Environmental Risks Posed by Sunken Wrecks

Research methods and environmental aspects

Case No.: 1399-14-01942-6

Swedish Maritime Administration, 2014

The cover photograph shows the ROV of the Maritime Administration during an investigation of Villon.
Photography: P-Dyk

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Summary

Shipwrecks containing oil or other hazardous substances pose a threat to the marine environment. In 2011, the Swedish Maritime Administration (SMA) completed an inventory of shipwrecks that could possibly pollute Swedish waters. From archive-based research, a total of 2,700 shipwrecks were found to have pollution potential, according to the definition by Bergen Museum. The 2,700 shipwrecks were categorized according to the relative potential threat and 31 were identified as being the most important for further investigation. In 2014, the SMA was given a new government task to set up a method for *in situ* investigation of shipwrecks that might cause pollution and identification of any possible adverse effects on the environment. The project "Environmental risks from sunken wrecks" was carried out in close cooperation with the Swedish Coast Guard, the Swedish Agency for Water and Marine Management (SwAM), the Swedish National Maritime Museums, and research experts in corrosion science (Swerea-KIMAB), sampling and analysis of hazardous substances (FOI), ecotoxicology, and development of a shipwreck risk assessment model (Chalmers University of Technology).

In situ investigations of four shipwrecks were done using an ROV and/or divers, and in addition to visual inspection, corrosion and hull plate thickness analyses were performed. At two of the wreck sites, current meters (RDCPs) were deployed, which were also equipped with sensors for conductivity, temperature, oxygen, and turbidity. All the data will be used for validation of the shipwreck risk assessment model VRAKA, which will then be ready for use in further national handling of potentially harmful shipwrecks. The planning and work with *in situ* investigations formed the basis of proposed Standard Operating Procedures for future operations.

The cooperation between the competent authorities that were involved worked very well, and the cost efficiency of shipwreck investigations may be significantly improved if operations can be incorporated into to the usual tasks of the relevant authorities; i.e. if Coast Guard diving exercises were to include shipwrecks of interest in their exploratory work, the net cost of the field operation would be reduced.

For future work on a national Swedish strategy for the handling of shipwrecks that may entail a risk of pollution, we propose that SwAM should be given the main responsibility, with assistance from all the other competent authorities. If the strategy proposed is implemented, starting in 2015, all shipwrecks that are potentially harmful to the environment should have been confirmed as being a threat or ruled out as being no threat by the year 2030.

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List of Terms

ADCP	Acoustic doppler current profiler; acoustic current-measuring equipment, which can measure the direction and speed of the current at different depths of the water column.
AUV	Autonomous underwater vehicle.
Bioavailability	The fraction of a chemical substance that can be absorbed by organisms and thereby adversely affect them, if the substance is toxic.
Biogeochemical cycle	As with the water cycle in the sea and atmosphere, other substances also show natural cycles. Biological and geological processes transform chemical substances when they are incorporated into an organic material or mineral, or when they are released when organic material decomposes or a mineral dissolves. The biogeochemical cycles can be considered to be a result of the functioning of the ecosystem.
Ecosystem	Interplay between organisms and their (abiotic) environment within a certain geographically or functionally well-defined unit.
Ecosystem services	The functions or services that nature performs (i.e. ecosystems perform) and that benefit humans. An example of *provisioning* ecosystem services would be food from the sea, such as fish and shellfish. Biogeochemical cycles are an example of *supporting* ecosystem services, i.e. those that are necessary to keep the ecosystem functioning, but they are extremely difficult to assess in monetary terms.
Ecotoxicology	The field of science that deals with the effects of hazardous substances on the ecosystem.
FMIS	The Ancient Monument Database of the Swedish National Heritage Board.
In situ	Latin expression, which literally means “on site”. In the context of wrecks, it means at the location where the wreck is lying on the sea floor.
Meiofauna	Animals measuring 63 µmto 1 mm that live in sediment. The term meiofauna covers most common groups of marine invertebrates, such as crustaceans, polychaetes, and bivalve molluscs; either as adult organisms or in larval form.

Multi-beam	MBES, multi-beam echo sounder; provides a high-resolution and detailed image of the sea bottom. In particular, it is used for nautical mapping and searching for objects located on the sea floor. It provides information on position with good precision at any particular depth. It is normally fixed to the hull of a vessel, or installed on a polethat can be lowered into the water at the side of the vessel. It can also be installed on an ROV.
PAH	Polycyclic aromatic hydrocarbons, a group of common toxic components of oil.
POC	Person of contact.
ROV	Remotely operated vehicle; remote-controlled underwater vehicle.
RDCP	Recording doppler current profiler. Another type of ADCP with the advantage of easy connection to additional sensors in order to measure other chemical and physical parameters at the unit.
Side-Scan Sonar	Sideways-located sonar, which can be attached to a vessel, but is normally towed on a wire behind a vessel. In particular, it is used to search and identify objects on the sea floor. It normally has very high resolution, so that objects can be seen in fine detail. Positioning of an object at the bottom is less precise. It can also be installed on an ROV.
SOP	Standard operating procedure; standard procedure for uniform execution of recurrent work of a routine nature.

1 The Assignment

Currently, no Swedish agency has special responsibility for wrecks that might cause pollution in Swedish waters. In the investigation carried out by the Swedish Agency for Public Management in 2007, it was suggested as a first step that an inventory of wrecks that are a potential threat to the environment should be created, and this was performed by the Swedish Maritime Administration (SMA) in 2011. As a second step, the Agency for Public Management suggested a methodological study with physical inspections of the most important items *in situ*. In 2014, the SMA was given the task of working out a standard operating procedure, in cooperation with the Swedish Agency for Marine and Water Management (SwAM) and the Swedish Coast Guard (SCG), for *in situ* studies of wrecks, if possible with assessment of the environmental effects of wrecks on the marine environment. As with the problem of remediation of polluted land sites, wrecks with the potential to pollute waters were recognized as being a widespread and probably costly environmental issue. Underwater work is by definition time-consuming and demanding, and to obtain reliable serial measurement of, for example, ocean currents, it is recommended that measurements over at least one annual cycle should be included. Therefore, the very tight time frame of the project was a limiting factor for the possible end results that the project could be expected to achieve.

1.1 Description

The Swedish Maritime Administration's appropriation direction of 2014 reads as follows:

On May 20, 2009, the government commissioned the Maritime Administration to create an inventory of wrecks in Swedish territorial waters, in order to clarify how common they are and how much of a threat they are to the environment. The Assignment was presented on January 14, 2011 and the Maritime Administration stated that it had identified 31 wrecks that could pose a real threat to the environment and which should be investigated further.

The Maritime Administration should therefore investigate whether it is possible to identify any environmental effects in the surroundings of any of the wrecks. The report should include an assessment of any possible effects on the marine environment and suggestions for further action. Regarding the assessment of any environmental effects and preventive measures, the assignment should be performed in cooperation with both the Agency for Marine and Water Management and the Coast Guard.

The assignment will be financed with funding from category 20. The report should be submitted to the Swedish Agency for Public Management (Ministry of Industry, Employment, and Communication) by October 31, 2014. After that, it will be decided whether the assignment will be extended into 2015.

1.2 Performance

Based on the work the SMA previously performed on the *Environmental risks from shipwrecks* and *ChemSea* projects, a project group was created with representatives of the SMA, the SCG, the SwAM, the National Maritime Museums, the Swedish Defence Research Agency (FOI), Swerea-KIMAB, and Chalmers University of Technology. The representatives on the project group were responsible for the work of the respective organization on the project, regarding both personnel and infrastructure. Altogether, some 60 individuals took an active part in the project.

Since other authorities and universities are affected by or interested in the shipwreck issue, a reference group was created with additional representatives from the Environmental Protection Agency, the Geological Survey of Sweden, the Armed Forces, the Transport Agency, Lund University, and University of Gothenburg. The Swedish University of Agricultural Sciences, the Swedish Meteorological and Hydrological Institute (SMHI), and the Swedish Civil Contingencies Agency (MSB) were also invited, but they were unfortunately unable to participate. Two reference group meetings were arranged: the first one in April, giving the participants an opportunity to put forward their opinion on the structure of the project. The second meeting, in October, informed the participants on the results achieved during the project and gave them an opportunity to make suggestions regarding the strategy for the future (Figure 1). It should be noted that both reference group meetings were very rewarding and they have improved the outcome of the project. The positive attitude that prevailed at the reference group meetings is also a good sign regarding possible future use of the improved collaberation between authorities concerning handling of shipwrecks that might pose a threat to the marine environment.

Figure 1. Reference group meeting in Gothenburg on April 25, 2014. Upper panel: Göran Ekberg, National Maritime Museums. Lower panel: Ulf Sender, Swerea-KIMAB. Photography: Christian Heynen.

2 Background

In 2007, the government commissioned the Agency for Public Management to investigate and provide suggestions on who has the right or obligation to handle, remediate, and move shipwrecks and abandoned boats (Agency for Public Management, 2008). In its report, the Agency for Public Management suggested a three-step approach to identify and handle the wrecks located along the Swedish coast that are a possible threat to the marine environment. The first stage was to create an inventory of the wrecks that might cause pollution, and to develop a general risk analysis tool. As the second stage, the Agency for Public Management suggested physical inspections (*in situ*; on site) of the highest risk-classed objects, and the third and final stage would be drafting of a monitoring and remediation program.

The first stage was performed in 2009–2011, when the government assigned the Marine Administration to create an inventory of wrecks in the Swedish territorial waters in order to determine the frequency of wrecks that may be a threat to the environment (SMA, 2011). The assignment was presented on January 14, 2011 in the report *Environmental risks from shipwrecks* (from here on referred to as *Stage 1*), which stated that the Marine Administration had identified 31 wrecks that could pose a real threat to the environment and that should be investigated further. In parallel and as a cooperation with *Stage 1*, Chalmers University of Technology was developing a proposal for a risk assessment model for dealing with wrecks that might cause pollution—the risk assessment tool VRAKA (Landquist et al. 2013 & 2014).

The second stage suggested by the Agency for Public Management was initiated in 2014 during the course of the project *Environmental risks posed by sunken wrecks* (from here on referred to as *Stage 2*), which is based on the hydrography and *in situ* investigation of 2–5 wrecks. The goal in Stage 2 was to provide evidence on whether the wrecks investigated would require any remedial measures regarding threats from oil and/or environmentally harmful substances, or whether they could be crossed off the list of the wrecks that might cause pollution. Another goal was to use the data collected for further development and validation of the risk model VRAKA, which—once it becomes operative—might assist in the cost-effective handling of wrecks that may cause pollution in the future.

The wreck issue is complex and involves a number of authorities, especially:

- the Swedish Agency for Marine and Water Management, which has overall responsibility for monitoring and finding solutions to problems in the marine environment;
- the Swedish Coast Guard, which is responsible for operational environmental protection measures at sea;
- the Swedish Maritime Administration, which is responsible for taking care of wrecks that adversely affect shipping or fishing.

Authorities and institutions that are also involved are:

- the Swedish Environmental Protection Agency, which together with the SwAM shares responsibility for monitoring of toxic substances in the marine environment;
- the National Maritime Museums, which know about the historical aspects of wrecks;
- the Geological Survey of Sweden, which is responsible for geological mapping of the sea bed and has operational responsibility for monitoring of toxic substances in sediments;
- SMHI, which is a national repository for marine environmental data in the fields of marine biology, chemistry, and physics;

- the Swedish Armed Forces, which have extensive experience of underwater operations, wrecks, and mines;
- the Swedish Civil Contingencies Agency (MSB), which is responsible for protection against oil damage to land, including the shore;
- the Swedish Transport Agency, which is responsible for the rules and regulations regarding pollution by vessels;
- the Swedish Defence Research Agency (FOI), which is experienced in the chemical analysis of environmentally dangerous substances from wrecks and combat material in marine dumping areas;
- Swerea-KIMAB AB, which has expertise in corrosion research.

In addition to the authorities and institutions involved, Chalmers University of Technology is conducting research in cooperation with the University of Gothenburg (GU) and Lund University (LU) concerning the risk assessment of wrecks and ecotoxicological effects of oil. GU and LU are also investigating the legal aspects of responsibility for wrecks. Lund University is also doing a lot of work related to diving and listing of wrecks.

All of the authorities involved have their own viewpoints, competencies, and interests regarding the wreck issue. For successful cooperation, it is important to shed light on both the differences and the common aspects of the subject.

2.1 The Swedish Agency for Marine and Water Management

The SwAM provides a very unsettling picture of the threat posed to the marine environment by a number of shipwrecks along the Swedish coast. Leakage of chemicals and/or oil products from the cargo or bunkers of these sunken vessels constitutes a significant threat to (among other things) the marine environment, fishing, and outdoor recreation.

The SwAM believes that to be able to produce an objective risk assessment, it is extremely important to collect data from the vessels that are believed to pose the greatest threat to the environment. Many of the shipwrecks that can be assumed to still contain environmentally hazardous substances on board have been on the sea floor for a long time and are presumably in a bad condition due to corrosion. Several of the wrecks that are thought to be an environmental threat have had oil leakages from time to time, which could be seen at the surface. Small continuous discharges of oil can have considerable negative consequences for the marine environment. From a global point of view, the annual amount of oil originating from small continuous leakages is equivalent to the size of the full load of a supertanker (VLCC), i.e. twice as much as was discharged from the supertanker Amoco Cadiz in 1978. Continuous leakage of small amounts of oil in a water area mainly affects the organisms in sediment if the oil density is high—and if the density is lower, then the majority of organisms are affected in the whole water column, from top to bottom. From an environmental point of view, it is vitally important that we obtain an overall idea of the risk, and an idea of where we must take steps to prevent discharge of environmentally hazardous substances into the marine environment.

2.2 The Swedish Coast Guard

Because of the Coast Guard's responsibility for environmental protection at sea, it is interested in everything that can contribute to a heightened degree of preparedness and facilitate its work when an environmental rescue operation is required. One of the SCG's aims is therefore to use the risk assessment from *Stage 2* regarding the wrecks that were chosen, to yield data that can be used in an operational sense to reduce the length of time between an event occurring and remedial action. Another goal is to use the data from investigations to improve the general level of knowledge within the authority concerning the environmental risks associated with wrecks. Altogether, this will improve the level of preparedness in environmental rescue. One goal related to the operational side is that the project would give Coast Guard divers the chance to participate actively, with opportunities for training and development of methods being additional benefits.

