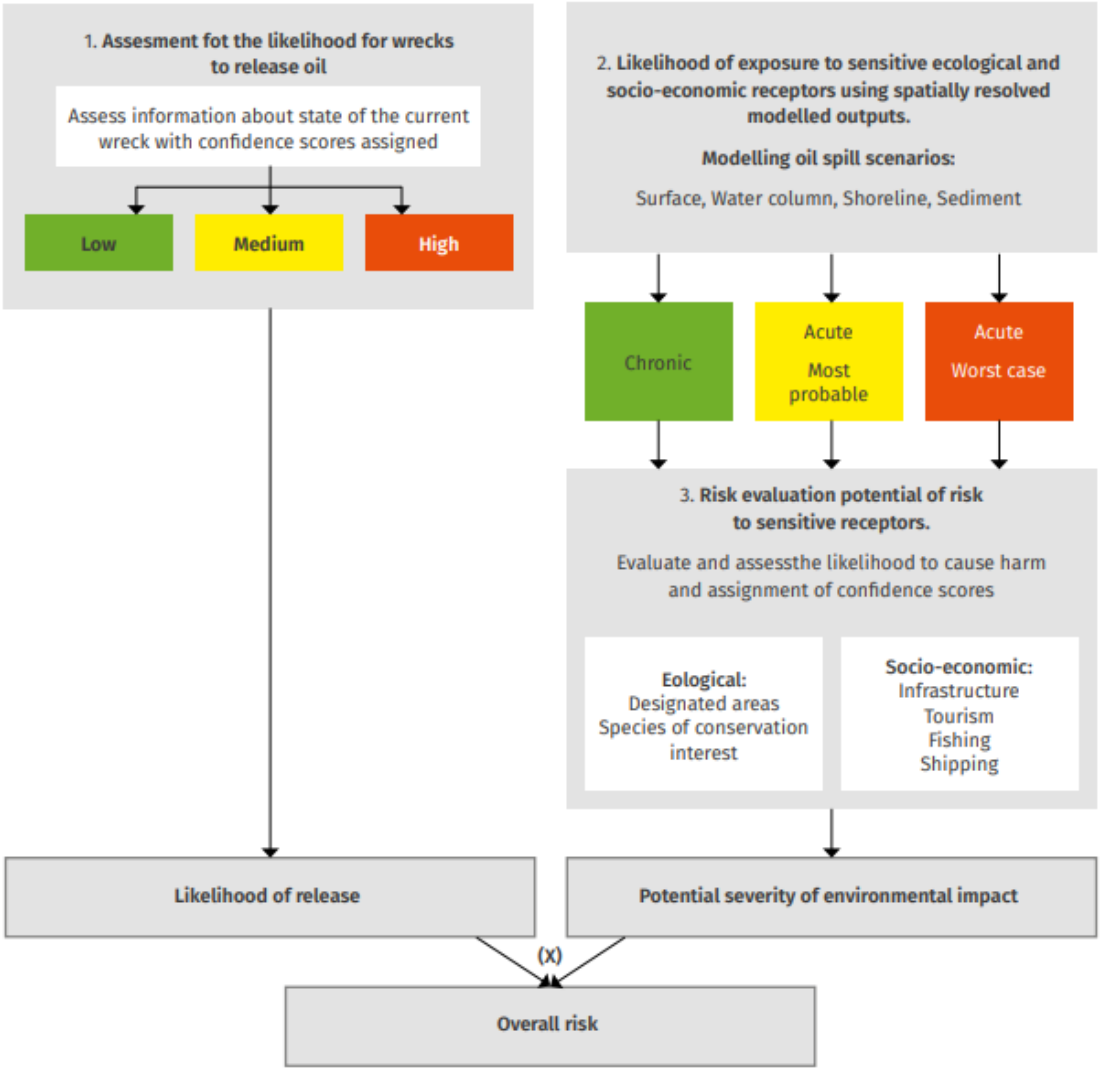


Figure 43. Flow diagram illustrating the assessment process for carrying out the environmental desk-based assessment (E-DBA) for wrecks, for which the Ministry of Defense, Poland, is responsible (Hac & Sarna, 2021).

4.5. ORRA Oil Removal Risk Assessment Toolbox

A tool for assessing the risk of oil salvage operations of wrecks was developed by Alfons Håkans in the beginning of 2013 in Finland. It considers ten factors that affect the conditions of an oil removal operation (Fig. 44). The main aim for the development of this new approach was to give guidance to underwater works, especially for oil removal operations of wrecks. The ultimate goal is to have a systematic approach for assessing the complexity and risks during an oil removal operation. The results allow designing a realistic approach for the salvage operation to address these risks and to better assess the costs of the work.

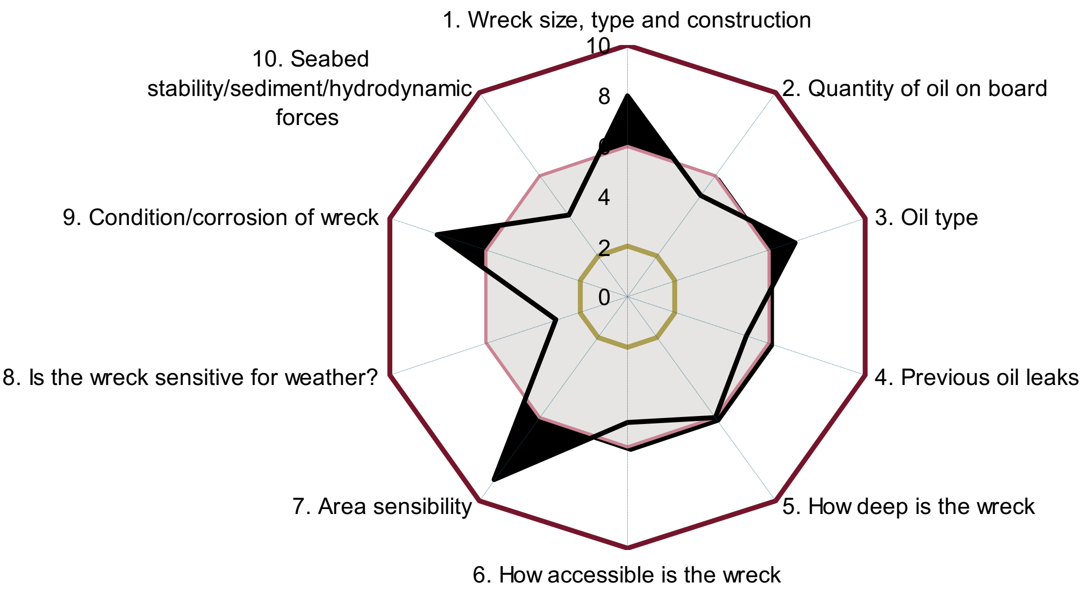


Figure 44. Preliminary sketch of the ORRA tool (Rytkönen, 2016).

The parameters have a scale from 0 to 10, where a certain predefined limit is set to describe the threshold at which the operation will be difficult, costly, and/or take more time and resources. In the example in Fig. 44, the threshold value was set to 6, which describes the medium conditions, i.e., normal conditions where no extra concern is warranted. In the example, the factor 1. Wreck size, type, and construction have a result of 8, which corresponds to extra concern on the type of the vessel. The factor 9. condition/corrosion has a value of 8 as well, describing that additional concern related to the wreck, where special underwater efforts need to be carried out to reach the fuel oil tanks. Factor –6. How accessible is the wreck, defines the wreck´s position on the seabed, how deep it might be buried in the sediment, and how much dredging, cargo removal, and steel cutting operations are required to reach the oil tanks. Design principles of these underwater operations have been described in (Rinne et al., 2016).

Figure 45 displays the ORRA philosophy, where the uppermost horizontal line describes the total costs of the oil spill caused by the wreck in the future. Typically, wrecks are leaking sporadically, and authorities are forced to carry out investigations to resolve the origin of the oil spill and enact countermeasures. Small spills occurring every year pollute the surrounding environment, and the total costs of the countermeasures, investigations, and ad hoc booming, etc., multiplied by the duration of the problem, are usually higher compared to carrying out an oil removal operation prior to the wreck starting to leak its content. Such a proactive operation also results in the avoidance of acute or chronic pollution, which is the result of the oil spill from the wreck (Rytkönen, 1999).