2.3 The Swedish Maritime Administration

The SMA is a service-based business structure responsible for accessibility, mobility, and safety in the Swedish waterways and in coastal waters. The agency concentrates on commercial shipping, but it also takes the interests of recreation traffic, fishing, and the navy into account.

The SMA should work to ensure that the goals of the transportation policy regarding water transport are achieved in a cost-effective way. It is the SMA that builds, maintains, and develops infrastructure at sea. It is through the SMA that the state maintains its waterways, performs hydrography and sets delimitations, and produces navigational charts and other information on marine geography. The SMA offers a number of important services, such as ice breaking, piloting, and giving out of water traffic information to all the thousands of vessels that use our waterways. A large proportion of the service is run 24 hours a day, 365 days a year.

The SMA is also the authority responsible for both flight-rescue and sea-rescue services, which includes management and coordination of all rescue services through the Joint Rescue Coordination Service (JRCC), and also participation in rescue operations with its own resources in the form of rescue helicopters and seagoing units.

Hydrography, sea safety devices, and production of navigational charts are fundamental for nautical safety and protection of human lives on inland waters and at sea. The routine hydrography work performed by the SMA regarding nautical charts also includes documentation of shipwrecks and reporting of them to the Swedish wreck database, FMIS. Wrecks and other items can be obstacles to navigation, and they are marked in navigational charts as obstructions on the sea floor. Many of the wrecks on the navigational charts have uncertain positions that were defined according to old methods and these need to be updated with modern hydrography.

2.4 The problem of wrecks from an international standpoint

The complexity of the wreck issue imposes stringent demands regarding well-functioning communication and cooperation. The work in *Stage 1* resulted in the formation of a national network, which is an excellent starting point for all future work relating to the wreck issue. In addition to the national work in Sweden on environmentally dangerous wrecks, there is also growing international interest in this issue. Experience from the Swedish projects relating to wrecks can be used in the Baltic region—to increase the general level of knowledge on possible strategies that can be used to handle wrecks that are potentially harmful to the environment. At the same time, there is also existing international experience, whereby Sweden could learn from other countries, such as wreck remediation operations in Finland. One example of a forum for sharing of such knowledge is Helcom Submerged, where the Swedish work from *Stage 1* and an earlier version of the risk assessment tool VRAKA are presented.

3 Identification of methods for detailed investigation of wrecks

Probably the biggest challenge in the work on risk assessment and investigation of wrecks is the necessity to coordinate all the interdisciplinary competencies required—ranging from knowledge of maritime history, nautical science, shipbuilding, marine engineering, marine chemistry, biology, and geoscience to knowledge of marine measuring technology, hydrography, and diving. The work in *Stage 1* resulted in a network with excellent coverage of the multidisciplinary problems that the work with environmentally dangerous wrecks involves.

3.1 Archives

When *Stage 1* was reported to the Ministry of Enterprise in January 2011, it was accompanied by a list of 31 shipwrecks, which the investigation identified as a potential environmental threat. This list became the starting point for the choice of wrecks to be investigated during *Stage 2, Environmental Risks Posed by Sunken Wrecks,* in order to produce a method for *in situ* inspection and prioritization of those wrecks that might cause pollution.

Of the 31 wrecks on the original list, one was salvaged according to the information that became available after January 2011, i.e. Sefir, which sank in 1980. Of the other ones, five are located outside of the Swedish territorial waters: Jan Heweliuz, Koronowo, Fu Shan Hai, Malmi, and Necati Pehlivan. These six shipwrecks were removed from the original list before making the final choice. At the same time, information arrived from sport divers, giving two more vessels: Hoheneichen and Minde. Among others, the archives used to obtain information were the Ancient Monument Database of the Swedish National Heritage Board FMIS with the search engine Fornsök (the Swedish National Heritage Board, 2014), the National Archives (2014), the SMA archives, and digital archives on the Internet.

3.2 Selection of case study items

Of the remaining 27 wrecks, five (5) shipwrecks were selected that would be suitable for the investigations to be performed during the currently reported project. It must be noted that the amount of oil on board is not a decisive factor for whether the wreck will be suitable for investigation at this stage of the project. To ensure that the field work would advance, four additional wrecks were chosen as a back-up, in case circumstances made investigation of any of the first five chosen wrecks impossible.

Apart from the criteria used in *Stage 1* to produce the list of 31 wrecks, an additional filter was required to choose items for the case study in *Stage 2*, since both time and budget limitations were tight. To facilitate the selection process and improve efficiency, three additional restrictive criteria were chosen, which largely determine the cost of risk assessment and *in situ* inspection of wrecks, i.e. accessibility, diving depth, and availability of information.

3.2.1 Accessibility

The accessibility referred to the geographic distance between the location of the wreck and a port suitable for the project's investigation vessel. Since the project had a very short period of time for field work and a limited budget, it was considered important to minimize the travel time of the investigation vessel to and from the location of the wreck.

3.2.2 Diving depth

Diving depth refers to the greatest depth at which the wreck could be so that diving can be carried out by the divers available to the project. By disregarding wrecks located at greater depths than would allow safe diving by the divers available to the project, the cost of diving operations could be made affordable within the framework of the project's budget. The Coast Guard divers are allowed to go down to 40 meters and no more. Diving depth also refers to the depth to which an ROV (remotely operated underwater vehicle) could operate with the equipment available to the project.

3.2.3 Availability of information

Availability of information refers to the information required to perform diving, sampling, deployment of the measuring equipment etc. on the wreck. Such information information should, among other things, describe the existing conditions at the location of the wreck, the condition of what is left, the positioning of bunker tanks, and the structure and content of the cargo.

Many of the positions of wrecks that are available in archives are highly uncertain, and are only roughly stated. The positions are deducted from the "master's protests", where the last noted position from the vessel log books has been stated or has been documented by others who in some way witnessed the loss of the ship. The wreck could have drifted some thousands of meters away from the most recently noted position before sinking to the sea floor, and the position could have been corrupted before archiving—or taken by old positioning methods, with an uncertainty of thousands of meters. If the wreck has been the subject of a previous investigation or remediation, then the position will usually be more exact, since the wreck was actually *found* at a certain position on the sea floor. Some of the wrecks along the Swedish coast have already been covered by modern hydrography methods, and in such cases the position is exact and the wrecks are easy to find again.

3.2.4 Result of selection

The five vessels chosen were Skytteren, Harburg, Altnes, Thetis, and Villon, which are listed here in no particular order. Skytteren is lying at a depth of almost 70 meters, which is very deep for human divers, which conflicts with the above criteria. However, it was decided that the previous investigation with charting and instrumentation, and also the large volume of information available on the vessel, outweighed the consideration about the depth of the wreck. The four vessels chosen as a back-up were Irevik, Minde, Hoheneichen, and Wästanvåg. After further searching in archives, drawings of Skytteren, Altnes, Thetis, and Villon were found, but not drawings of Harburg—which is why Harburg was excluded from *in situ* investigations.

3.3 *In situ* investigation of wrecks

The depth of water at the location of the wreck is decisive for the choice of appropriate investigation methods. Investigation with so-called "light divers" can normally be performed to a depth of 40 meters. Diving below 40 meters requires much more extensive diving resources and safety equipment, which is why video investigation with a remotely operated underwater vehicle (ROV) can be more cost-effective. Hydrographic surveying with acoustic equipment attached to the hull, i.e. a multi-beam echo sounder, at a depth of some 50–70 meters generally provides good resolution for detection and identification of details in the wreck. In deeper waters, the work can be performed by means of a towed side-scan sonar, which normally provides data with very high resolution. The sonar is towed close to the sea bed and the wreck to gain maximum resolution. Alternatively, an ROV or AUV (autonomous underwater vehicle) equipped with a multi-beam and/or side-scan sonar can be used for inspection in deep waters.

Most of the wrecks are located in open sea beyond the base line, which is why it is important that the vessel performing the investigation of the wrecks should able to operate under the weather conditions that exist in these areas. Large vessels are generally more stable in bad weather, but normally cost more to operate than smaller vessels. Regardless of the size of the vessel and how stable it is, planning of all underwater operations must take winds, currents, and other sea conditions into account. In order to perform safe and effective ROV and diving operations, the vessel must be able to remain stationary above or next to the wreck. Vessels with approved DP (dynamic positioning) equipment have a number of transverse and longitudinal propellers, and can lie still and perform precision maneuvering over the wreck for a long time with a tolerance of only a few meters. It is an advantage if the DP system has been approved for diving work, to avoid anchoring operations, which waste valuable time. Vessels without DP must be able to lower several anchors close to the wreck, to be able to remain sufficiently still to carry out a safe underwater operation. Anchoring operations can take time, especially if the anchors must be moved to get different positioning over the wreck.

The vessel-related costs can vary and mostly depend on the size and age of the vessel, operating costs, the crew, and technical equipment. A relatively small vessel, about 20 meters long, with a crew of 3, equipped for hydrographic surveying and underwater investigation can cost about 35,000 SEK a day without any profit. A corresponding vessel that is larger, about 60 meters long, with a crew of 12 would cost about 150,000–200,000 SEK a day. If the vehicle is technically very advanced and multifunctional with advanced technical investigation equipment, it could cost about 400,000 SEK a day. Stability of the vessel in bad weather is critical for performance of safe underwater operations, since the working platform must be very stable and keep still during the work. Offshore operations normally require a larger vessel with a high degree of stability in bad weather, while a smaller vessel can turn out to be a more expensive alternative, since cancellations due to bad weather can be costly. Joint planning of different activities and assignments at sea also gives the opportunity to perform other operations in sheltered areas, if the weather makes offshore operations impossible. Investigational operations can also benefit from coordination regarding transportation between different operating areas along the coast, in order to reduce the cost of transportation of individual items.

To gather sufficient information to be able to make decisions about priorities and solutions, a systematic investigation of wrecks in several stages is necessary. In order to make the assessment of wrecks uniform, it is important to use a standard procedure. All documents and information on the wreck must be readily available during the planning and performance of an underwater inspection. The research is focused on those parts of the wreck where a potentially harmful load (e.g. oils or chemicals) has been stored. The hull, tanks, holds, venting equipment, and so on must be examined to determine whether they have been damaged or affected by corrosion. Any leakage from the wreck must be documented and sampled. In line with the standard procedure, the results of various individual investigations will form the basis of a thorough risk analysis of the wreck.

3.3.1 Hydrographic survey

The vessel that will survey the site of the wreck must be equipped with a multi-beam system and should probably be able to tow a side-scan sonar or operate an ROV/AUV with multi-beam. Hydrography with a modern multi-beam echo sounder and/or side-scan sonar provides the first indications of the status, condition, degree of preservation, angle at which it is sitting, and location on the sea floor. It also provides important information on the topography and the type of sea floor, and whether there are obstacles—such as fishing net or dangerous parts—on or close to the wreck. High-definition 3-dimensional data on the wreck and its immediate environment can be collected from the depth information. After quality control, the processed hydrographic data is then visualized in a three-dimensional graphics program in which the details and hull of the wreck can be analyzed. An intensity map is produced for the topography of the sea floor around the wreck, in order to get an indication of the type of sea floor and any prevailing current direction. The hydrographic data collected is used as a basis for further investigation, ROV filming, and diving inspections.

3.3.2 ROV

A remote-controlled underwater vehicle (ROV) with a video camera can be used for a first visual inspection of the wreck. Both the result of the hydrographic survey of the wreck and the construction drawings of the ship are used for planning of the ROV inspection. Three-dimensional hydrographic data can also be used in the investigation by orienting the ROV online in the model and manoeuvring it to important parts of the wreck. This requires high-quality underwater communication on positioning between the boat and the ROV. The video camera on the ROV must also be of high quality and effective, with a wide-angle lens. There can be relatively strong currents in the water around the wreck, which can make an ROV operation difficult, if not impossible. The ROV must therefore be sufficiently large and have powerful motors for propulsion in order to be able to manoeuvre safely and reach all the parts of the wreck that need to be investigated. There is also a risk that the ROV could become tangled in the wreck or in remains of fishing gear or other loose objects that have been caught up in the wreck. There must always be a back-up plan on how to free the ROV, either using divers or another ROV.

The video of the wreck (Figure 2) gives an indication of corrosion and fouling of the hull, deck, and smaller parts with organisms. The condition of the goose-neck piping (venting devices) to the bunker and load tanks is especially important, and should be examined to assess the risk of future leaks. Any rests of fishing nets and other dangerous obstacles must be documented before any examination by a diver takes place. If it is too deep for investigation by a diver, the ROV can be equipped with devices for measurement of hull thickness and mechanical cleaning of the hull (brush/scraper) at the places where the measurement of thickness is to be done. This means that there must be technically more advanced ROV equipment. ROVs can also be equipped for sampling of sediment around the wreck.

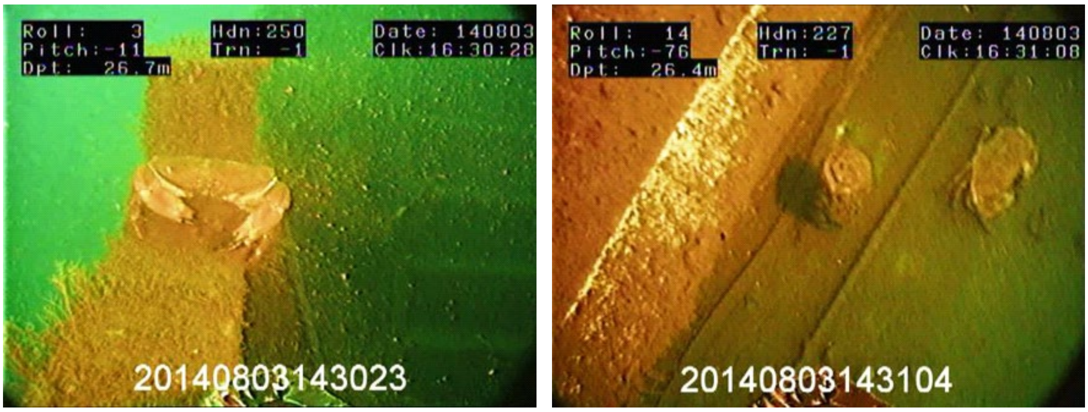

Figure 2. Permanent "guests" on the Thetis wreck; examples of marine bio-fouling. Right panel: a rusty "sounding pipe" for measurement of the level in the tank. Photography: SMA

3.3.3 Divers

A diving operation must be planned and prepared, taking into account the depth, number of divers available, the diving equipment, the vessel, and the type of assignment. The time taken for each dive and the total diving time per day will vary depending on the depth.

Light diving is normally performed at depths down to 40 meters. At this depth, the effective diving time is limited to five minutes to perform the actual work on the sea floor if direct ascent is used (ascent from the bottom to the surface without stops). When diving is performed at this depth, the body must have time to get rid of the nitrogen that has been stored in the blood, which means that it can take hours before the next dive can begin. If the diving is done in shallower water, the working time can be considerably longer. The dive time at the sea floor can also be extended if the ascent is performed gradually, stopping for a certain time at particular depths. Gradual ascent requires additional planning, but it may be an alternative if spending more time at the wreck is important for an effective diving operation. If diving is performed with air supplied through a hose from the surface, then there is good access to air and this also allows good communication between the diver and the diving supervisor. Apart from the diver and the diving supervisor, there is always a third diver on stand-by, in line with the regulations of the Swedish Work Environment Authority governing occupational diving. A shot line attached to the wreck with a buoy on the surface makes descent and ascent easier for the divers. It also ensures safer diving and saves a great deal of time, since the divers arrive directly at the specified position on the wreck. If a helmet-based diving system with an umbilical for air supply is used, then diving can be performed down to 50 meters, which makes it possible to access more wrecks for inspection without needing to use heavy divers. However, diving with a helmet requires additional training and a special diving certificate.

Certain diving operations require additional arrangements to ensure safety (Figure 3). A safe and effective diving operation requires planning and preparations, which, among other things, means taking weather conditions into account—such as waves, wind, and currents—and also the light and visibility conditions in the water. The type of work, methods, tools, and other aids must be carefully planned and prepared. A safe and stable platform with proper equipment and detailed information for preparations are required to be able to perform the work safely and effectively, which will also minimize the time the vessel spends in the area. A diving operation for documentation of a large wreck in water that is shallower than 40 meters normally takes one day. Investigations involving measurement of hull thickness and sampling normally take an additional day.

Figure 3. Diving inspection of KBV 003 Amfitrite. Photography: The Coast Guard

3.3.4 Sampling of fuel and/or chemicals on board

As mentioned above, the only thing that can rule out a possibly environmentally hazardous wreck as a threat to the environment is evidence of empty tanks and storage spaces. The purpose of *in situ* sampling is therefore to identify any kind of oil or hazardous substance that is still on board, and also the volume remaining. Based on ship construction drawings, archived information, and hydrographic data, a first assessment can be made of what kind of preparation for sampling would be most appropriate. In *Förstudie om vraksanering* (*Pre-study of ship wreck assessment and remediation*) (Hassellöv, 2007), there was a first estimate of the cost of *in situ* inspection, including identification of the type and volume of dangerous substances remaining at the wreck of S/S Skytteren. The cost estimates were provided by private diving and oil remediation companies, and were about 0.5–2 million SEK per wreck.

3.3.4.1 Sampling of on-going oil leakage from wrecks

The illegal spillage of oil on a regular basis has meant that the SCG has developed routines for sampling of oil from vessels and of discharged material lying at the surface of the sea. A Teflon sheet is usually used to absorb oil, after which the oil-soaked sheet is sent for laboratory analysis at the National Forensic Centre (NFC). In these analyses, the chemical composition of the discharged oil can be used as a "fingerprint" to trace the source of the discharge, so this methodology can be used to link a discharge to a particular wreck. However, as the NFC only does crime-related work, an alternative laboratory may have to be involved so that the analyses can be performed according to internationally standardized methodology.

When a wreck is inspected with an ROV or by divers, it would be best to be able to perform targeted analyses of the observed leak (whether oil or some other substance)—for example, solvent that is leaking and coming to the surface, deposits on the sea floor, or insoluble chemicals that are readily apparent. However, sampling under such circumstances is not routine and is mostly performed on a case-by-case basis, on location, with the equipment available.

3.3.4.2 Conventional method for identification of tank contents

The conventional method for identification of oil and/or water in a closed tank is to drill a vertical series of holes, starting from the bottom edge and then up along the tank, to see what is behind the metal. If the tank contains both water and oil, it can be assumed that there are two separate phases and—depending upon the difference in density—that the lighter phase of the two will be sitting on top. The volume of the oil remaining in the tank (if any) can then be ascertained by finding the water/oil interface.

The purpose of *Stage 2* was mainly to develop a method for *in situ* inspection of wrecks, including sampling of oil. Diving operations have been performed by Coast Guard divers; this has involved light diving not exceeding a depth of 40 meters, and for safety reasons, the divers are not allowed to swim into wrecks. Furthermore, with the conventional inspection method with drilling of holes in the tank wall, there is an increased risk that the wreck or the tank will collapse and cause uncontrolled leakage. Increased preparedness for correction of oil spillages during tank drilling would also require a budget exceeding that allocated for *Stage 2.*

In addition to a full inspection with identification of tank contents, there are also other ways of knowing that there is no oil left in tanks. An example of this would be heavily corroded goose-neck vents (tubes for tank ventilation), especially on shipwrecks that are upright on the sea floor, such as the wreck of the fishing boat Thetis.

3.3.5 Corrosion sampling

The shipwrecks that are the greatest threat to the environment are structures made of steel, which means that they will deterioriate from corrosion while they are on the sea floor. The extent and rate of corrosion is affected by a number of factors related to both the vessel and the environment. Examples of vessel-related factors are how recently and how well the hull was painted at the time of wreckage; and if a tank was filled with oil, the corrosion may be kept in check. Environment-related factors are the salinity, the oxygen concentration of the water and sediments around the wreck, and biological activity in the form of fouling by plant and animal life and microorganisms on the hull of the wreck.

Corrosion analysis of shipwrecks concentrates on identification of the degree of decomposition (the *corrosion status*) and the rate of the decomposition process (the *corrosion rate*). To get the best possible idea of the corrosion status and the corrosion rate, many samples must be taken at different places on each wreck. For example, certain parts of the hull of a vessel are especially exposed during normal operation, which is why steel plates in especially exposed areas are often designed to withstand this higher degree of exposure. Despite having these stronger plates, a high degree of exposure can cause structural changes such as microscopic cracks in steel, which can result in more rapid corrosion.

In addition to the corrosion status of the hull, it is also important to assess the corrosion status of any tanks that are suspected to contain oil or other environmentally dangerous substances. However, *Stage 2* did not cover performance of a full corrosion analysis of such suspected tanks. Due to the limited budget of the project, it was not possible to maintain the required degree of preparedness for oil spillage if leakage happened as a result of sampling. Letting divers enter the wreck to approach tanks that cannot be reached from the outside is also a potential occupational hazard.

3.3.5.1 Metal sampling

Samples for further assessment of corrosion status and corrosion rate should preferably be taken from tanks that—based on archive data on the wreck—are suspected of containing a potentially hazardous substance. In those cases where diving into the wreck entails significant occupational risks, samples can be taken from the plates on the hull or, alternatively, from steel structures on the deck, such as goose-neck vents, hatches, etc. (Figure 4).

The maximum rate of corrosion on a tank of a wreck is determined by local factors, such as the presence of welds, rivets, and splits, and also metal-metal contact with precious materials (such as piping or connectors made of copper or brass). It is therefore very worthwhile to take samples of steel that have:

- welds
- rivets
- splits
- any contacts with precious metals.

Professional photography is also useful for documentation of the above-mentioned local factors. Try to take samples with an area of about 1 dm^2 (10 × 10 cm). Put the samples into labeled sampling bags, stating the place of sampling and the type of material (to be planned before the diving operation). In addition to steel, samples can also be taken from the “rust carapace” (hard crystalline deposits that are likely to be on the hull).

When taking samples of steel, exposure to heat must be kept to an absolute minimum in order to avoid changes to the structure of the metal. The use of hydraulic cutting tools is preferable to using torches, saws, etc. Highly corroded parts of the deck should preferably be pried off.

Figure 4. Ventilation hatch from before and after blasting. Photography: Swerea-KIMAB

3.3.5.2 Measurement of plate thickness of the hull/tank

Three to five measuring points should be identified in advance, based on archived data—and together with the diving supervisor. Thickness measurement should first and foremost be performed on steel sheets of any tank that may have an environmentally hazardous cargo. It is more likely, though, that thickness the measurements will be performed on the metal hull of the wreck, where the choice of measuring points can be made according to whether a specific side portion of the hull corresponds to the bunker or loading tank.

At each measuring point and for exactly the same position, five values should be collected and saved for later statistical analysis. Repeat measurements in the same position every few years will allow calculation of the corrosion speed of the hull, which can be used as a basis for planning of any remediation.

Before diving, the positions of the measuring points should be planned from the vessel's construction drawings and stated in terms of horizontal and vertical distances from well-defined points on the wreck, which will be easily recognized by divers. The positions of the thickness measurements that have been performed must also be carefully documented by the diver, with horizontal and vertical distances, in order to verify that measurements have been performed as intended—and also to be able to locate the positions again for repeat measurements. If possible, the surface should be treated first to remove bio-fouling, paint, and the products of corrosion, in order to minimize the uncertainty of measurement by the instrument.

3.3.5.3 Sampling of water for chemical and physical parameters

The national and regional environment monitoring programs have a collection of data on basic chemical and physical parameters, such as oxygen, salinity, and temperature (section 3.4). Sampling in the form of depth profiles is usually carried out on a monthly basis at specific measuring stations. In addition to already available monitoring data from a location geographically close to the wreck, it can be useful in corrosion studies to take water samples (about 1 L) for chemical analysis (e.g. salinity, pH, alkalinity, and nutrients) in the immediate vicinity of the shipwreck.

3.3.6 Environmental parameters for *in situ* investigation

When dealing with wrecks that are potentially harmful, the aim is to minimize the effect on the marine environment. It is therefore important to study the surroundings. The environmental parameters in the immediate vicinity of wreck, such as the depth, the type of sea floor, the chemical composition of the water, and current-related parameters also provide important information that can have a bearing on the decomposition of the wreck. For example, corrosion can be affected in different ways depending on the availability of light, which in turn depends on the depth and turbidity. Light penetration encourages bio-fouling by photosynthetic organisms, which then produce oxygen that accelerates corrosion. Another example is the characteristics of the sea floor; the stability and structural integrity of the wreck can be affected by how soft the sea floor is and whether it is sloping or prone to subsidence.

3.3.7 Existing data and monitoring programs

Extensive environmental data sets have been gathered in the regional and national monitoring programs (SwAM 2014a). Previous research projects can also provide valuable environmental data, but but these are often more difficult to get an overview of and be able to locate.

3.3.7.1 The Swedish Marine Archive (SHARK)

The on-going work with implementation of the Marine Strategy Framework Directive (2008/56/EG) includes examination and harmonization of the European monitoring programs (Dulio et al. 2010). The purpose is to draft the norms for environmental quality, so-called descriptors, which describe what constitutes a good environmental status (HaV 2014b). To be able to assess the status of the environment according to the eleven descriptors, criteria have been identified regarding what is a good environmental status for each descriptor. To be able to identify whether the criteria have been fulfilled, 56 quantitative indicators have been put forward and then used as a basis for the national supervision programs. The indicators—in the form of marine biological, chemical, and physical parameters—are stored in SHARK, which is administrated by SMHI, which is the national repository for such data (SMHI 2014a). In addition to the on-going development work on environmental monitoring under the Marine Strategy Framework Directive, there is plenty of information available in the previous regional and national monitoring data. These data are also part of SHARK.

3.3.7.2 SGU sediment data

The Geological Survey of Sweden, which is responsible for environmental monitoring of sediment in offshore areas and which is also the national repository for data on sediment chemistry and environmental chemistry based on sediment samples, stores information on geological conditions at the sea floor (SGU 2014). Sediment sampling is performed at well-known sediment accumulation points at 16 stations in different marine basins. The main purpose is to monitor the sea-floor environment and trends in accumulation of environmental pollutants in sediment. In addition to sediment sampling, since 2014 salinity, temperature, oxygen level, and turbidity, and also the current speed and direction of the water column have been monitored at the stations. This is a very positive development, since there are very few data on currents at the sea floor in the SMHI database(s).

3.3.7.3 Data from previous research projects

Among other things, the Swedish Institute for the Marine Environment is concerned with collection and analysis of data from the marine environment. It also maintains a register of experts associated with its activities who could, in certain cases, be consulted regarding access to relevant marine environmental data from previous research projects (Swedish Institute for the Marine Environment, 2014).

The website "Havet.nu", which is maintained by the Baltic Sea Center of Stockholm University and Umeå Marine Sciences Center (2014), also has a registry function regarding researchers and research areas, which can give possible ways of accessing data outwith the traditional monitoring programs.

3.3.7.4 Mapping of parameters: currents, salinity, oxygen, and turbidity

The relevance of existing data will vary from case to case, depending on where a wreck happens to be located relative to the stations of the national monitoring programs. It can therefore be well worth complementing rough information from existing data with specific measurements that are made in the immediate vicinity of the wreck.

Current measurements with an ADCP (an acoustic doppler current profiler) provide information on the direction and speed of the current from the sea floor to the ocean surface over the course of several months. After that, a change of battery is needed, and the data can be obtained from the memory card at the same time. Certain types of ADCP can also be equipped with different sensors, e.g. for conductivity (salinity), temperature, turbidity, and oxygen level. Measurements of current performed over a year give a good idea of the natural seasonal variations and the prevalent current direction and velocity. The information can then be used in VRAKA, partly to improve assessment of corrosion conditions and partly to improve our estimation of which biotopes are most at risk from discharge of environmentally hazardous substances at a particular wreck.

3.3.8 Sampling of environmental pollutants close to the wreck

When tracing chemicals that have spread to the surroundings, sediment is examined first, since heavy metals and organic pollutants attach to particulate matter and accumulate in organisms that will eventually end up in sea-floor sediment. This sampling should be combined with measurements of current, to estimate the most probable direction of discharge and to assess where samples for characterization of background levels of environmental pollution can be taken. Furthermore, it is important to know the type of sea floor under and around the wreck. Usually it is accumulation beds—i.e. areas with little water movement that allow particulate matter to fall to the bottom—that are used for analysis of enrichment of environmental pollutants in sediment. Theoretically, the first accumulation bed downstream of a wreck would be most appropriate for sampling of environmental pollutants. Another possible approach would be to sample sediment that has accumulated inside the wreck, but one possible argument against this is that the sediment would not be representative of a natural sedimentary environment.