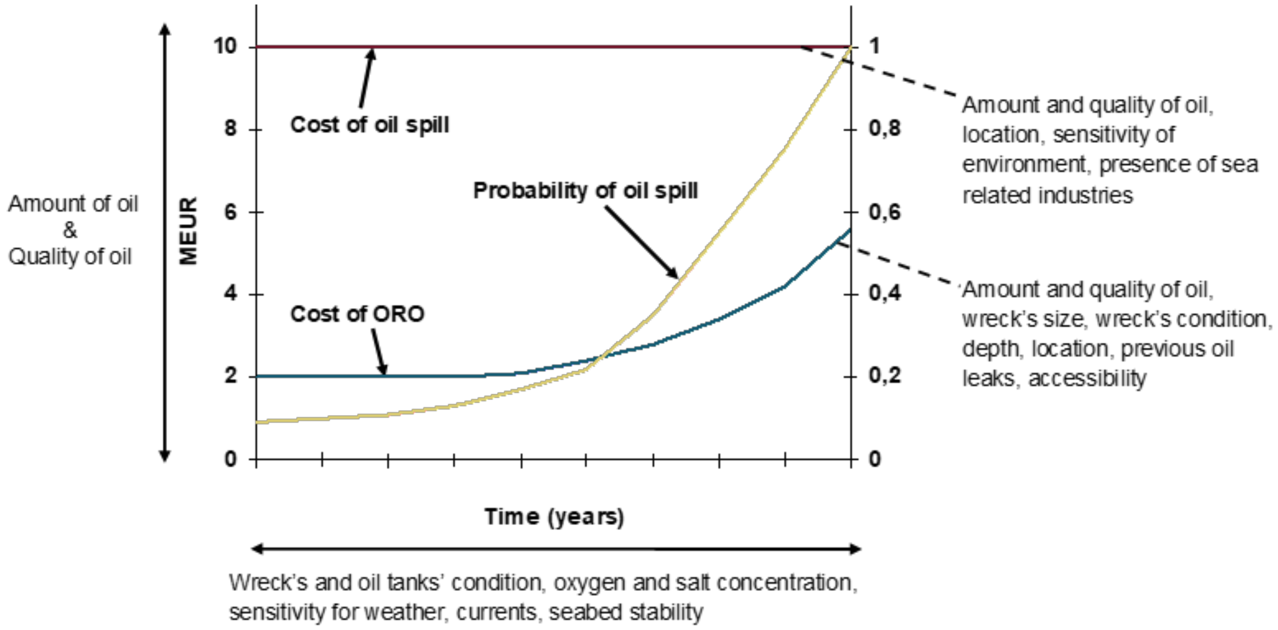


Figure 45. The cost of carrying out an oil recovery operation (ORO) is lower when the oil is located in the tanks. Once the probability of oil leakage from the tanks increases, e.g., due to corrosion, the cost of the oil recovery also increases. The definition of ORO and factors affecting ORO are described in (Rinne et al., 2016).

ORRA was also developed to include an assessment or description of the stages leading to an oil removal operation, which is highlighted in Figure 46. The first phase requires reviewing existing information about a shipwreck, for example, from a wreck register. In many situations, this information only provides preliminary data, and several important factors need to be investigated by additional studies and/or by in situ surveys. This phase provides a list of factors that can be used for prioritizing between wrecks with the greatest pollution potential or significance of impact on the execution of the oil removal operation (Rytkönen, 2016). This leads to the second phase, in which the VRAKA model is used to assess the probability of an oil leak from the wreck. VRAKA is described in Landquist et al. (2016 and 2017) and above.

The third phase is to assess the consequences of the oil leakage, which is already built into the VRAKA model. For example, using VRAKA (e.g., Tier 2) includes parameters considering the volume released, distance to the shore, and the sensitivity of surrounding areas. The potential oil spills during the operation (i.e., technical spills) are part of the next phase, where the focus is directed on factors and information related to a successful oil removal operation. To summarize, archive information, monitoring, risk assessment, and technology options for an oil removal operation are the parts of the ORRA process. The output is the estimated ratio for success for a certain salvage technology, with expected costs for the operation (Rytkönen, 2016).

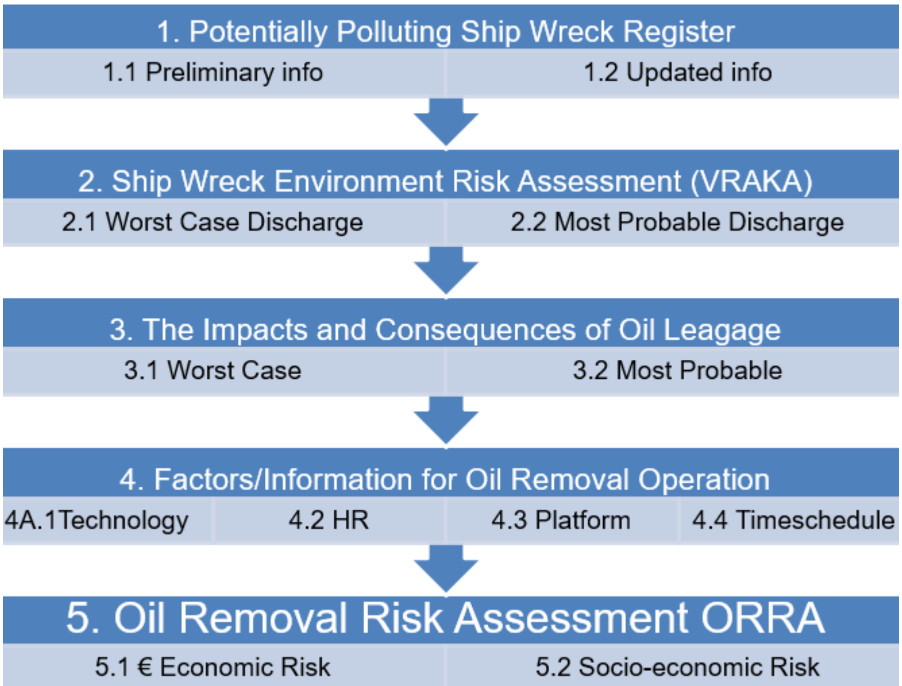


Figure 46. The oil removal risk assessment phases in the ORRA method (Rinne et al., 2016).

4.6. Risk Index Method

Attempting to assess the risk of a release of oil from a potentially polluting marine site (PPMS) can be a very subjective process. The Marine Site Risk Index (MaSiRI) is designed to provide a more objective approach to this process by adopting a table-based evaluation scheme, while still allowing for the inevitable unknown conditions by including a subjective expert correction in a suitably controlled manner. Building on a geographic database of PPMS records, the MaSiRI algorithm applies data filters to remove PPMS records for which the model is not applicable and then estimates a basic risk index based on core data that almost all sites would contain. It can then refine the results for those sites that have auxiliary data, varying the assessed risk as appropriate, according to standard rule sets.

A risk level of confidence is computed and adjusted to express dynamic confidence in the risk value (e.g., due to reliance on estimates rather than measured values). Where appropriate, an upper and lower bound of risk can be used to assess the range of values associated with an estimated parameter. This information can be visualized by a composite quality symbol.

MaSiRI has been demonstrated on three illustrative shipwrecks and then compared against the Development of European guidelines for Potentially Polluting (DEEPP) project database from the Pelagos Sanctuary in the western Mediterranean. The aggregate MaSiRI results of the comparison are broadly similar to DEEPP, within the limits of the comparison. However, they provide a more detailed analysis in the case of estimated pollutant volume and ubiquitous assessment of levels of confidence (Masetti & Calder, 2014).

5. Survey and in situ inspection of shipwrecks

5.1. General

The surveying of shipwrecks can in practice be divided into the following groups:

- wrecks not yet found, where the task is to use the best available technology to detect them and establish their exact location;
- known wrecks with no indication of an oil leakage, but they are considered to constitute a risk to the marine environment;
- and known wrecks that are leaking oil or other hazardous products.

When a wreck without an established position shall be subject to a survey, the work usually starts as a desk study, during which all available information related to the wreckage or sinking is collected. However, a desktop study is always of interest, to provide detailed background information regarding the wreck and events during the wreckage. After finding the position or if there already is a known position of a wreck, a survey of the wreck can be carried out. This can involve high-quality imaging of the wreck, through multibeam or photogrammetry techniques, and/or sampling of sediments in the area close to the wreck, or other parameters needed for a risk assessment of the wreck. Finally, to complete or enhance the reliability of the risk assessment and prioritization of the concerned shipwrecks, but before an oil removal operation can be carried out, an in situ inspection of the wreck can be carried out. This inspection can provide information on the state of corrosion on the wreck and if and where oil is still contained in the wreck. Finally, a monitoring program could be put in place to follow up on the status of the wreck within certain set time intervals, if no oil removal operation is planned in the near future. The various stages are described in more detail below in the following sections.

5.2. Desk-based studies

Desk-based studies refer to various archival studies with the main goal of collecting as much information on the ship, cargo, and all factors affecting the wreckage or sinking. Technical data, main drawings of hull and tanks, and bunkering data are all relevant information. Descriptions from witnesses or crew and data collected by divers or other bodies may be helpful to get an understanding of the possible amount of fuel or hazardous cargo onboard, the wreck's main particulars, and orientation on the sea floor. The technical data to be collected here includes information on the fuel tanks and cargo holds, hull construction, hull thickness, etc.

The year of construction and the shipyard may impact the current status of the shipwreck, e.g., the use of different steel quality at different places over the years. If the ship was remodelled at any time, that information is of interest as well. The name and location of the shipyard may help in obtaining the drawings of the ship.

The basic parameters to be collected here are:

- Name of the ship, and possible previous names of the ship,
- IMO number for modern wrecks,
- Year of construction,
- Year of rebuilding or significant retrofitting projects,
- Year of wreckage or sinking,
- Reason for wreckage or sinking,

- Main particulars of the ship,
- Type of the ship (tanker, cargo, passenger, military, other),
- Nationality/flag,
- Hazardous cargo (including volumes contained during the wreckage),
- Work safety/contamination risk,
- Munitions onboard,
- Orientation (standing on keel, bottom up, on side P/S),
- Wreck in sections,
- Condition of the ship at the time of the wreckage,
- War grave/historical care,
- Drawings (GA, tank layout/specific, thickness of steel plates, piping).