In practice, it is probably very difficult to single out specific effects of a particular wreck on the marine environment, unless there are very special conditions with no other possible sources of adverse effects. An alternative approach is to apply the precautionary principle, since a growing number of field studies and studies done under *in situ*-like conditions in the laboratory have shown that even very low concentrations of oil have adverse effects on the marine environment (for more details, see section 4). Even though it may be difficult to identify exactly which part of the marine ecosystem has been affected by a particular wreck, it is possible to conclude that a wreck leaking hazardous chemicals will contribute to a worse environmental situation.

An on-going leakage can be identified in water or sediment by placing passive samplers around the wreck. The samplers adsorb chemicals dissolved in water, and remain in place for about a month before being collected for analysis. Due to the short project time and missing information on current direction around the objects in the field study, no passive samplers have been used in *Stage 2,* but they are discussed further as a possible future tool in section 3.5.

3.4 Methods with potential for development for monitoring and investigation of wrecks

Several methods have the potential to be developed into valuable tools in the framework of a long-term strategy for monitoring and risk assessment of wrecks. The authority that will assume responsibility should follow the technical developments and update SOPs as appropriate.

3.4.1 Targeted sampling with ROV and divers

In the course of the project, it became clear that targeted underwater sampling should be developed. Currently, there is no standard equipment available, and issues of this kind are addressed globally on a project basis without any particular solution gaining wide acceptance. It would be beneficial if the relatively small ROVs of the Marine Administration and Coast Guard had this capability, which would require development of the entire chain of analysis—from sampling to adjustment of laboratory analysis methods.

If a cargo that is hazardous is part of the whole problem, equipment for detection and analysis can be brought on board, so that the hazardous substances can be identified quickly and other measures can be taken—such as decontamination of the ROV or termination of the diving operation.

3.4.2 Passive samplers and bio-indicators

Passive samplers consist of an absorbent, which is allowed to equilibrate with the surrounding water and then to accumulate, for example, organic compounds from the surrounding water. The passive samplers are deployed for about a month, and then they are retrieved for chemical analysis. Such samplers can be used to monitor wrecks whose position is already known, where they can be placed at regular intervals (years). This can, for example, alarm that a tank has started to leak, which can change the prioritization of measures that have already been planned. Samplers are relatively cheap, and general sampling campaigns should be carried out to give cost-effective analyses. To gain an optimal understanding of the relative contributions of the wreck and its surroundings to pollution, the plan would be to place passive samplers both upstream and downstream of the wreck.

Passive samplers can give information on the concentration of various hazardous substances in the environment, but they are limited by the detection limits of the analytical method used to identify these substances. In ecological and ecotoxicological terms, it is also a problem that low concentrations of several different toxins all at once can have a more adverse effect on organisms than the sum of the adverse effects of individual toxins (i.e. there is a synergistic effect rather than an additive effect). This is something that passive samplers cannot predict. Bio-indicators can therefore be used to study the combined ecotoxicological effects of many different stressors at the same time—such as mussels, which filter large amounts of water in one day (Fornander 2010). Comparison of how well mussels are doing (i.e. their physiological status) upstream and downstream of the source of discharge will give a measure of the effect on the environment at a particular location. As with the use of passive samplers, it is important to know the main direction of the current and other possible sources of discharge in the vicinity to be able to adequately assess any effect downstream of the wreck.

3.4.3 Non-invasive methods for identification of tank contents

To avoid putting the structural integrity and stability of the wreck at risk by making holes, ideally a non-invasive method should be used to identify the content of a sealed tank. One such technique that is used for wrecks is neutron back-scattering (NBS). The technique is based on the fact that different materials will reflect a neutron beam in different ways, which makes it possible to distinguish between the response detected from oil and water behind an intact sheet of steel. The method is marketed as a quick and cost-effective method and is available as a service with an estimated daily cost of 25,000 SEK.

A closer look at the NBS method showed that it can only give answers to a very limited number of questions. To distinguish between oil and water behind a sheet of steel, there must be an identifiable interface; otherwise the instrument cannot distinguish between water alone and oil alone, even after calibration. The depth of measurement behind the plate will depend on the thickness of the steel plate, but under the most favorable conditions (i.e. with a thin plate) it is ten cm at best. If the plate is 2 cm thick, then the depth of measurement is likely to be 3–4 cm behind the plate.

The uncertainty of the measurements combined with their limited depth led to the decision not to use NBS in *Stage 2*. In the longer term, if many wrecks must be inspected, there might be cases when application of this method would increase the value of information gathered during *in situ* inspections; for example, if a wreck was not particularly damaged when it went down and there has been careful documentation of how much remaining oil would be expected to be there. Then NBS would perhaps be a cost-effective alternative to verify archived data. However, in most cases it is doubtful that NBS would become a cost-effective method, given the considerable uncertainty of the analysis.

Contact with the company that developed the NBS technique for underwater use revealed that the new, promising methods are being developed. The new method should hopefully be ready for *in situ* testing in 2015 and, in contrast to NBS, will not have the same problems in distinguishing whether there is water alone or oil alone behind a sheet of steel. In addition, the method has a considerably higher depth of measurement and will hopefully be able to provide information over the entire measuring distance, from the thickness of the metal on one side of the tank to identification of the contents, and then to the thickness of the metal on the other side of the tank. The method is also being developed for use by divers and/or ROVs.

3.4.4 Detection of leaks of chemicals by underwater vehicles

The larger kinds of ROVs, or also AUVs, can be equipped with detectors such as mass spectrometers that can detect leakages of fuel or chemicals. By searching a particular area, chemicals that are being released can be traced. The leak can be compared to “smoke”; it is transported by the underwater current and is gradually diluted. The source of the discharge can then be traced by computer modeling. This method has been developed internationally for leakage of fuel from wrecks and leakage of explosive substances from dumped munitions. To our knowledge, this technique will not be available in Sweden in the foreseeable future.

3.4.5 Placement of offer anodes

Deployment of sacrificial anodes, e.g. zinc anodes, which is normally done to reduce corrosion on the hulls of ships, would be interesting in many respects. By weighing and measuring zinc anodes before deployment and at regular intervals (months/years) after deployment, one can obtain a measure of the rate of corrosion at the wreck. Using sacrificial anodes can also be a way of reducing the rate of breakdown of the wreck from corrosion, thereby helping to buy time until remediation work is possible (Heldtberg et al. 2004).

4 Ecotoxicological effects of environmentally hazardous substances from wrecks

Adverse effects of oil accidents in the marine environment are well known from pictures of beaches covered with dead birds, fish, and mammals. On the other hand, low concentrations of oil have long been considered to be something that nature alone can take care of and break down. This assertion is correct, but today we know that it is an over-simplified one. There are microorganisms that specialize in decomposing oil, but they are only found at low densities in Swedish coastal waters. Since the beginning of the 21st century, ecotoxicological research on natural plankton and sea floor sediments has shown that oil has adverse effects at concentrations as low as those currently permitted when discharging bilge water (15 ppm). The effects have been observed both in the form of changed community structure (altered species composition) and changed community function (e.g. the ability to process nutrients), which can have a long-term effect on the biochemical cycle in coastal ecosystems (Hjorth et al. 2007, Hjorth et al. 2008, Petersen et al. 2009, Lindgren et al. 2012). Biochemical cycles have been classified as important ecosystem services, since they contribute to the support of functioning marine ecosystems (Swedish Environmental Protection Agency, 2009).

Although more and more studies are highlighting the fact that even low concentrations of oil have a negative effect on the marine environment, it is difficult to specifically attribute the effects of low oil concentrations to particular wrecks. This is partly due to the fact that it is difficult to know exactly where the oil ends up when dealing with small amounts dissolved in water. The other reason is that there are many other ways that oil can be discharged into coastal marine environment, such as from shipping. The fact that there are numerous sources of oil in the sea is yet another reason for reducing the individual contributions, to decrease the total amount of pressure on the marine environment. To date, there have been no reliable estimates of the proportion of oil that is released annually into the sea that can be attributed to shipwrecks.

One alternative to the challenge of identifying the effects of a wreck *in situ* would be to make an empirical assessment based on experiments with low concentrations of oil—either under laboratory conditions similar to those *in situ*, or in the field. An example of a field study would can be to enclose natural plankton colonies in large containers and then expose them once to a very low dose of oil (Hjorth et al.. 2007 & 2008)

Another factor that makes studies on the environmental effects of oil more complicated is that oil is an umbrella term for a very complicated mixture of different chemical substances. Up to 17,000 (!) substances have been identified in different oils. The most prominent of them are polycyclic aromatic hydrocarbons (PAHs), which are highly toxic and common components of oil. PAHs are therefore often used as model substances in studies on the ecotoxicological effects of oil.

As part of of *Stage 2*, Chalmers kept developing methods for assessment of the effects of low concentrations of oil on the marine environment. Carefully sieved surface sediment containing a natural community of meiofauna (animals 63 μm to 1 mm in size, Figure 5) and microorganisms was used as a model system. The sediment was then incubated in small metal containers (plugs) without lids, similar to a snuffbox, in a large volume of sea water (Figure 6). This model system has the advantage that it covers the organisms, their interaction with each other, and their interaction with the environment, and it is therefore more ecologically relevant than classical ecotoxicology (Artigas et al.. 2012). In classical ecotoxicology, only one type of organism is studied at a time and the degree to which a substance is toxic is often assessed from the concentration that kills half of the test organisms (LC_{50} value).

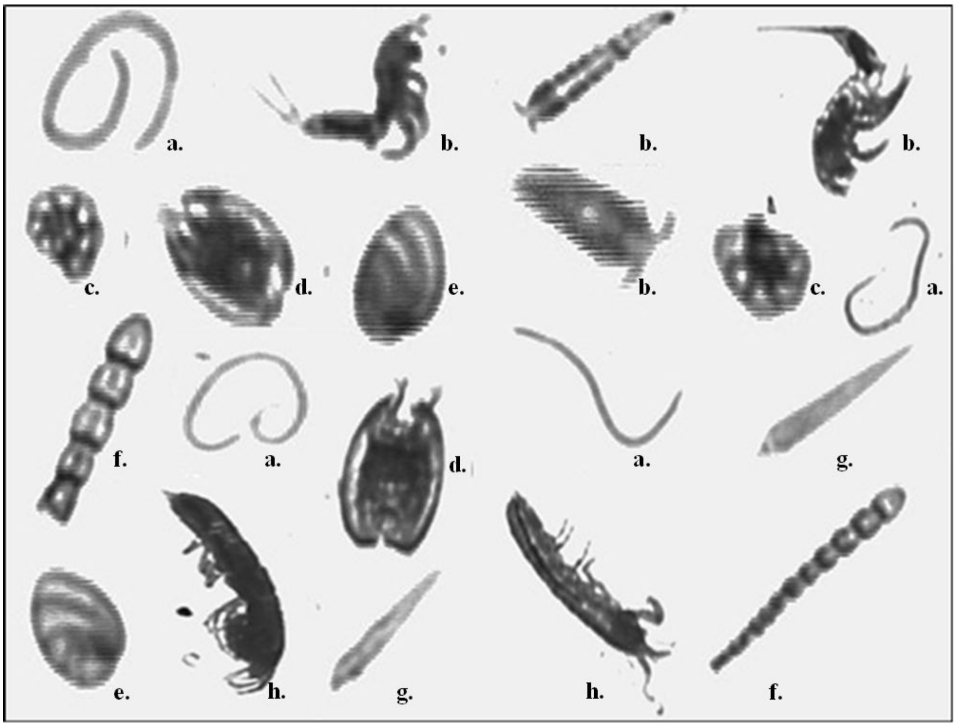

Figure 5. Pictures of meiofauna taken for automatic digital image analysis with ZooImage software.

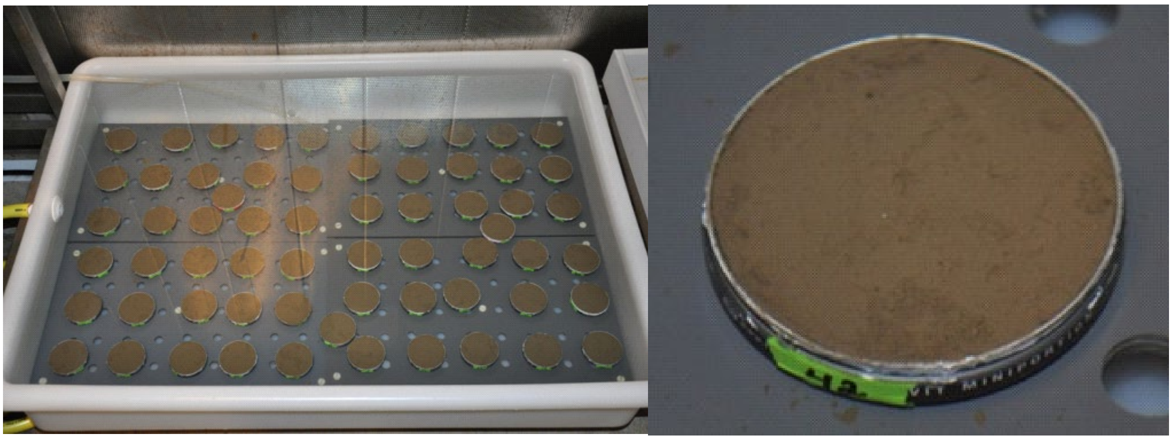

Figure 6. Experimental set-up at the Sven Lovén Center for marine sciences, with conditions similar to those in situ. The panel to the right shows a sediment plug (actual size).

Three different experiments were performed in the laboratory at the Sven Lovén Center for marine sciences, Kristineberg, with sediment taken in or just outside of the Gullmar Fjord. The type of oil used was MK-1 diesel, and the concentrations to be studied were based on calculations of PAH content.