In addition, there are other parameters or information that can be of interest as input data for the risk assessment and for future in situ investigations. Examples of these are the distance from the wreck to shipping fairways and the intensity of ship traffic in the vicinity of the wreck, military activities in the area, intensity of storms, intensity of fishing activities with bottom gear, and intensity of diving on the wreck (Landquist et al., 2016).

5.3. Geophysical and other surveying methods

Geophysical and other survey methods of shipwrecks commonly include surveys such as:

- Bathymetric surveys to determine the depth of the wreck location and to assess the nature of the seabed,
- Surveys using side scan sonar, acoustic camera (i.e., high frequency scanning sonar), multibeam sonar, or photogrammetry to determine the particulars of the wreck, to identify other objects in the vicinity, and to get a detailed image of the wreck and its condition,
- Surveys of the sea-floor using an acoustic sub-bottom profiler (SBP) to detect objects covered by sediment and to detect layers of contaminated sediments (with heavy diesel oil), or
- Magnetometry survey of metal object distribution with a magnetic signature, such as parts of the hull, equipment, and cargo scattered around the wreck (Hac & Sarna, 2021).

For more information on geophysical and hydroacoustic survey methods, the reader is referred to sections 4.3.1 and 4.3.2 of the HELCOM Thematic Assessment on Warfare Materials in the Baltic Sea (HELCOM, 2024). In recent years, large sea areas have been surveyed for the purpose of electronic sea charts, including mapping of the seabed. This has resulted in data, which includes “anomalies”, that provides candidates for the positioning of non-identified shipwrecks. A common method to use is side scan sonar (SSS), usually towed by a surveying vessel (Fig. 47). The sonar sends out two sound beams with a high frequency, which are reflected by the sea floor and objects on the sea floor. This reflection is then used to produce an image of the sea floor.

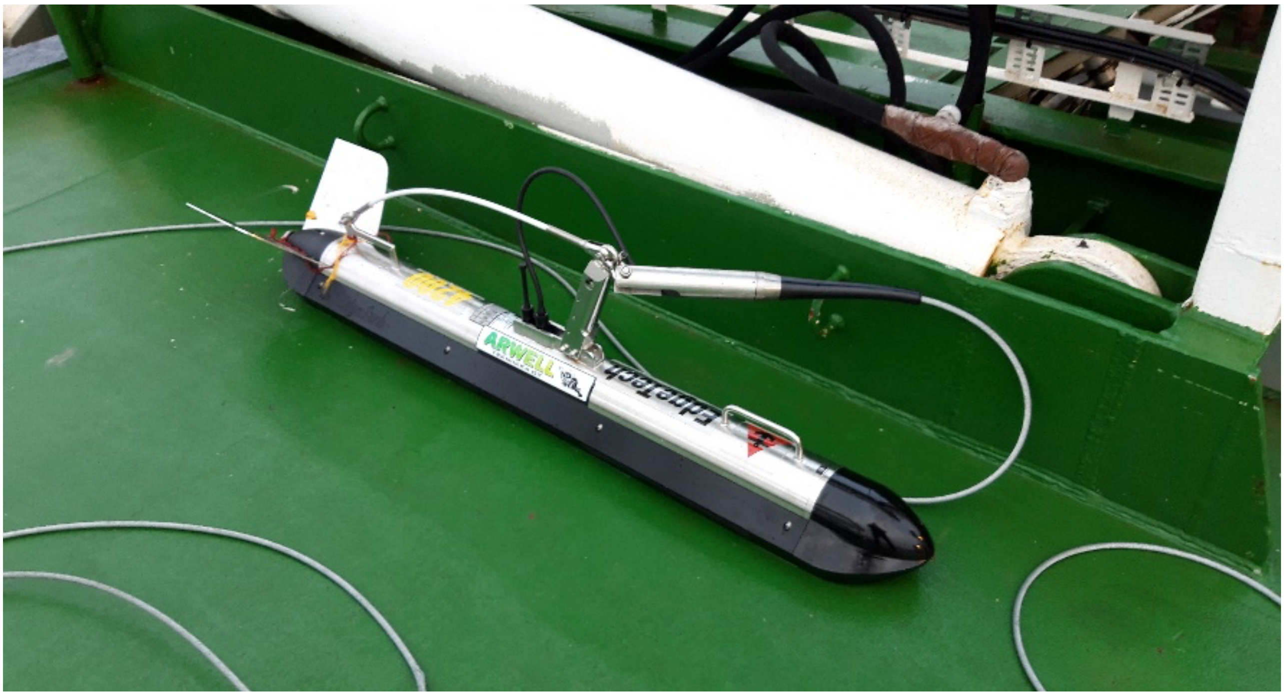


Figure 47. A Side Scan Sonar (onboard MV Aranda). Photo: J. Rytkönen.

Another, more advanced method to use is multibeam sonar. This technique is based on sending multiple beams of sound, with a broad swath. The sound is then reflected to the transceiver, and with the time registered, a detailed image of the sea floor and objects on the sea floor can be created. Figure 48 presents two images produced using a multibeam sonar. The wrecks are clearly visible, and the type of ship, orientation, and form can be noted. Images using multibeam can be used for temporary verification of possible changes on a wreck and to be used for salvage/oil removal planning. To receive an even higher quality image of a wreck, for accurate positioning of possible fuel tanks (for marking and planning of positions of penetrations into tanks) or in-depth evaluation of the status of a wreck, a 3D model or photomosaic of a wreck can be produced. Data are acquired by ROVs or divers with a large number of photos, from different angles. The photos are always overlapping. They are then stitched together using photogrammetry software to make a 3D model and other products, e.g., a photomosaic or a digital elevation model (DEM) image (Fig. 49).

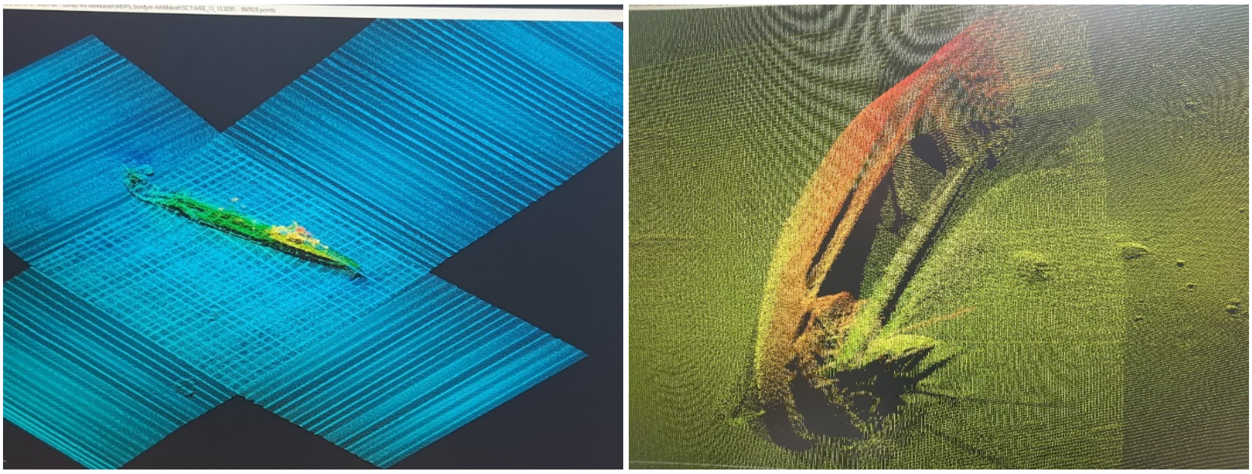


Figure 48. To the left is a preliminary image of the Soviet wreck Gordyi in the Gulf of Finland, and to the right is a wreck with lost fishing gear on the cargo holds bow section (SYKE).

If one is interested in the bottom topography and the distributions of the upper layers of the sea floor, a special sub-bottom profilometer can be used. These sensors can also be used to detect submerged objects besides a wreck.

Figure 49. Photogrammetric reconstruction of the shipwreck Harburg, located in the inlet to Stockholm, Sweden.

5.4. In situ inspections of shipwrecks using divers or ROVs

After having detected the shipwrecks that are candidates for further investigation, due to, for example, prioritization by risk assessment, confirmation of the wreck or in situ investigation of its status is usually performed by divers or, in large water depths, by Remotely Operated Vehicles (ROVs) or Autonomous

Underwater Vehicles (AUVs). Sonar imaging provides the position of a wreck and imaging. However, only a close visual inspection by divers or ROVs using digital imaging can provide details of the condition of the wreck, such as the location of holes, leaks, corrosion, etc.

Whether divers can be employed for the inspection of a wreck depends on the physiological limitations as well as on national rules. It can be very effective in shallow depths as divers are adaptive and can easily use the required equipment. However, the dive time at the wreck is reduced with increasing water depth, while the decompression time during the ascent increases. In addition, divers need to rest for a certain time between each dive. Hence, several divers are needed for a continuous inspection of a wreck. The use of diving tanks is usually limited to a depth of 50 m to 60 m. At water depths of 60 m to 80 m, divers need to use Trimix (nitrogen, oxygen, and helium), and at water depths exceeding 80 m, saturation diving is needed. However, since the execution of diving in deep waters (>60 m) is very complicated, inspections of wrecks at these depths are usually carried out using ROVs or AUVs (Alcaro, 2007). There are several types of ROVs available. The models and sizes of ROVs vary and depend on the task. The standard set of equipment is usually sonar, digital camera, and/or video camera, lights, and manipulator arms. The ROV is connected by cables to the survey vessel's monitoring room, where operators control the ROV and monitor it through screens. Figure 50 shows an example of a ROV used for wreck surveying and oil removal.

The survey is usually focused on the general condition of the wreck and the state of deterioration and corrosion. Details such as holes in the hull or other signs of deterioration are of interest. The divers or ROV can measure the hull thickness (and then the corrosion rate can be assessed) at predetermined locations, take photos and videos of the hull, and make general observations. If the ROV is equipped with a sonar, it is also able to survey the surrounding sea floor for anomalies that can turn out to be munitions, mines, hazardous objects, or parts of the wreck. Lost fishing gear or other debris, such as ropes and wires that are stuck to the wreck or are loose in the water column above or close to the wreck, are also of interest to document. These can hinder and cause a hazard to a future oil removal operation.

Figure 50. Large ROV onboard work vessel Vina used for survey and oil removal operation of the wreck Rone in 2022. The ROV is equipped with two manipulator arms, one for cleaning the hull of the wreck from organic debris and old paint, and one for carrying drilling equipment (not attached in the photo) (Photo: JF Lindgren).

The estimation of the state of corrosion and corrosion rate on the wreck is of great interest. Corrosion is a result of multiple variables, including the condition of the steel in the hull before the wreckage, salinity, oxygen conditions, and the presence of biological organisms on the hull. An estimation of the corrosion rate of wrecks in the Baltic Sea and the North Sea is provided in Sender (2011). Based on the report, the corrosion rate can vary between 0.03 mm/year and 0.07 mm/year. These rates are valid for water depths ranging from 50 m to 150 m. The report also describes the different types of corrosion, the main parameters affecting corrosion, and provides recommendations for monitoring intervals for wrecks of interest.

In many cases, the fuel tanks in a wreck contain a pocket of air in the tank's topmost location. Due to the oxygen in the air, this is a position where the corrosion rate is higher compared to other parts of the tank. Therefore, the topmost parts of fuel tanks can be points of interest. Important information can be attained by measuring the remaining steel plates' thickness at, for example, tank areas, and then estimating the corrosion rate of the wreck. To measure the thickness, various underwater material thickness gauges can be used. Repeated on-site measurements are the only reliable method to estimate and predict the hull condition.

The survey can also be focused on determining the type and quantity of hazardous material in the wreck. An inspection of the cargo area can identify the type and amount of cargo contained in the wreck. If there is oil left, and what volumes are left in the wreck, is also information that is very valuable to a future oil removal operation. Various types of oil act differently when entering the water and have different viscosities, which is very important in the oil removal phase. This will provide important input on what type of pump is needed and whether the oil needs to be heated in the tank prior to pumping to the vessel on the surface. In most cases, the only way to determine the volume and type of oil inside the wreck is to use divers or ROVs to drill small holes in the hull at locations where, for example, bunker tanks and the machine room are located. This will answer whether oil is contained in the tank and, depending on the distance to the highest point in the tank (and if you have the tank particulars), the volume that is contained can be calculated. If additional holes are drilled, a better calculation can be made. A sample of the oil can also be taken for analysis of the type of oil. The holes must be immediately resealed using plugs (metal or wood) to prevent the oil from leaking into the aquatic environment.

Another technique that has, in some cases, been applied in trying to determine the volume of oil inside a tank is neutron backscatter measurement. This is a non-intrusive technique where high-energy neutrons are sent into the hull and tank, and the higher the number of reflected neutrons, the higher the hydrogen content of the liquid on the other side of the steel hull. This can then be compared to the number of neutrons that are reflected back if the compartment inside the hull only contains water to calibrate the sensor. The technique avoids the probability of an uncontrolled release of oil. However, the readings can be affected by other metal or debris in the tank, the oil can be mixed with water, skewing the measurements, or no tank, only containing water, is available for calibration. Preferably, the application of neutron backscattering should be combined with drilling holes in the hull (Hill et al., 2022).

In addition, information regarding a wreck that may be needed is, for example, a general understanding on the wreck's orientation on the sea-floor, the state of the wreck on the sea floor, the possible accessibility to fuel tanks, the need for clearing of sediment prior to an oil removal operation, and possible munitions on the wreck.

5.5. Water and sediment sampling, and physical parameters

During the in situ study of a shipwreck or in a separate survey, sampling of water and sediment, and measurements of physical parameters can be conducted. This can provide information on whether the wreck is leaking oil or other hazardous substances and provide important data to the risk assessment, for example, for estimating corrosion rate. Water and sediment samples can be taken by divers or ROVs and analysed for hydrocarbon and PAH concentrations. Sensors can be stationed on the sea-floor in the vicinity or on the wreck. The typical physical parameters to be measured are:

- Sea currents are usually measured with an acoustic doppler current profiler, which will give the vertical distribution of the horizontal sea current velocity, usually in one-meter to four-meter intervals. Knowing the sea current profile in the vicinity of the wreck provides information for taking water and sediment sampling at the right locations, downstream of the wreck. The magnitude of the sea current at the level of the wreck also provides information on whether the current will be a problem hindering diving or ROV operations during the oil removal operation.

- Temperature, salinity, and oxygen profiles inform about the conditions in general and provide information for estimating the corrosion rate.
- Turbidity measurements provide information about the working conditions for the possible salvage operation.

Analyses of the retrieved water and sediment samples can cover many parameters, depending on the width and focus of the survey. Interesting parameters are:

- Indicators of aerobic conditions (dissolved oxygen) in the sediment
- Substances particularly harmful to the aquatic environment, such as copper, zinc, cadmium, lead, mercury, hydrocarbons, polycyclic aromatic hydrocarbons (including alkylated PAHs).

Sampling of sediment can be performed with samplers (e.g., a Van Veen sampler) and provides material for chemical, geological, and biological analysis. Sediment samples are usually collected with these methods as the surface profile of the bottom material remains intact and can then be analysed in more detail. Hac & Sarna (2021) state that four to six samples taken around a wreck, or downstream, are sufficient to determine the chemical conditions at the sea floor. However, if there is known contamination from a shipwreck, more samples are needed. For example, as many as 1 022 samples were taken to detect and evaluate the entire contaminated area around the shipwreck Stuttgart, in Gdansk Bay. In Finland, sampling was performed during the planning stage for certain oil removal operations to obtain background contamination values, then during the operation phase, and finally, some months after completion of the operation. To determine if any post-work leakage or contamination remained, which should be studied later.

Sampling aquatic organisms can also provide information on whether the wreck affects the environment negatively. Zoobenthos is composed of the organisms living in the sediments, both at its surface (epifauna) and in the sediment (infauna). The diversity and community composition of macrozoobenthic organisms (>0.5 mm) in the area in the vicinity of a shipwreck, due to the relatively long life cycle, can be good biological indicators for long-term changes in the environment (Hac & Sarna, 2021).

5.6. Monitoring of hazardous shipwrecks

HELCOM contracting parties perform environmental monitoring of their territorial waters and EEZ. For example, the Finnish Environment Institute monitors the state of the Baltic Sea four times a year with the research vessel Aranda and one coastal monitoring cruise with a smaller vessel. The cruises are part of the monitoring of long-term changes in the state of the Baltic Sea, but also serve the national monitoring program for Finland's Marine Strategy and the HELCOM monitoring programme of the Baltic Sea countries. During these cruises, physical, chemical, and biological parameters are collected and measured, but also hazardous substances both in the water column and sediments. Based on the monitoring data, it is possible to assess the oxygen concentration, eutrophication, and possible temporal and spatial changes occurring in plankton and benthic fauna.

Research vessels can also be used to monitor hazardous shipwrecks. The research vessel RV Aranda has, for example, been used successfully to chemically and biologically monitor five wrecks in Finnish waters. There are, of course, also other research vessels in the Baltic Sea area. After risk assessing potentially polluting shipwrecks and prioritizing between them according to the risk, the positions of the selected risk wrecks can be made available to the research vessels for possible long-term monitoring. Dozens of high-risk wrecks could be targeted for this kind of long-term monitoring, while others could be subjected to only temporary surveys and monitoring, for example, of the state of corrosion and the overall deterioration of the wreck.

Larger buoys can be used to measure both meteorological and hydrodynamic properties. Measurements of wind and currents in the area of a wreck can provide important input data for oil drift models to assess where the possible oil spill from a wreck would end up, under certain environmental conditions. Examples of oil drift models are CHEMMAP (McCay, 2015) and Seatrack Webb (which is most commonly applied in the Baltic Sea area). Additionally, this type of data is important for the planning of in situ investigations of wrecks or oil removal operations. It provides the operators with information on wave and wind conditions in the area throughout the year.