4.1 Methods for assessment of the environmental effects of low oil concentrations

In the first experiment (performed before *Stage 2*), which took place over the course of 60 days, the lowest concentrations of PAHs that still had adverse effects on meiofaunal and microbial communities were studied. At the start, we analyzed background concentrations of PAHs in sediment at the place of sampling. Then in the actual experiment, we studied the effects of concentrations that were 2 to 20 times higher (corresponding to 1,300 and 13,000 µg/kg of dry weight of sediment). To ensure that no artifacts would result from the fact that the experiment was performed in the laboratory with sediment, we also included a control where no oil was added. Compared to the control sediment community, the treatment with diesel resulted in a significantly altered meiofaunal community structure and a reduced nitrification capacity in the microbial community. Nitrification is an important stage of the nitrogen cycle. The effects were still as strong after 60 days, and it was found that the differences between the treatments and the control, as a result of the oil added, increased. The conclusion was that even low concentrations of oil can adversely affect meiofaunal and microbial communities for at least 60 days (Lindgren et al. 2012).

In addition to oil being a complex mixture of different substances, its toxicity can change depending, for example, on whether it can bind to sediment particles. One can say that the toxicity of oil becomes less when its bioavailability is reduced, i.e. when the proportion of oil that can be taken up by organisms is reduced. Different types of sediment have different abilities to react with oil, which means that the same concentration of oil in two different types of sediment can result in unequal amounts of oil available to organisms. In a second experiment, similar concentrations of PAHs were added to three different types of sediment. The results confirmed the hypothesis that bioavailability is decisive for the amount of PAHs added that can actually affect organisms in the sediment. After 60 days, the treatment that involved the highest total amount of PAHs had the lowest proportion of bioavailable PAHs and at the same time had the lowest degree of negative effects on the microbial community. It also turned out that a specific type of PAHs, the so-called alkylated PAHs, played an important role in the adverse effects that resulted. In six of eight cases, there was a correlation between alkylated PAHs and the adverse effects seen (Lindgren et al. 2013).

Chronic exposure to a hazardous substance at low concentrations—for example, oil in the environment—can be seen as a stress factor that leads to selection pressure, both at the individual level and at the community level. In other words, vulnerable organisms in a population will be eliminated whereas the organisms that can tolerate the stress factor will be selected for. This can be seen as a positive effect—that the degree of tolerance or resistance becomes stronger. Unfortunately, this is not the whole truth. The organisms that are tolerant of oil are not necessarily those that are most fit to resist other stress factors, e.g. climate change. The result of the developed tolerance is reduced biodiversity (or genetic diversity), both at population level and the community level, so that the total resistance of the community becomes less.

In a third experiment, the development of tolerance against PAHs in the microbial community was studied over 90 days. Development of tolerance was observed after both 60 and 90 days (Lindgren et al.., in preparation). This shows that the capacity to develop tolerance is something that must be taken into account when investigating the environmental effects of oil pollution. If a community has developed tolerance, this can be misinterpreted as reflecting a healthy environmental status—whereas in actual fact the genetic diversity has been reduced. We also aim to conduct studies with sediment from areas of accumulation upstream and downstream of

Skytteren. PAHs from the sediment samples will be analyzed for both the total concentrations of PAHs and the proportion of PAHs that are available to organisms. At the same time, sediment samples will be taken to carry out short-term experiments to determine whether tolerance has arisen against PAHs in oil.

The results of the ecotoxicological studies can then be used to assess what consequences oil leaking from a wreck can have for the marine environment. Currently there are no complete models of oil risk that include assessment of the environmental effects of oil, but continued efforts are being made to include these effects on the environment in VRAKA.

4.2 Digital Environmental Atlas

In addition to effects on the marine environment, the diverse wildlife along the coast is also threatened by oil discharged from wrecks. Different types of coastal habitats will be affected by an oil discharge to different extents, and it is a well-known fact that remediation costs are related to how vulnerable an area is. The vulnerability of different coastal habitats has been categorized in the Digital Environmental Atlas, which is a map-based tool developed by the County Administrative Board (2014). Modeling of how a discharge of oil from a wreck spreads (for example, in “Seatrack Web” of the Swedish Meteorological and Hydrological Institute (SMHI)) gives information on which type of coastal habitat is threatened and thereby also a quantitative measure of any adverse effects on the environment (SMHI 2014b). In the future, it would be good to develop a similar facility for effects on the marine environment, so that various types of sediment and their communities could be categorized in a similar way to the coastal habitats in the Digital Environmental Atlas.

5 The risk assessment tool VRAKA

VRAKA is a method that can be used as a basis for decision making regarding potentially environmentally harmful shipwrecks (Figure 7). It is a method for probabilistic risk assessment, which means that it is possible to make a quantitative assessment while taking the degree of uncertainty into account (Landquist et al. 2014).

Risk estimation tools in VRAKA are under development. A structure for estimation of risk is being developed, and work is in progress to incorporate relevant data as a background to the structure. The risk estimation tool involves a number of steps (Figure 8) whereby the user assesses the frequency of a number of events and enters site- and wreck-specific indicators, which together might possibly cause the kind of damage to the wreck that would trigger an oil leak. Based on this, the probability of an oil leakage is estimated and, in combination with the expected volume of oil discharged, the first risk estimate is made. The next step is to assess the consequences of such a discharge, and tools for this are being developed.

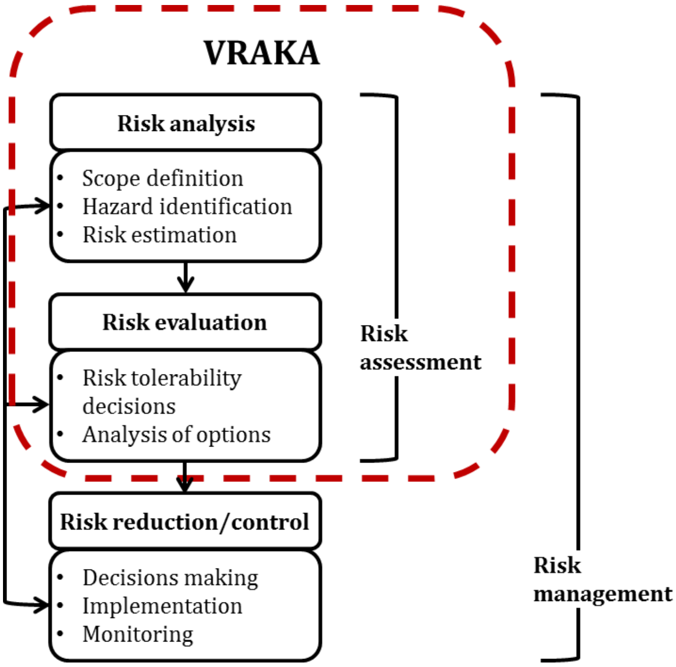

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Figure 7. Scheme of VRAKA regarding the risk assessment process.

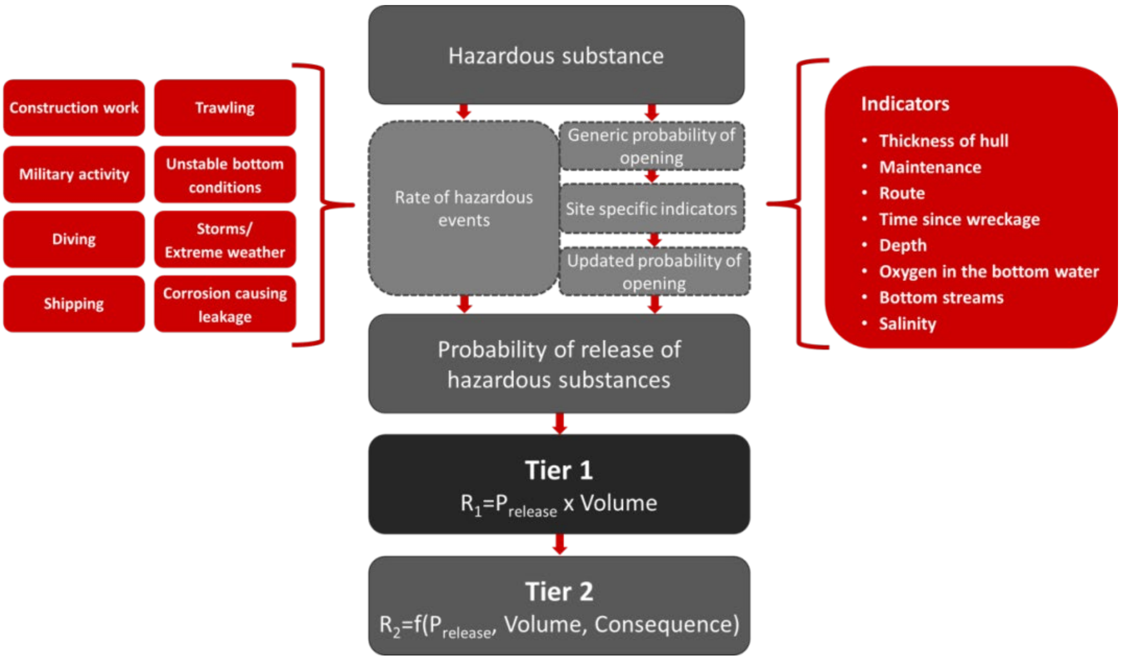


Figure 8. Risk estimation in VRAKA.

The assessment of consequences will be based on the probability of discharge combined with how the discharge spreads and the economic, social, and environmental effects that this will have on the surroundings. A possible alternative would be to combine Seatrack Web (the tool developed by SMHI to calculate the spread of substances with pollution potential at sea, based on, e.g. wind and wave data) with the Digital Environmental Atlas (in this GIS-based environmental atlas, the Swedish coast is divided into several levels of vulnerability) to assess the effect of the discharge and thereby assess the risk of oil discharge from a particular wreck.

Risk assessment in VRAKA can be performed with relatively little information. On the other hand, this can result in a high level of uncertainty in the outcome. If a less uncertain result is needed, more input data can be provided to update VRAKA. Part of the output from VRAKA is information on the parameters that contribute most to uncertainties in the result. To make the process more efficient, a tool for an initial risk assessment is suggested, where wrecks of high and low risk can easily be sorted out. Figure 9 shows a flow chart of VRAKA with an initial, simpler prioritization as a first step. In this way, a greater number of wrecks can be assessed and, if the risk is high or the result is uncertain, a further, more detailed assessment can be performed with the tools developed under VRAKA. The initial assessment would start with an evaluation of whether there is any oil at all remaining in the wreck. If this is not the case, the wreck can be excluded from the investigation. If presence of oil is still suspected, then the assessment can be taken to the next step.

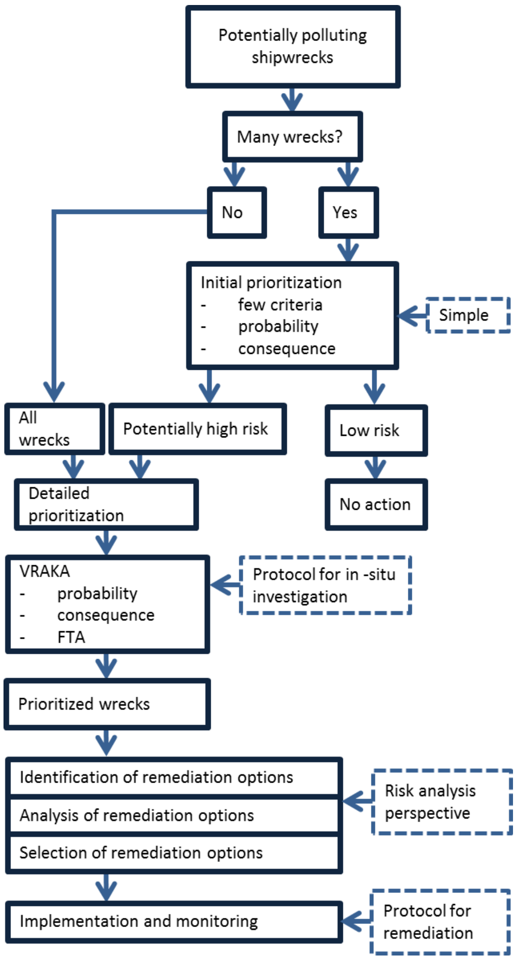


Figure 9. Flow chart of VRAKA complemented with a method for initial prioritization.

To make the risk assessment process for wrecks even more efficient, we suggest that in addition to a more detailed assessment (Figure 8), a simple initial assessment model should be used to single out objects of extremely high and low risk (Figure 10). This initial prioritization would be based on four factors, i.e. the volume of oil in the wreck, the condition of the wreck, the distance from the shore, and the vulnerability of the nearest shoreline. The user is guided through the assessment using a table where each indicator is described in relation to low, moderate, and high effect.

	Low severity	Moderate severity	High severity
Volume	< 100 m^3	10-500 m^3	> 500 m^3
Status	< 20 years since wreckage	20-60 years since wreckage	> 60 years since wreckage
Distance from shore	> 10 nm	1-10 nm	< 1nm
Vulnerability; nearest shore is:	Sand, steep cliffs and rock faces, or built up.	Beaches with pebbles, boulders, or gravel or beaches with cliffs.	Reedbeds, meadows, fine sediment beaches or mixed beaches

Figure 10. Table for assessment of the degree of effect of the 4 different indicators, i.e. volume, status, distance, and vulnerability.

The effect of each specific indicator is then combined to provide the risk for a particular wreck. Figure 11 shows how each level of effect corresponds to a color. The risk is assumed to be high if at least two fields are in black, to be moderate if at least two fields are in red, and to be low otherwise. If there is no oil in the wreck, then it can be assumed that the risk is negligible.

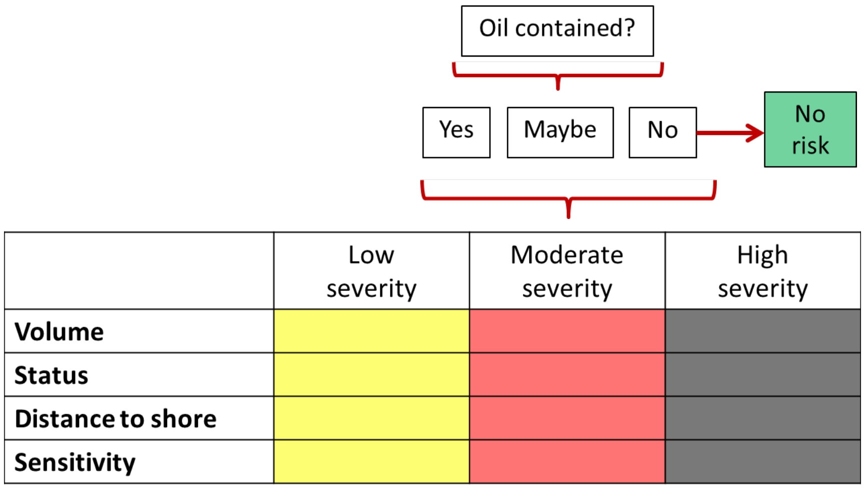


Figure 11. Model for risk assessment based on information fromFigure 9.