Another way of monitoring hazardous shipwrecks of priority is placing an underwater monitoring system around a wreck, with the aim of detecting possible oil leaks from the wreck. In addition, other sensors could be attached to the system to provide other types of data, e.g., salinity, sea currents. The data and power transfer are a complex part of this kind of system. Usually, sub-sea data collection systems (data loggers or other data storage units) need to be retrieved and changed, or loaded by experts onboard the survey vessel. Other systems can be approached by divers or ROVs to collect the monitoring data (e.g., via Bluetooth or direct data transfer). If the wreck is not located in a shipping lane or in a bottom trawling area, a floating buoy can be anchored close to the wreck, and all data from the sub-sea sensors can be linked to the buoy and sent via satellite or other means to a ground station. There are also subsea sensor systems, which are submerged and perform measurements, but can temporarily rise to the surface and transmit the data.

6. Remediation and salvage measures for polluting shipwrecks

6.1. Methods to eliminate or reduce the environmental risk from shipwrecks

Different operations can be carried out in order to evaluate, minimize, and eliminate the environmental risks deriving from potentially polluting wrecks. Remediation measures can be initiated reactively after an oil leak has been detected and confirmed to originate from a shipwreck, or if proactive measures are to be taken on a wreck, after risk assessment and prioritization. Depending on the position of the wreck, water depth, deterioration of the wreck, the rate of oil leaking from the wreck, volume of oil contained in the wreck, the type of oil there are several options for remediation work depending on the available resources, funding and the environmental conditions surrounding the wreck site. The options range from closing the hole being the source of the leakage in the wreck up to recovering the entire wreck. A survey of the wreck site is an important part of the remediation measures. It enables the salvor to determine the source of the leak, the position of fuel tanks, and other relevant positions on the wreck, to develop a plan and use the best option to stop the leak or remove the oil. Possible options to eliminate or reduce the environmental risk from a shipwreck are listed below and are more detailed presented in NOAA (2013) and Alcaro et al. (2007).

Sealing the leaking points of the wreck is an effective method to halt the immediate environmental effects of the spill. However, the method is only a temporary solution, as it does not remove the remaining oil in the wreck. It can be an effective method to provide more time to plan the oil removal operation.

Controlled salvage of the released oil in the water column can be necessary as a type of emergency measure if the source of the oil leak is difficult to locate or the leakage position is located deep inside the wreck. This type of operation can have relatively low costs, however, the risk of oil entering the marine environment is greater than for an oil removal operation. In case of a continuous small release of oil from a shipwreck, a type of large cone or box can be lowered, as closely as possible, over the point of release to collect the oil. Using a hose, the oil can be salvaged to the recovery vessel. An example of this type of salvage is the initial part of the oil removal operation from the shipwreck Finnbirch in Sweden. Here, the operation started with a collection of the leaking oil in the water column by the Swedish Coast Guard, before resources for an oil removal operation of the wreck could be assembled (SwAM 2019).

Capping (or backfilling) of the entire wreck or the cargo aims to completely cover the wreck or the cargo to avoid a future leakage of pollutants from the wreck into the marine environment. Typically, capping material consists of sand, gravel, or clay, depending heavily on the purpose and the locally available material. A more complex capping material may contain geotextiles, other synthetic materials, and other permeable or impermeable materials in multiple layers. The material may also contain an addition of active substances, in the form of organic carbon or other modified forms, to slow down the flow of contaminants from the material (U.S. EPA 1998, U.S. EPA 2004).

It is a method that might be suitable for wrecks that are highly deteriorated, and any other activity has a high probability of releasing oil to the surrounding environment. Although the capping of the wreck can introduce pollutants into the water, it may be considered effective and fulfil the objectives. Capping was, e.g., used in the port of Helsinki, where wrecks of old deteriorated trawlers were towed to dredged ditches that were prepared with clay at the sea floor to prevent pollutants from entering through the sea floor. This method can be both very costly and it is difficult to ensure that oil or other pollutants cannot escape from the capping and affect the marine environment.

Recovery of the wreck is an operation during which the entire wreck is lifted to the surface for easy access to tanks, etc., for oil removal. Not only the oil but also other types of hazardous or contaminating materials and substances can be removed from the wreck. Afterwards, the wreck can be sent to waste treatment for material recycling or be lowered back to the sea floor. The challenges of this technique are connected to the possible breaking of the wreck during the lifting operation and the equipment needed when dealing with larger wrecks.

Oil removal operation, where the hot-tap method represents the most common, is the preferred and low-risk method for the removal of oil from submerged wrecks. It is therefore described in more detail.

In the first stage the hot-tapping points on the shipwreck are selected, for example the highest points in bunker tanks, machinery spaces and at the highest points in the wreck in general where oil might accumulate (Fig. 51). Secondly, the area around the drilling points is cleared of organic debris and hull paint, to attach drilling equipment, using suction or magnets. Then, access holes into the selected compartments in the wreck are drilled using special drilling equipment, and the presence of oil is confirmed. Note that drilling of holes for verification of the presence of oil can also be performed using a Cox gun. It uses a cartridge to fire a solid or hollow bolt into and through the steel. Next, a baseplate or flange is attached over the hole in the wreck, and when the drilling equipment is removed, a valve is attached. A hose can then be connected to the valve, and the oil can be pumped to a vessel on the surface. Heating of the oil, usually with steam or heating coils that are inserted into the tank, can be necessary prior to pumping if the oil is highly viscous. Depending on the viscosity of the oil or water depth of the wreck, the pump can either be located on the deck of the vessel on the surface, a suction pump, or close to the hole in the wreck, a screw pump (Archimedes pump). The diameter and construction of hoses are calculated and chosen depending on the depth of the wreck, as well as the type and quantity of oil. The weather conditions also affect the mechanical wear and tear on the equipment, and hoses need to be able to cope with these conditions as well. The operation is then repeated at all the positions on the wreck that were selected for penetration and oil removal.

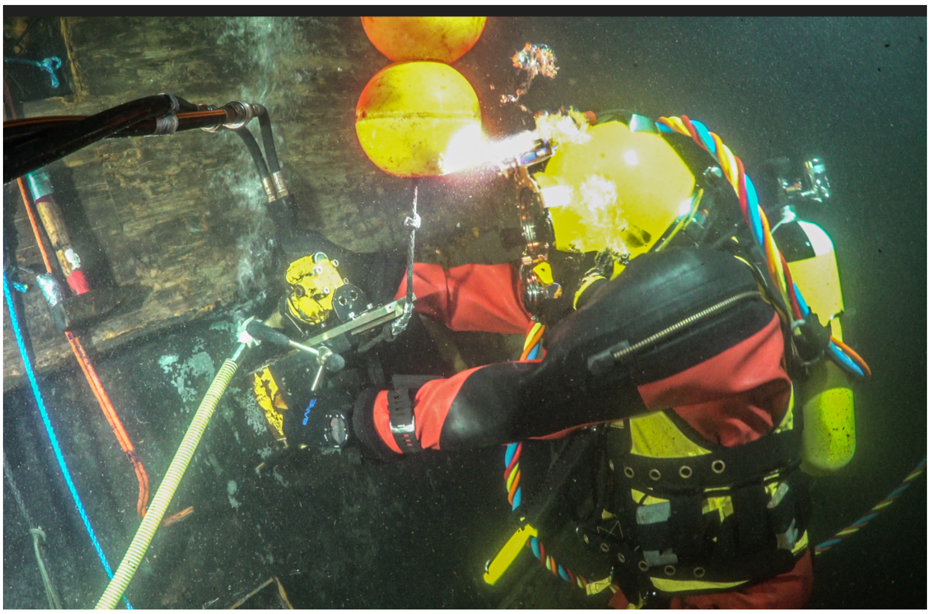


Figure 51. A diver drilling a test hole into the fuel tank of a sunken coastal freighter, for inspection of the presence of oil (photo: Badewanne/SYKE).

During the planning phase of an oil removal operation, the following additional factors should be considered:

- Underwater visualization of the area of work on the wreck during the operation.
- Planning and marking of penetration points on the hull.
- The oil removal plan should include the operational organization, time schedule for the operation, the vessel(s) used, work method plan including underwater techniques and oil removal techniques, plan for storage of recovered oil on board, and an environmentally sustainable disposal at facilities on shore. The oil storage and disposal plan should include how the recovered oil will be stored first on board and then how the recovered oil and oily waste will be further transferred for final processing. This may vary with the type of oil, quality, and quantity of the oil.
- There should also exist an overall operation risk analysis, which includes an action plan in case of oil leakage during the operation, and an action plan for other incidents, e.g., accidents which result in human injuries.

6.2. Aspects affecting the remediation or salvage measure

Water depth and hydrodynamics

Previous oil removal operations showed that water depth is one of the main parameters affecting the operation. The largest number of successful oil removal operations have been conducted in a water depth of less than 100 meters, while operations in deeper waters have been scarce. This is mainly due to the technical difficulties in conducting operations. Divers cannot be used, and instead ROVs have to be applied. Hoses and pumps connected to the wreck need to be longer and put higher demands on reliability. The temperature of the water also decreases with depth, up to a certain point, which also puts demands on heating the oil before pumping can be commenced. If indeed the oil needs to be heated, there is a possibility that the hoses also need to have heating, preventing the oil from cooling and therefore becoming more viscous on the way to the surface. Waters far from land are also more vulnerable to heavy wave patterns, which can cause delays for the operation and then increase the costs of the operation significantly. Wrecks that are located in more shallow waters are more easily accessible; however, it is likely that the wreck has, over time, been more affected by mechanical abrasion from waves and sometimes ice, resulting in a wreck in poor physical condition. This can increase the possibility of incidents during the oil removal stage, with the results in an accidental release of oil.