6 Case study items

The four case study items chosen—Altnes, Skytteren, Thetis, and Villon—were investigated in more detail by ROV and with divers. The studies of the vessel drawings were supervised by the shipbuilders Professor Jonas Ringsberg and Dr Per Hogström. In addition to the description of operations in this chapter, further documentation and pictures can be found in in Appendices 4–7. The measurement data are incomplete at this point, since only the first three months of measurements from Skytteren were available for evaluation.

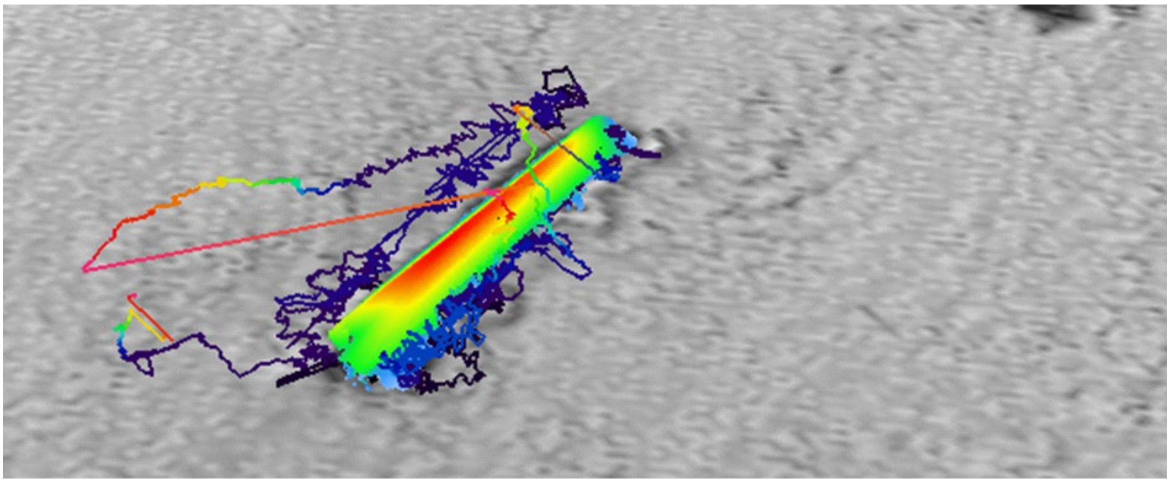
6.1 Altnes

Motor cargo ship built of steel in Norway in 1978

Length	107 m
Width	15 m
Size	3961 GRT
Engine	6-cylinder diesel engine, 4,000 horsepower

At the time of wreckage, Altnes's home port was Kingstown, St Vincent, and Granada. On January 16, 1998, Altnes was on her way from Port Arthur, Texas, to Sundsvall loaded with 5,115 tons of petroleum coke (a substance similar to coke that is used to produce aluminium). In heavy fog, Altnes collided with the cargo ship Shannon east of Anholt in the Kattegatt. Altnes did not sink immediately, but drifted in an area with heavy sea traffic for several days before going down. Today, Altnes is resting on her side at 23–36 meters depth. When she sank, it was estimated that the ship contained some 30 m^3 of heavy fuel oil, about 3 m^3 of lubricating oil, and 10–15 tons of gas oil on board. According to the information available, about 20–22 m^3 of oil was salvaged.

Altnes lies with her stern at 80 degrees with a starboard list angle of 130 degrees—almost upside down. The rudders and propellers are visible in the hydrographic data. It is also possible to visualize the lower edge of the collision damage on the underwater images of the hull on the port side, which is partially buried in sediment. The port anchor can also be distinguished in the anchor pocket.



Picture 12. Multi-beam data from Altnes with the "trace patterns" after ROV investigation around the wreck.

ROV investigation was performed on June 29, 2014, by the hydrographic surveying vessel Anders Bure (Figure 12). There were south-westerly winds of 2–6 m/s and a north-east current of 1.3 knots. Two anchors were thrown at an angle, so that the vessel could stay in a good position over the wreck. The stern was first filmed with the ROV, after which the vessel changed anchors, so that the fore section could be filmed. The current imposed some limitations on both anchoring and maneuvering of the ROV.

The bottom paint seemed to be intact and there was generally very little corrosion on the wreck. There was some minor marine bio-fouling of the deeper vertical parts and the parts where the hull cut off the light from the surface. Generally speaking, there was no extensive corrosion on the visible parts of the hull. There was significantly more bio-fouling on the parts located below 30 meters. Remnants of trawl nets had been caught in the rudders and propellers.

Investigation by divers was done on October 5, by KBV 001 Poseidon. There was a south-easterly wind of 12–14 m/s with insignificant current. The wind complicated the anchoring, and a three-point anchor system had to be used to ensure a good position relative to the wreck. The DP of the vessel was not approved for diving use. A dive inspection with filming and measurement of hull thickness was performed in the forward part of the wreck. The hull thickness measurement was performed at two points on the port ballast tank 3, under the bilge keel and on the flat bottom. Samples of sea-floor sediment and water were also taken during the dive. The dive was performed with an umbilical, with a total diving time of 92 minutes at a depth of 30–39 meters.

6.2 Skytteren

Cargo steamboat/floating whaling factory built in 1899 in Belfast, Northern Ireland

Length	172 m
Width	19 m
Size	12531 GRT

The Norwegian whaling factory Skytteren was interned in 1942 in Gothenburg. Together with nine other ships, she took part in Operation Performance on April 1, 1942, with the purpose of escaping from Gothenburg to England—and providing the allies with ball bearings and steel. However, the German navy had been alerted to the plan, and was already patrolling in wait outside Swedish territorial waters. The operation failed: Skytteren was shot at by the German warships and the ship was so damaged that the captain ordered that the vessel should be scuttled. Now the ship is lying on her side at a depth of 74 meters. The amount of oil on board at the time she sank is unknown.

Skytteren is lying with her stern at about 270 degrees, with the port side facing the sea floor (Figure 13).

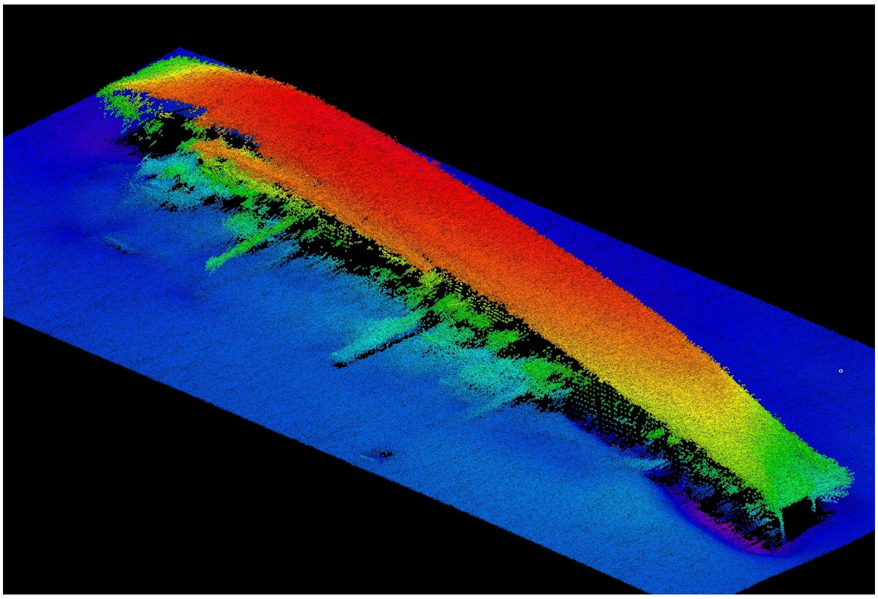


Figure 13.

Multi-beam data from Skytteren.

The current-measuring equipment (RDCP) with oxygen, turbidity, temperature, and salinity (conductivity) sensors was used on May 11, 2014, by the hydrography vessel Anders Bure. There was a weak southerly wind with a northbound current of about two knots. The RDCP ended up about 84 meters north-east of the wreck. The first retrieval of data was done on August 8, 2014, and showed a clearly prevalent northerly current with a typical current speed of 0.2–1.7 knots (Figure 14).

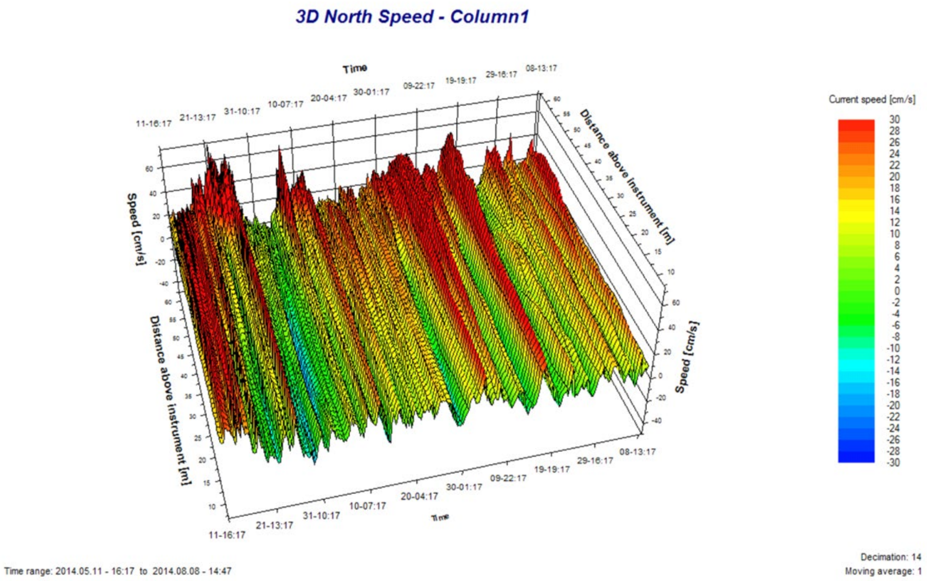


Figure 14. Analysis of current components in the north-south direction. Predominantly northbound current.

An ROV investigation was performed on August 8, 2014, by the hydrography vessel Anders Bure in connection with battery exchange and retrieval of data from the RDCP. There were southerly winds with a speed of 2–6 m/s, a northbound current of about 2 knots, and a wave height of about 0.3 meters. Since the distance to the sea floor was more than 70 meters, it would have been problematic to lay anchor with a smaller vessel. Two anchors usually need to be used at an angle to ensure a good position over a wreck. The length of the anchor rope must be at least 3–4 times the water depth for the anchor to get a good grip on the sea floor, which in the case of Skytteren would mean 300 meters of anchor rope (× 2). Instead of that, the working vessel of the Marine Administration, Scandica, had anchored a large mooring buoy immediately to the south of the wreck on one of the previous occasions.

Anders Bure berthed with a rope on the buoy and kept releasing the rope until the vessel moved with the current to a good position over the wreck. Before inspection of the wreck with the ROV, it was used to salvage the RDCP for data removal and battery exchange. This operation took a lot of time due to the strong current and deep waters, and it was also difficult to put the RDCP back in place for continued logging of data.

Filming with the ROV was done on the north side of the wreck (the keel of Skytteren), at the fore section and stern. The south side of the wreck was difficult to reach due to the strong current, which resulted in difficulties in maneuvering the ROV in a safe way without running the risk of it getting caught in protruding objects and remains of fishing gear. Underwater inspections in deep waters with a relatively strong current require large vessels with subtle maneuvering ability (dynamic positioning) and an ROV with powerful propulsion and proper winch equipment for handling of its cable. The wreck is quite badly corroded and one can see fairly large flakes of rust that have fallen from the hull to the bottom. Large parts of the wreck have been subject to bio-fouling. No dive inspection was done on Skytteren, as the wreck is located in water that is too deep for light diving.

6.3 Thetis

Fishing vessel made of steel, built in 1961 at Karlskrona shipyard

Length	30 m
Width	6.4 m
Size	147 GRT
Engine	Diesel engine 960 horsepower

Thetis used to belong to the Swedish National Board of Fisheries and had a solid structure. At the time of the accident, the home port of Thetis was Kungshamn. On October 24, 1985, she was on her way from a fishing ground to Kungshamn when she suddenly capsized and sank just outside Smögen. Thetis is currently lying at a depth of about 30 meters and is often visited by leisure divers. At the time of wreckage, there was thought to have been about 17,400 m^3 of fuel on board.

Thetis is lying with her stern at 225 degrees and she is standling upright on the sea floor with a starboard list angle of a few degrees (Figure 15). Sonar data show that the wheelhouse is gone and that there are remains of the fishing net are lying at the stern. The hatch to the little cargo hold on the deck is missing.

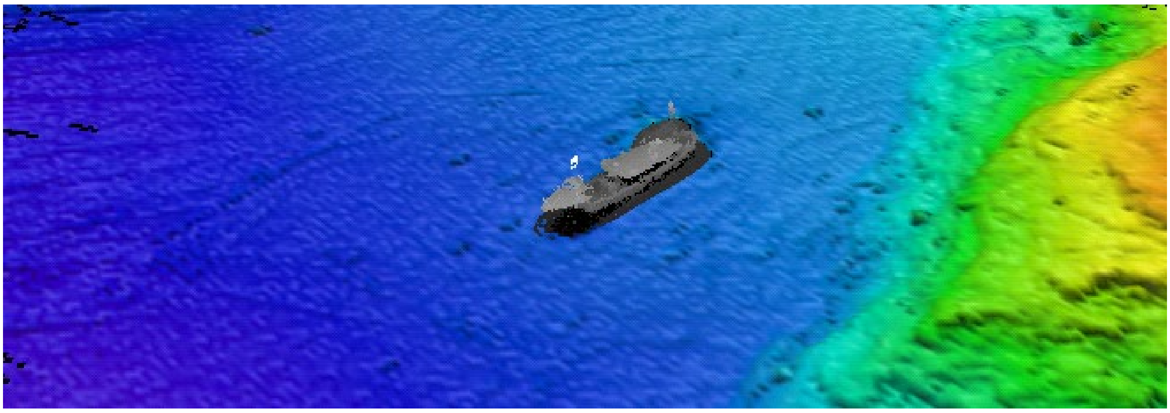


Figure 15.Multi-beam data from Thetis.

The ROV investigation was performed on August 3, 2014, using the hydrography vessel Anders Bure. There were south-westerly winds with a speed of 2–5 m/s with a north-north-east current of 0.6 knots. Anchoring was done with two anchors at an angle, at a depth of about 30 meters.

Filming with the ROV was started at the fore section and continued around the wreck. Generally speaking, corrosion of the wreck was extensive on the hull and smaller details; for example, some of the ventilation pipes leading to tanks had come off and were lying on the deck. Most of the paint was gone. Remains of the wheelhouse appeared to be lying on the sea floor, starboard of the wreck. Remains of fishing equipment and purse seine were lying at the stern and were spread out a short way from the wreck on the starboard side. The sediments close to the wreck were of clay, with seashell-derived material and sand in the surface layer.

The dive inspection was performed by KBV 430 on August 7, 2014. The hydrography vessel Anders Bure was also involved, and assisted with diving. It anchored with two anchors at an angle immediately to the south-east of the wreck. KBV 430 was berthed at a descent rope that was firmly attached to the fore section of the wreck. There were south-westerly winds with a speed of 4–6 m/s with a north-easterly current of 0.5 knots. The diving depth was 21–33 meters.

The divers filmed the wreck around the hull and on the deck. In addition to the observations done during filming with the ROV, it was noted that the deck was rusted through in four places, down to the cargo hold. The wreck was estimated to have about 20–30% of its paint left. All inspected ventilation pipes leading to the tanks were rusted through. A hatch to a ventilation chamber was salvaged for corrosion analysis.

During this operation, the diver used a sensor for underwater positioning so that we could follow and document the diver's "trace" around the wreck. The same technique is used to follow and document ROV operations at the sea floor. However, in this particular diving operation the equipment failed and the "trace" could not be recovered.

Another diving investigation was performed on October 1, 2014, by KBV 032 Lysekil and thickness measurement was performed at six points on the hull. On this operation, sampling of sediment and water was also done. The points on the hull where the thickness measurements were performed were ascertained and documented on the plans and by filming.

6.4 Villon

Motor cargo ship, made of steel, built in 1959 at Kust shipyard in Höganäs

Length	54.2 m
Width	8.3 m
Size	437 GRT
Engine	12-cylinder diesel engine, 800 horsepower

At the time of the accident, the home port of Villon was Stockholm. On December 2, 1985, she was on her way between Trelleborg and Stugsund loaded with 641 tons of malting barley. It was stormy with gusty winds, and the cargo shifted, resulting in a poor list angle. Villon sank while being towed to Simrishamn. Today, the vessel is sitting upright at a depth of 18–37 meters and is frequented by sports divers. At the time of wreckage, Villon is estimated to have had 4,000 m^3 of fuel oil and 150 liters of lubricant oil on board.

Villon is lying with her stern at 225 degrees and is standing upright on the sea floor (Figure 16). The depth data show that the hatches to the hold are missing, but otherwise the vessel appears to be intact and undamaged.

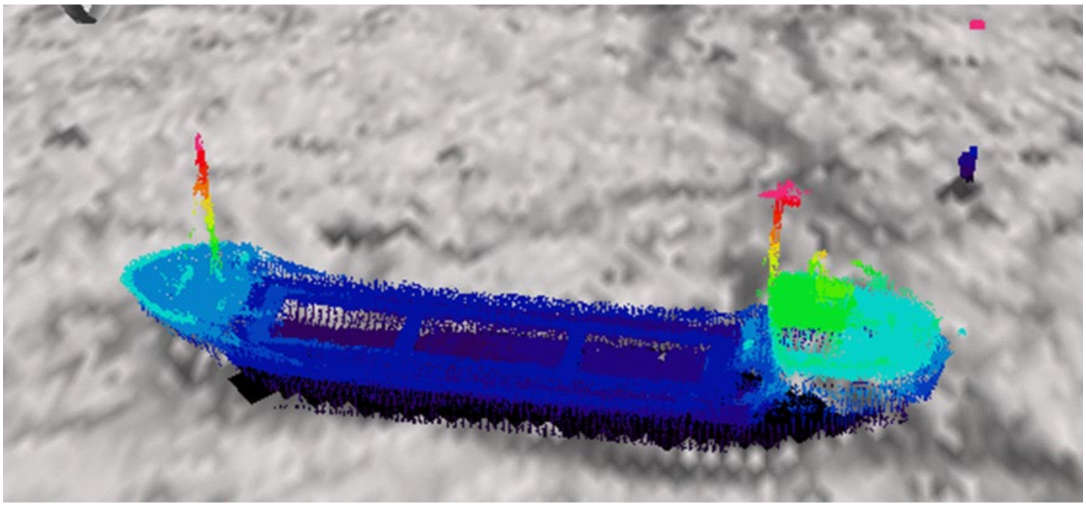


Figure 16. Multi-beam data from Villon. Note the current-measuring equipment (RDCP) close to the sea floor (in the upper-right part of the picture).

An initial ROV investigation was carried out by the hydrography vessel Anders Bure on June 1, 2014. It was calm weather with a shifting wind, and there was a south-westerly current of about 0.8 knots. Anchoring was performed with an anchor placed north-east of the wreck, allowing the vessel to stay right above the wreck during the investigation. The depth was 37 meters. In less calm weather, it would have been necessary to anchor with two anchors at an angle.

ROV filming was begun at the stern of the wreck and then continued around the deckhouse, the hull, and above the deck. The bunker area and the ventilation pipes of the bunker tanks were obscured by a deck, so there was no inspection of this area.. Remains of fishing nets and fishing lines were caught in the hull. On one occasion, the ROV got caught in a fishing line and the accompanying diver from the dive firm P-Dyk had to dive and release the ROV. The wreck showed a moderate degree of corrosion with a lot of marine bio-fouling.

Current-measuring equipment (RDCP) was used on June 25, 2014 (Figure 17).

The diving investigation was done from KBV 499 with the help of KBV 003 Amfitrite, and involved filming and measurement of hull thickness. The wind was south-south-westerly with a speed of 10–12 m/s. KBV 003 was placed windward, south of the wreck, with dynamic positioning so that it would stay leeward of the smaller diving boat KBV 499. Two descent ropes were secured on the wreck, one immediately forward of the deckhouse and one next to the bulwark on the starboard side. Measurements of thickness were performed on the hull next to the port bunker tank (double-bottom tank 4) and the port ballast tank (double-bottom tank 3). Sediment samples were also taken on the port side. Six sets of dives were performed in the course of two days, with a total diving time of 116 minutes.

The condition of the hull was confirmed to be good, with only a small amount of corrosion. The double-bottom tanks, bunker, and ballast were half-sunk in the sediment. Thickness measurements were documented on the plans and by filming.

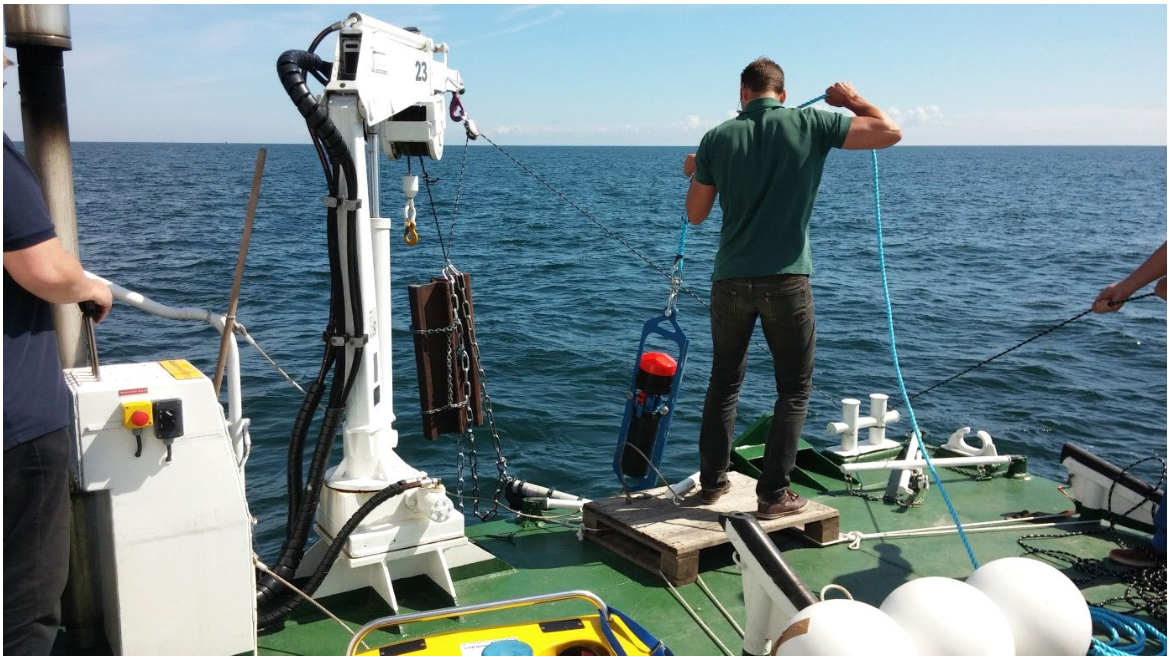


Figure 17. Deployment of current-measuring equipment RDCP next to Villon.

7 Suggestions for further measures

A prerequisite for a long-term sustainable solution and implementation of a program for monitoring and further measures is that an appropriate authority should be given the task of—and responsibility for—systematic investigation of the wrecks described in the inventory from *Stage 1*. In *Stage 2*, suggestions were put forward regarding the structure of a national program for dealing with environmentally hazardous wrecks, as well as specific recommendations for standard procedures in the investigation of wrecks that may be a threat to the environment.

7.1 Suggestions on the structure of a national program for dealing with environmentally hazardous wrecks

In concrete terms, further work should be structured as follows:

First of all, the 31 prioritized wrecks from *Stage 1* should be investigated in accordance with the SOP produced in *Stage 2*. In parallel, archive studies and probably hydrography/localization should be carried out on the 285 wrecks that were classified as potential threats to the environment in *Stage 1*. If this work is started in 2015, then the 31 prioritized wrecks can be either written off the list or incorporated into a national plan for monitoring and remediation of environmentally hazardous wrecks by 2030. The other 285 wrecks will either be ruled out or confirmed as a real threat.

The Swedish Agency for Marine and Water Management and the Environmental Protection Agency share the responsibility for monitoring of the marine environment. “The Agency for Marine and Water Management has an overall responsibility for the environmental monitoring program Coast and Sea, while the Environmental Protection Agency is responsible for the parts concerned with environmental toxins in the marine environment”(HaV 2014a, Environmental Protection Agency 2014). We suggest that the Agency for Marine and Water Management should be given overall responsibility for investigation of wrecks and also prioritization of any remediation work that might be necessary by giving operative assignments to other relevant authorities, institutions, and companies with relevant resources, knowledge, and abilities. We suggest using the standard routines produced for investigation of wrecks, and the risk assessment tool VRAKA, which was developed further in *Stage 2*.

As mentioned earlier, underwater operations and hydrography are costly and very demanding in terms of vessel resources and time. A large part of the costs (the largest one in many cases) can be attributed to transportation to and from the operating area; that is, if a monitoring and survey program for wrecks is put together with full allocation of all the resources required, it will be very costly. However, during the work on *Stage 2* it became clear that there is a good chance of performing various parts of the investigations of wrecks in parallel with or in-between other assignments that are routinely performed by an agency. For example, hydrography of particular wrecks can be performed at a much lower cost if there is a chance of using vessel resources that have been set aside mainly for charting of the sea floor for the benefit of shipping in the vicinity of the wreck. Since hydrography work is dependent on the weather, there are cases where the routine work cannot be done but when there might be a chance of locating a wreck nearby instead. Similarly, the Coast Guard might sometimes have a chance to combine diving exercises with wreck inspections, if an appropriate exercise area and the wreck are located close to each other. The Geological Survey of Sweden might also have a chance to perform a small amount of sediment sampling close to wrecks located along the planned route of a routine sediment monitoring program. On the other hand, it could be that the wreck investigation might generate valuable data for existing monitoring programs. Just as sampling of sediment around the wreck would add data to the SGU database, placement of ADCPs in the vicinity of a wreck could be integrated into the marine database of SMHI. Generally speaking, there are very few data series on sea-floor current measurements, and a national wreck program would therefore improve access to data on sea-floor currents for validation of oceanographic models.

Regarding the other 2,300 wrecks, which were judged as being impossible to write off the list of wrecks (from *Stage 1*) that might be environmentally dangerous without any further investigation, there could be common interests based on cultural, historical, and environmental considerations. The new Historic Environment Act (1988:950), which came into force on January 1, 2014, only grants reduced coverage to the wrecks that went down after 1850, since only those shipwrecked before 1850 are automatically covered by the blanket protection given to ancient monuments. Given the Swedish definition of a potentially environmentally hazardous wreck, in principle all of these wrecks would be excluded from the blanket protection of ancient monuments. In addition to this blanket protection, it is also possible to apply for protection of newer wrecks on special grounds, but this is on condition that the wrecks have been located. To decide which wrecks should be given special protection, they must be of historical interest with more detailed information available—and the other 2,300 other wrecks must be located.

To summarize, the resources used for dealing with environmentally hazardous wrecks could well be used more efficiently, provided there is very good cooperation between the relevant agencies. The cooperation between agencies in *Stage 2* clearly shows that it can work very well. The Sjöstjärnan project is an existing platform for further cooperation, a collaboration and cooperation among agencies regarding information exchange and collection of depth data and sea floor data (Swedish Armed Forces, 2014). By making a joint decision twice a year on the geographical areas in which—and the extent to which—various agencies should collect depth and sea floor data, it will be possible to identify possible issues for cooperation. If the Agency for Marine and Water Management is given overall responsibility for updating the information relating to potentially environmentally hazardous wrecks, then the existing list of wrecks could be used at the Sjöstjärnan meetings to help determine those that would be located close to geographic operating areas of different agencies during the coming year.

7.2 Financing of a national program for handling of environmentally hazardous wrecks

Even though this coordination would mean significantly more efficient use of resources, additional public funds are needed to cover the additional costs that wreck investigations actually entail. This also requires coordination, since the three agencies that are mainly involved belong to different ministries: the Ministry of the Environment, the Ministry of Justice, and the Ministry of Enterprise and Innovation, Energy, and Communications. The existing platform—the Coordination Group for Marine and Water Issues – SamHav (Hav 2014c)—that was created for cooperation of agencies at the top management level should be able to provide active assistance in locating an appropriate joint finance model between the three ministries involved.