For oil removal operations, the wind and wave conditions in the operation area usually determine which days are suitable for operations. Large waves result in a need to pause the operations, as the increased vessel movements of the salvage vessel result in difficulties in deploying divers and equipment. It can also result in increased hydrodynamic conditions close to the sea floor, affecting equipment attached to the wreck, for example, hoses.

Hydrodynamic conditions at various wreck sites differ and can change, e.g., seasonally. They affect the possibility of diving, and the precautionary aspects divers have to consider before entering the water. They can also affect the positioning of the salvaging vessel at the surface and the hoses connected to the wreck. The main hydrodynamic forces that can affect a wreck on the sea floor are:

Currents having non-oscillatory character, with time scales from 10 minutes up to hours, cause sediment transport and siltation patterns on the sea floor. Tidal motion is a significant driver in the ocean. However, its magnitude in the Baltic Sea area is insignificant.

Wind-driven oscillatory waves can affect a wreck close to the coastline and in shallow water, where the wind-induced currents and morphological changes of the sea bottom also affect the wreck and the surrounding area.

Turbulence, e.g., randomly oscillating flow patterns, can be caused by passing ships.

Obstacles on and in the vicinity of the wreck

In many cases, different kinds of obstacles are found on the hull or superstructure of shipwrecks. They have to be cleared or removed before it is possible to perform an oil removal operation. These can be lost fishing gear, such as nets, trawls, or lines. Cables or ropes from the ship that are still attached to it might be located in the water column above the wreck. Masts and antennas may have fallen over and may now be protruding from the wreck at various angles. All of this can make operations very challenging and dangerous for divers or ROVs. All these obstacles should be documented and cleared by ROV or divers before an operation. This provides safe working conditions during the oil removal operation itself. Wrecks that contain or are surrounded by munitions require special attention. Separate operations for disarming and removing the munitions prior to any salvage and oil removal operations might be needed.

In addition, wrecks can, depending on the amount of organic material in the water column and the time since the wreckage, be partially covered by sediment. An operation to remove the sediment may be needed to locate and access to the fuel tanks for oil removal. Large suction pumps can be used to remove sediment and other debris covering the wreck. The cargo in the ship can also form an obstacle for oil removal operations. During the Park Victory oil removal operations, a large amount of cargo needed to be removed from the ship in order to gain access to the fuel tanks. Finally, sessile organisms, such as corals, sea anemones, barnacles, and others, can be attached to the wreck, as the surface of the wreck constitutes a suitable hard substrate habitat for these types of organisms. It may be necessary to remove this biofouling to locate bunker tanks and to be able to attach drilling equipment that uses magnets to attach to the hull. This can be performed with high-pressure water equipment, mechanical scrubbing, and brushing by divers or ROVs.

Viscosity of oil

Lessons learned from, for example, projects in Finland and Sweden have shown that older types of oil have been more soluble due to the existence of lighter hydrocarbons in the fuel. However, projects also showed that oil that has been in tanks for a long period of time might fractionate into viscous and non-viscous parts. This puts high demands on the equipment used. Even though a light fraction might first be easily pumpable, the more viscous fractions may hinder the equipment, causing malfunctions as they enter the pump and hoses. Due to the improvement of oil refineries' cracking methods, modern bunker fuels are more viscous. Heavy fuel oils usually pose a challenge and need to be heated for several hours, depending on the size of the tank and equipment used. Heavy fuel oil may in some cases can be pumpable using an Archimedes pump without heating.

Measures in case of oil leakage during an operation

In some cases, there might be a significant probability of an oil leakage during an operation, or an oil leakage may occur during the operation. There must always be preparedness for these events during an operation. For example, all operations should take place inside an area that is protected by floating oil collecting booms. In open sea areas, a secondary boom can be anchored outside this inner circle based on the prevailing wind and sea current directions. For large-scale projects, access to skimmer capacity and a stand-by recovery vessel may be required. Alternatively, communication with the Coast Guard, which has access to this equipment, may be possible. Another protective measure against oil leakage from the wreck during the operation is having a large pyramid-like structure hanging over the location of operation on the wreck. If an oil leak occurs, the oil enters the pyramid instead of the marine environment. The pyramid should be attached to the salvaging vessel by a hose, making it possible to pump the oil to the surface. Furthermore, divers can have access to a small handheld pyramid construction if the oil leakage is small and can be captured by placing the pyramid above the position of the leak.

7. Conclusions

This assessment is a description and assessment of the environmental problem posed by potentially polluting shipwrecks in the Baltic Sea. It is based on data from by HELCOM contracting parties, published reports, and scientific publications. It informs about the status of work with shipwrecks by the contracting parties and provides suggestions on how to risk assess and prioritize between wrecks, and various methods on how to deal with or remediate polluting wrecks. The report introduces the legal aspects of shipwrecks, for example, the Nairobi International Convention on the Removal of Wrecks, or liability aspects when a wreck is leaking oil. Environmental consequences of shipwrecks discharging their hazardous content into the sensitive Baltic Sea are briefly touched upon when presenting risk assessment methods. Additional information can be found in other material from HELCOM, such as the HOLAS III assessment[20].

The main part of the data for the report has been gathered during the first working years of EG Submerged. Information has been updated as new information has been received. The idea of this compilation is to assist the HELCOM contracting parties in addressing the problem of polluting shipwrecks by providing information, preferred methods, lessons learned, and good examples from other contracting parties. Finally, this assessment is based on work carried out in the HELCOM contracting parties on potentially polluting shipwrecks, mostly from input from members of the EG Submerged. Certain countries, i.e., Finland and Sweden, have provided more information than others, as they have more data available.

The assessment shows that the awareness and concern among the HELCOM contracting parties regarding polluting shipwrecks grew following a previously made compilation in 2010 (Svensson, 2010). The study concluded that the potential pollution from shipwrecks was an environmental issue, but was receiving little attention. No research on pollution from shipwrecks in the Baltic Sea was found in database searches, and although the topic had been raised a few times, nothing had been done within the HELCOM framework (Svensson, 2010). The study showed that all HELCOM contracting parties had designated authorities for identifying shipwrecks, although mainly for the purpose of safety of navigation. Now, this new assessment shows that great progress on the issue has been made in several HELCOM contracting parties, especially in Sweden and Finland, where national wreck programs were initiated and several oil removal operations were performed. In Poland, Denmark, and Estonia, studies and survey operations related to shipwrecks were conducted to identify priority objects and assess the state of the wrecks. Progress by other countries that was not reported to the EG Submerged has not been addressed in this assessment.

To conclude, this report provides a status update on the HELCOM contracting parties' awareness and work with potentially polluting shipwrecks and exemplifies activities that were performed on wrecks. It provides methods that can be used for risk assessment and prioritizing between potentially polluting shipwrecks, followed by methods for surveying and in situ inspection of wrecks, and finally describes salvage methods for removing oil from wrecks or other ways to reduce the risk the wreck poses. Hopefully, the report can assist existing or future work with polluting shipwrecks, to lessen or remove the threat they pose to the marine environment, and in the end, contribute to a healthy Baltic Sea.

[20] https://helcom.fi/wp-content/uploads/2023/03/HELCOM-Thematic-assessment-of-hazardous-substances-marine-litter-underwater-noise-and-non-indigenous-species-2016-2021.pdf

The cost of oil removal operations from shipwrecks has been shown to be far less compared to the cost of oil clean-up operations after a spillage. These calculations do not include socioeconomic and environmental costs. Hence, a proactive removal of oil from shipwrecks is a cost-effective approach to alleviate the problem. Another positive consequence, besides cost efficiency, is that you negate the negative effect on the marine environment that would ultimately be the effect of the spilled oil or other hazardous products.

References

Alcaro L., Amato E., Cabioch F., Farchi C., Gouriou V. 2007. DEEPP Project. Development of European Guidelines for Potentially Polluting Shipwrecks, ICRAM, CEDRE.

Andresen K.J. 2022. Pilot study for source pollution detection and risk assessment practices for historical wrecks with and without ammunition - applications for condition assessment of Danish coastal waters within the EU Water Framework Directive. Academic report from the Department of Geoscience, Aarhus University, 56 pp.

Danish Navy. 2013. The emptying of the Fu Shan Hai. 24th July – 12th September 2013. 27 Slides.

Estonian Public Broadcasting. 2020. Gallery: Oil spill from WWII wreckage cleaned up in Narva Bay. https://news.err.ee/1094829/gallery-oil-spill-from-wwii-wreckage-cleaned-up-in-narva-bay

French McKay D. 2015. Applying Spill Impact Modeling to Wreck Risk Assessment. 39 slides. Applied Science Associated LtD. https://portal.HELCOM.fi/meetings/SUBMERGED%203-2015-266/Related%20Information/1_Applying%20Spill%20Impact%20Modelling%20to%20Wreck%20Risk%20Assessment.pdf

GESAMP. 2007. Estimates of oil entering the marine environment from sea-based activities. IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), Rep. Stud. GESAMP No. 75, 96 pp, ISBN 978-92-801-4236-5.

Goodsir F., Lonsdale J.A., Mitchell P.J., Suehring R., Farcas A., Whomersley P., Brant J.L., Clarke C., Kirby M.F., Skelhorn M., Hill P.G. 2019. A standardised approach to the environmental risk assessment of potentially polluting wrecks, Marine Pollution Bulletin: 142.

Hac B. 2014. Hazard of seabed contamination by oil products from motor shipwrecks based on the example of the Stuttgart shipwreck. Meeting of the HELCOM Submerged EWG, Szczecin 29-30.10.2014. 41 slides.

Hac B. 2018. Preliminary action plan for the retrieval activities on the Franken shipwreck. Report from the research expedition carried out on the Franken shipwreck on 23rd-28th April 2018 in the framework of the project "Reduction of the negative impact of oil spills from the Franken shipwreck. The Mare Foundation and The Maritime Institute in Gdańsk.

Hac B. & Sarna O. 2021. General Methodology of Oil Removal Operations on Baltic Shipwrecks. Proposition of a wreck management programme for Poland. Report of The Mare Foundation. ISBN 978-83-959773-1-2. 110 p.

Havs och vattenmyndigheten (Swedish agency for marine and water management). 2020. Investigation of biota and sediment in connection to dumping areas of chemical ammunition on the west and east coast of Sweden, 2019 (in Swedish).

Havs och vattenmyndigheten (Swedish agency for marine and water management). 2022. Exploratory fishing in a dumping area with chemical warfare agents, west of the island om Måseskär. Report 2022:10 (in Swedish).

HELCOM. 2013. Chemical Munitions Dumped in the Baltic Sea. Report of the ad hoc Expert Group to Update and Review the Existing Information on Dumped Chemical Munitions in the Baltic Sea (HELCOM: Helsinki) Baltic Sea Environment Proceeding (BSEP) No. 142.

HELCOM. 2024. Thematic assessment on Hazardous Submerged Objects in the Baltic Sea (Submerged Assessment - Warfare Materials in the Baltic Sea).

Hill P.G., Skelhorn M., Leather S. 2022. Assessing the environmental risk posed by a legacy tanker wreck: a case study of the RFA War Mehtar. Environmental Research Communications. 4, 055005

IMO. 2003a. Guidelines on places of refuge for ships in need of assistance. Resolution A.949/23.

IMO. 2003b. Maritime Assistance Service (MAS). Resolution A 950(23).

IMO. 2007. Nairobi International Convention on the Removal of Wrecks.

IMO. 2011. Nairobi International Convention on the Removal of Wrecks, 2007. 7.5.2010. http://www.imo.org/Legal/mainframe.asp?topic_id=1319

Ivanov Mm, 2022. Personal contact.

Jolma K. & Mykkänen E. 1996. The removal of oil from the wreck of the MS Estonia. Finnish Environment Institute (SYKE). Technical paper. 25.10.1996. 7 pp.

Jolma K. 2009. Kokonaisselvitys valtion ja kuntien öljyntorjuntavalmiuden kehittämisestä 2009 – 2018. (Total assessment to develop oil combating preparedness of the government and municipalities – in Finnish). Finnish Environment Institute (SYKE). 49 s. 27.1.2009.

Kärnä T., Ljungemyr P., Falahat S., Ringgaard I., Axell L., Korabel V., Murawski J., Maljutenko I., Lindenthal A., Jandt-Scheelke S., Verjovkina S., Lorkowski I., Lagemaa P., She J., Tuomi L., Nord A., Huess V. 2021. Nemo-Nordic 2.0: operational marine forecast model for the Baltic Sea, Geosci. Model Dev., 14, 5731–5749.

Kõuts T., Kaimo K., Pärt S. 2015. Shallow Water Shipwrecks Environmental Impact: MS VOLARE case study. Wrecks of the world III conference, October 12-13, 2015, Gothenburg, Sweden. 32 slides.

Landquist H. 2016. Environmental Risk Assessment of Shipwrecks – Model development and application. Doctoral Thesis - Chalmers University of Technology, Department of Shipping and Marine Technology. Gothenburg, Sweden. ISBN 978-7597-490-3.

Landquist H., Rosen L., Lindhe A., Hassellöv I-M. 2016. VRAKA—A Probabilistic Risk Assessment Method for Potentially Polluting Shipwrecks. Frontiers in Environmental Science, 4.

Lindgren J.F., Åberg F., Rubia Johansson J. 2021. Polluting shipwrecks in Swedish waters: investigations, risk assessment methodology and oil removal operations. International Oil Spill Conference Proceedings 2021 (1): 684035.

Lindström P. 2006. Vrak I Skagerrak, sammanfattning av kunskaperna kring miljöriskerna med läckande vrak i Skagerrak. Forum Skagerrak II.

Kaplan, S., & Garrick, B. J. (1981). On The Quantitative Definition of Risk. Risk Analysis, 1(1), 11–27. https://doi.org/10.1111/j.1539-6924.1981.tb01350.x

Masetti G. & Calder B. 2014. A risk index methodology for potentially polluting marine sites. Environment Systems and Decisions. Pp. 391 – 405. 2014.

Michel J., Etkin D., Gilbert T., Waldron J., Blocksidge C., Urban R. 2005. Potentially Polluting Wrecks in Marine Waters: An Issue Paper Presented at the 2005 International Oil Spill Conference. American Petroleum Institute, Washington, D.C., 76 pp.

Monfils R. 2005. The global risk of marine pollution from WWII shipwrecks: Examples from the seven seas. Proceedings of the International Oil Spill Conference (IOSC), May 15-19, 2005, Miami Beach, Florida, USA.

Mortensen O. & Rasmussen F.K. 2013. Bjaerning af olie fra FU SHAN HAI. Endelig rapport (in Danish) 19 pp.

Mykkänen E., & Rytkönen J. 1999. The threat of oil spill from sunken ships in Finnish coastal waters. Finnish Environment Institute (SYKE), Helsinki, Finland.

Mätik M. 2020. T-30 wreck pollution in Narva Bay. Ministry of the Interior. Slides, 15 Pp.

NOOA. 2013. Risk Assessment for Potentially Polluting Wrecks in U.S. Waters. 126 p + appendices.

Peltokorpi V. 2016. The Implications of Modern Law of the Sea on the Protection of Sunken Warships in the Gulf of Finland. Master's Thesis. University of Helsinki, Faculty of Law / International Law. 128 P.

Pärt S., Kõuts T., Rytkönen J. Rintamaa J., Landquist H. 2015. Report on wreck classification, potential for oil pollution. Report D 1.1 of the EU-BONUS-project SWERA (SWERA, Sunken Wreck Environmental Risk Assessment).

Rinne K., Rosenqvist N., Andersson L., Keso T., Rytkönen J. 2015. State of the art technologies and capabilities. Report D 4.1 of the EU-BONUS project SWERA (Sunken Wreck Environmental Risk Assessment). 71p.

Rinne K., Andersson L., Lehto K., Pyhälä M. 2016. Innovative Salvage Toolbox – Final Design Principles. Technical Report D4.3. BONUS-SWERA Project. May 2016.

Rousi H., Kankaanpää H. 2012. Itämerellä tapahtuvien öljyvahinkojen ekologiset seuraukset - Suomen kansallinen toimintasuunnitelma (The ecological consequences taken place in the Baltic Sea – Finnish Action Plan). Finnish Environment Institute, Helsinki, 2012. ISBN 978-952-402-7.

Rytkönen J. 1999. Uponneiden alusten öljypäästövaara (The threat of oil pollution from wrecks - in Finnish). Research Report: VAL34-992239. VTT Manufacturing Technology, April 1999, Espoo, Finland.

Rytkönen J. 2016. Draft Assessment of the Oil Removal Toolbox. Technical Report D3.3 of the EU-BONUS project SWERA. 21.12.2016. 33 p.

Rytkönen J. & Rinne K. 2016. Desk Study: Verification of main parameters of VRAKA and ORRA using selected historical wrecks. Technical Report D.3.2 of the EU_BONUS project SWERA. 49 P.

Rytkönen J. 2021. Wreck oil removal – authorities and other parties' competence development – proposal on the development of cooperation between authorities (in Finnish). Finnish Environment Institute (SYKE). Report of the Water Protection Programme. 20.04.2021. https://ym.fi/en/water-protection-programme. 43 P.

Rogowska J. & Wolska J. 2019. The threat to the marine environment resulting from the presence of World War II shipwrecks, on the example of the s/s Stuttgart. Department of Environmental Toxicology. Faculty of Health Sciences with Subfaculty of Nursing and Institute of Maritime and Tropical Medicine, Medical University of Gdansk. 23A Dębowa Str, 80-204 Gdańsk, Poland. Presented 27.02.2019. 21 slides.

Sender U. 2011. Korrosion på skeppsvrak i svenska vatten (Corrosion of sunken wrecks in Swedish waters – in Swedish). Literature report. Swerea KIMAB, 1.3.20111. 66p.

Sjöfartsverket (Swedish Maritime Administration). 2011. Miljörisker från fartygsvrak (Environmental risks from shipwrecks). Report: 090602-09-02375.

Svensson E. 2010. Potential Shipwreck Pollution in the Baltic Sea. Overview of Work in the Baltic Sea States. Report by Lighthouse & Swedish Maritime Administration 09-02375. 15.12.2010. 35 Pp.

SYKE. 2006. MS Coolaroon hylyn tutkimus (The investigation of wreck Coolaroo – in Finnish). Technical report. Finnish Environment Institute.

SYKE. 2009. Oil Removal from a 50 years old wreck of S/S Park Victory in 1994 – 2000. Finnish Environment Institute (SYKE). 52 pp.

SYKE. 2012. RV Aranda - Made to serve marine research. Handout, 2pp.

SwAM. 2019. https://www.havochvatten.se/en/facts-and-leisure/environmental-impact/shipwrecks/swams-work-with-shipwrecks/finnbirch.html. Accessed 2025-02-19

U.S. EPA. 1998. Contaminated Sediments Program. Sediment Assessment and Remediation Report. Guidance for In-Situ Subaqueous Capping of Contaminated Sediments. EPA 905-B96-004, USA.

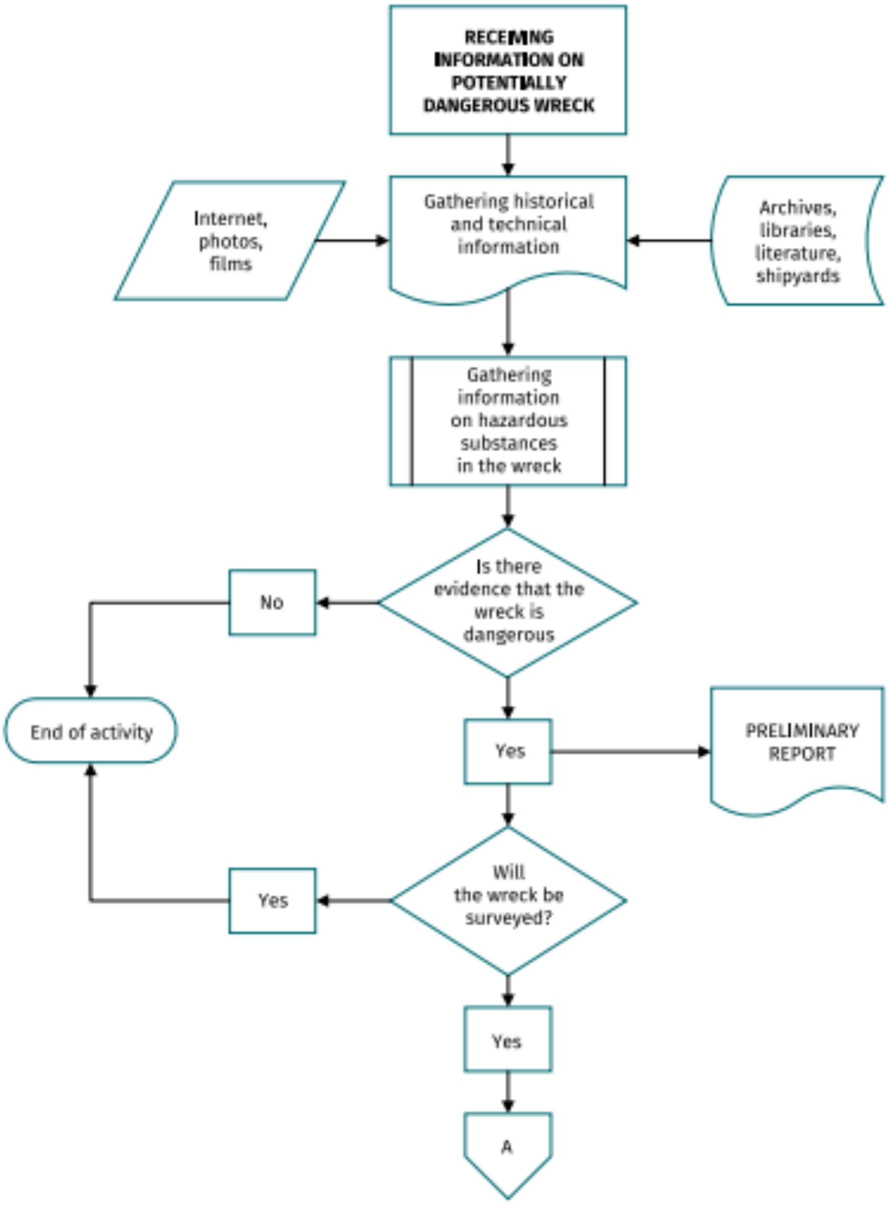
U.S. EPA. 2004. Presenter's Manual for: Remediation of Contaminated Sediments, Office of Solid Waste and Emergency Response, USA.

Vahter K., Pärt S., Kõuts T. 2015. Impact of shipwrecks to marine environment: M/S VOLARE shipwreck case study. Report D 1.2. of the EU-BONUS-project SWERA (SWERA, Sunken Wreck Environmental Risk Assessment). 42 P.

Wang K., Leppäranta M., Gästgifvars M., Vainio J., Wang C. 2008. The drift and spreading of the Runner 4 oil spill and the ice conditions in the Gulf of Finland, winter 2006. Estonian Journal of Earth Sciences, 2008, 57, 3, pp. 181-191.

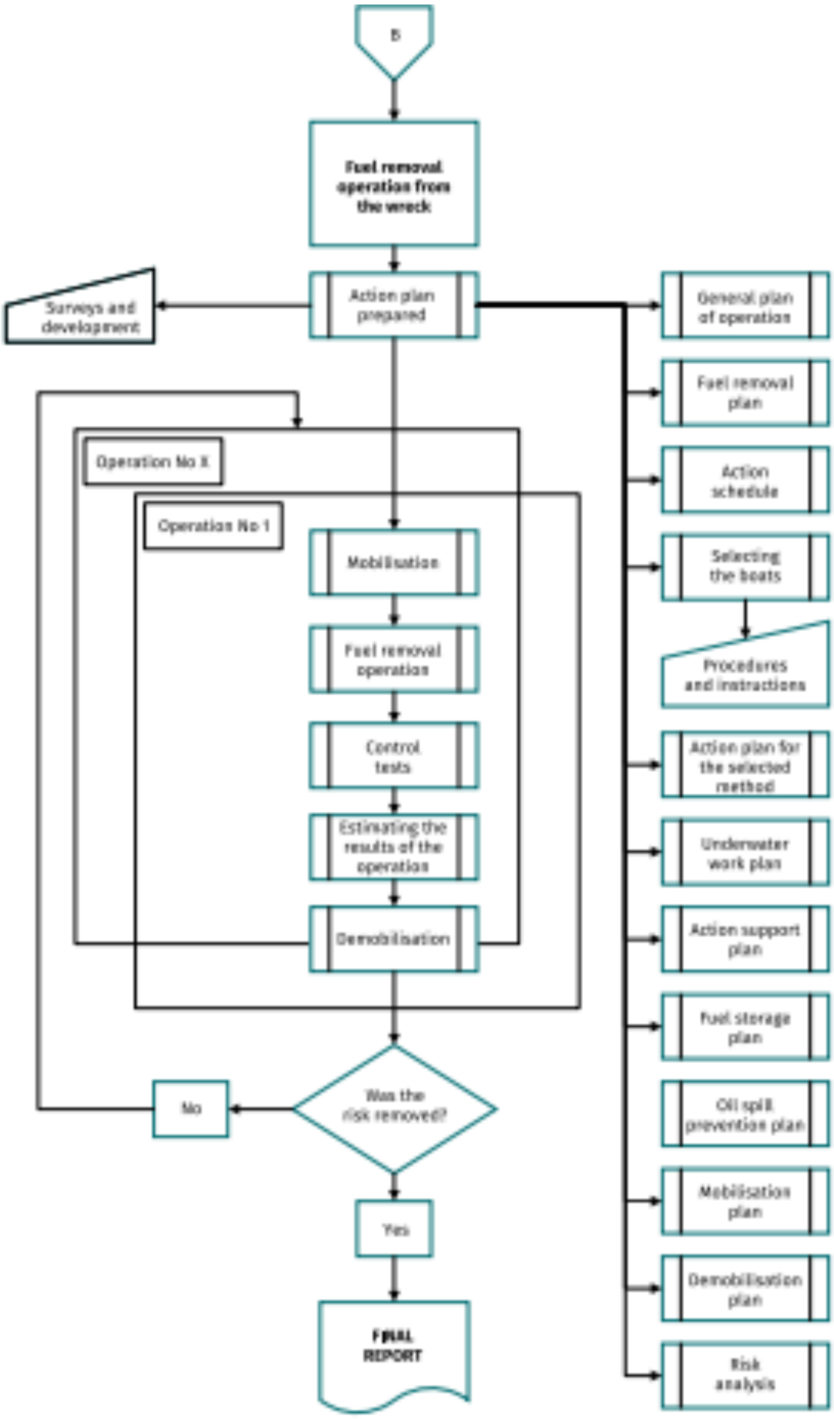
Appendices

Appendix 1. Flowcharts describing a procedure for data collecting and receiving information of a potentially polluting shipwreck, modified from Rinne et al. (2016).



Flowchart 1. Description on how to gather information regarding wrecks, including hazardous substances.

Flowchart 2. Description on how to perform an in situ investigation of a potentially polluting shipwreck.



Flowchart 3. Description on how to plan and perform an oil removal operation.