The joint finance structure must also allow allocation of funding for additional investigation equipment and for development of ROV-based sampling and measurement methods for those wrecks that are lying in very deep water. Parts of this development could be carried out in the form of research and development projects, and in *Stage 2* the project group discussed how they could apply for MSB financing for this purpose in 2015. Improved, functional, and operationally safe ROV-based investigation equipment can be used to advantage over and above simple inspection of wrecks. Thus, these developments are of great interest to several of the agencies involved, especially the Coast Guard. The Coast Guard is capable of performing remediation operations if they are needed, in emergency situations. Regarding investigation and remediation of wrecks, however, decisions must be made concerning the techniques and competences that should be on offer by government agencies and the techniques and competences that might be bought in instead, in the form of paid services from private companies. Given that Sweden will have an official environmental protection agency and that there will be a long-term need for investigation of wrecks, it naturally follows that continuous updating of investigation methods should fall under the authority of the goverment agencies. However, the answer to the question of whether remediation technology should also be provided by authorities is most probably no. Remediation operations will probably not be done routinely and they require highly specialized forms of competence, which are already available today from private companies.

Even though remediation of wrecks will not be performed routinely by the goverment agencies, the agency that is responsible should keep itself updated on new developments in remediation technology, since the technology is likely to become both better and cheaper. Similarly, it should follow the development of sensors for non-invasive measuring methods in order to ensure a faster, safer, and cheaper assessment of the potentially hazardous substances that remain on a wreck. It would also be appropriate to continue to interact with other countries regarding the handling of potentially environmentally hazardous wrecks. In the framework of, for example, Helcom Submerged, there might possibly be resources for cooperation on archive and operating issues concerning investigation and remediation of wrecks (HELCOM 2014). There are already links with Finland and Estonia in the form of on-going joint research programs on risk assessment of wrecks, such as SWERA (BONUS-SYKE, 2014). Moreover, all the Swedish agencies involved also have corresponding agencies in other countries, e.g. in the Baltic region, which will also give the opportunity to exchange information and swap experiences in dealing with environmentally hazardous wrecks.

The most important thing is to produce a long-term national plan for investigation of the wrecks prioritized in *Stage 1*. It can be assumed that about 5–10 wrecks per year can be investigated *in situ* and that another 10–15 wrecks a year could be researched in archives, which would result in processing of about 15–25 wrecks a year. The cost of a wreck investigation can be roughly estimated to be 1–1.5 million SEK per wreck on average, including archive searching, vessel time for hydrography, internal training of operating personnel before investigation of the wreck, the ROV, diving and sample analysis, documentation, and reporting. Investigation of 10 wrecks a year would cost about 10–15 million SEK a year. Archive-based research on 15 additional wrecks a year would cost 0.6 million SEK a year.

Earlier attempts to estimate the cost of remediation operations (Hassellöv, 2007) have shown that it is very difficult to make generalizations, and any estimates are by definition associated with considerable uncertainty. The Finnish environmental institute SYKE contracted salvage companies to remove oil from the shipwrecks Park Victory and Estonia. Park Victory sank 50 years ago and was in a very bad condition, which made removal of 410 m^3 of oil a difficult operation, resulting in a cost of about 38.6 million SEK. The cost of removal of 250 m^3 of oil from Estonia was 26.9 million SEK.

The costs of a national program for dealing with environmentally hazardous wrecks must be viewed in relation to the costs resulting from the decision not to take any further measures. Those on the Swedish west coast still vividly remember the oil contamination of the island of Tjörn from the wreckage of Golden Trader off the Danish coast. It was estimated that a total of about 500 tons of oil was collected by the Coast Guard and the local emergency services. Remediation was completed two years later, in the autumn of 2013, and in the end the cost had reached 167 million SEK.

7.3 Inspection of environmentally hazardous wrecks – recommended procedure

A suggestion for a standard procedure for investigation of environmentally hazardous wrecks was produced during *Stage 2*. The agency that is eventually given the responsibility for a systematic investigation and possibly remediation of environmentally hazardous wrecks (see *Stage 3* in the investigation of the Agency for Public Management, 2007) should have a routine in place for collection of information, descriptions of assignments, and reporting of underwater inspection in order to be able to prioritize salvage operations. Appendices 1–3 provide suggestions for procedures for investigation, i.e. Inspection Information, Description of Assignments, and Underwater Inspection. To use routines for investigation in an effective way, it is important to let al.l the personnel involved understand the purpose of—and the underlying issues behind—the three different stages. A good way of ensuring this would be to use some kind of short internal training or joint training of personnel from several of the agencies involved.

All the information collected on each wreck should be used for a first assessment of whether immediate removal of hazardous substances or other preventive measures is necessary, using the risk assessment tool VRAKA. Then an assessment of environmental risks and prioritization for long-term planning of any future decontamination operations can be made.

An Inspection Information report should be produced for each wreck. If an underwater inspection of the wreck is necessary, then the report should be sent to the relevant operational unit together with the Description of Assignment. An Underwater Inspection report should be produced for each wreck. The complete reports should be sent to the Commissioner at the authority responsible for remediation of environmentally hazardous wrecks.

7.4 Application for further work under extension of project

As briefly mentioned at the start, the time frame for the project was very tight in relation to the expected outcome. An application for extension of the project has therefore been submitted in order to complete the following:

- continued collection of RDCP and sensor data from Skytteren and Villon, December 2014/January 2015 and April 2015, in order to obtain longer series of related data;
- validation of VRAKA, by arranging an expert group workshop, November 2014;
- additional experiments on development of tolerance to PAHs in meiofauna and microbial communities, November 2014;
- completion of the corrosion analysis of metal samples from Villon;
- development of a method for sample-taking on wrecks; the Coast Guard in cooperation with FOI.

The cost of further work has been estimated to be covered by the funds already allocated.

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10 Appendices

1 - SOP 1: Inspection Information – collection of information before *in situ* investigation of wreck

2 - SOP 2: Description of Assignment – *in situ* investigation of wreck

3 - SOP 3: Underwater Inspection – report on *in situ* investigation of wreck

4 - Investigation of Altnes

5 - Investigation of Skytteren

6 - Investigation of Thetis

7 - Investigation of Villon

Inspection Information – collection of information before *in situ* investigation of wrecks

All information available on the wreck should be collected and collated. Documents are normally available in the archives of the Marine Administration, the Transport Agency, and the Maritime Courts (Maritime declaration from Maritime Courts appointed by the government (District Courts)). Additional information can to some extent be found in the Coast Guard or SMM archives. Other sources of information that might be useful are the Coast Guard archive of previous operations, such as diving/ROV inspections or oil removal operations; FMIS, classification organizations, latest or previous owner, shipyard that built or maintained the vessel, insurance companies, diving clubs, local knowledge, general Internet search, etc. Important blueprints and specific relevant documents that enhance underwater inspection shall be attached to the inspection information.

The report shall contain the following information:

- Report date: *YYYY-MM-DD*
- Report prepared by: *name, agency*
- Name of shipwreck: *NN*
- Previous name (name starting from) *NN*
- FMIS ID: *xx*
- Wreckage date: *YYYY-MM-DD*
- Flag at the time of accident: *xxx*
- Built on: *YYYY-MM-DD*
- Refurbished on, if applicable: *YYYY-MM-DD*
- Extensive refurbishment: *extension, change of tank configuration etc.*
- Dry docking: *YYYY-MM-DD, shipyard*
- Length × breadth: *ll x ww*
- Stated wreckage position: *N DD MM,mm / E DDD MM,mm*
- Depth, depth of sea floor: *xxx meters, minimal depth of the wreck/distance above the bottom, xxx meters*
- Access restrictions: *legally protected area or wreck, permit*
- Maritime declaration: *YYYY-MM-DD, district court*
- Insurance company: *company*
- Surviving witnesses: *name, contact information*
- Blueprints available yes/no

If blueprints are available, include in the report:

- Blueprints: source
- Bunker tanks yes/no
- Cargo tanks N/A yes/no
- Deck tanks N/A yes/no
- Ballast tanks yes/no
- Other tanks yes/no
- Cargo hold yes/no
- Machinery space yes/no
- Goose necks/ventilators yes/no
- Hull thickness yes/no
- Hull type: steel plate/aluminium/wood
- Original metal thickness mm

If information on fuel and cargo is available, include in the report:

- Type, amount, and distribution of oil on board at the time of wreckage: *HFO/DO/SMO*
    - State operating and maintenance oil
    - State other chemicals for operation and maintenance
- Planned route at the time of wreckage: *close to start/end can give an indication of amount in bunker*
- Type, amount, and distribution of cargo on board at the time of wreckage: *xxxxx*
    - Are there dangerous (classified) goods in the cargo?
        - Which categories/amounts are documented?
        - How was the cargo stored?
        - Perform classification of risk to own personnel:
            - Is increased self-protection required?
            - Do personnel need to be decontaminated?

If there have been previous underwater operations, include in the report:

- Date: *YYYY-MM-DD*
- Performed by: *name, agency*
- Type of inspection: *ROV, diving, hydrography, sampling, placement, equipment etc.*
- Inspection equipment/measuring equipment used:
- Platform used: *vessel/boat name*
- Position: *N DD MM,mm / E DDD MM,mm*
- Positioning method used: *GNSS with DGPS/RTK, USBL (underwater positioning)*
- Estimated positioning precision: *GNSS, USBL, in meters*
- Depth, bottom depth: *xxx meters, minimal depth of the wreck/distance above the bottom, xxx meters*
- Any anchoring next to the wreck or DP:
    - position, direction/distance from the wreck, one/several anchors/crowfeet/stern anchors.
- Orientation of the wreck:
    - Direction, upright, lying on side, upside down
    - Wreck sunken/partly sunken into the sediment
- Depth data from hydrography:
    - *Depth data model of the wreck and topography of the sea floor close to the wreck, 3D model*.
- Structural integrity of wreck: *broken apart, holes in hull, cargo hold hatches on/off, dispersed parts etc.*
    - Condition of hull:
        - *condition of paint, corrosion, pitting, bio-fouling with seaweed, barnacles, sea anemone, polychaetes etc.*
    - Condition of goose-neck ventilators:
        - *condition of paint, corrosion, pitting, bio-fouling with seaweed barnacles, sea anemone, polychaetes etc.*
    - Obstacles: *trawling/fishing net, broken masts/antennas etc.*
    - Leakage from hull/tanks, goose necks, other openings/holes:
        - From what part of the wreck?
        - DO/HFO/SMO/chemicals other substances
        - Estimated discharge (l/s, drops/s)

- Measures taken: *inspection, oil removal/drainage, closing of goose necks,other*
- Video: *photography/picture of the wreck*

Relevant ambient conditions if there are data available:

- Water transparency in water column: *xx m*
- Type of sea floor around the wreck: *rocky, sand-, clay- sediment, fouling, etc.*
- Trawl tracks around the wreck:

- Topography of sea floor around the wreck: *hilly, flat, inclined.*
- Landslides/earthquakes in the area
- Prevalent current direction/ speed
    - Surface
    - Sea floor
    - Tracks from the water current in sea-floor topography
    - Cavities produced by the water current
- Water data: *O_2, turbidity, redox, temperature, salinity, water analysis*
- Results of sea floor samples taken *on sediment gathered in and around the wreck*
- Storms/extreme weather

Earlier sampling and measurements performed on the wreck:

- Measurement of thickness of hull, goose necks etc.
- Sampling on holds/bunker tanks;
- Hull, steel/rust, a test piece with welds and/or rivets should be included. Test pieces should also be taken from the so-called corrosion carapace (hard deposits on the sheathing of the ship)

Human activity in the vicinity:

- Existing or planned utility works, such as gas pipes, cables
- Military activities
- Shipping
- Trawling
- Diving

Vulnerable environments or protected areas in the vicinity:

- Marine reserve/natural reserve
- Natura 2000 areas
- National interests
- Vulnerable habitats (Digital Environmental Atlas)

Assessment and recommendations:

Make an assessment of the expected state of the wreck based on the data collected. Provide recommendations for future investigation of the wreck.

Description of Assignment – *in situ* investigation of wrecks

The Description of Assignment should be sent to the executing unit together with the Inspection Information report. The Description of Assignment should state the contact person (POC) for water current data, corrosion status data, and chemical analysis data for the recipient analysis lab to be able to support the preparations for investigation of the wreck .

The Description of Assignment should contain the following information:

- Date: *YYYY-MM-DD*
- Name of wreck: *NN*
- FMIS ID: *xx*
- Performed by (unit):
- Time: *YYYY-MM-DD to YYYY-MM-DD*
- Permit: *N/A, date received, permit must be applied for*
- Measures taken: *inspection, oil removal/drainage closing of goose necks, other*
- Type of inspection: *ROV, diving, hydrography, sampling, deployment, equipment, etc.*
- Documentation with video, photography/images;
- Areas of special interest to be inspected/addressed;
- Thickness measurement of hull, tanks, goose necks etc. According to the attached scheme.
- Sampling for assessment of corrosion status:
    - Tools – torch, saw blade, hydraulic cutting tools (preferred)
    - Sample the hull, steel/rust; a test piece with welds and/or rivets should be included. Test pieces should also be taken from the so-called corrosion carapace (hard deposits on the sheathing of the vessel)
    - Sampling of water around the wreck
- Collection of current data for assessment of distribution of bunker oil and cargo
    - State time frame
    - Can be performed with passive samplers for leaking chemicals
- Sampling for assessment of hazardous goods/fuel is carried out in cooperation with the laboratory performing the analysis
    - If any crime is suspected, the sample should also be sent to SKL
    - Cargo/bunker, if leakage of hazardous substance, or if possible, through goose necks or other openings
    - Samples of sediment collected in the wreck
    - Samples from sediment plugs around the wreck, preferably taking into account the data on current “upstream” and “downstream” of the wreck.
    - Sampling of water around the wreck.

Procedure for measurement of plate thickness:

Three to five measuring points should be identified in advance, based on the archive data and the suggestions of those performing the dive operation, concentrating on existing tanks with a hazardous substance and/or appropriate part of the of the ship’s sheathing. Thie thickness should be measured five times at each measuring point to allow adequate statistical assessment of the result.

The position of the measuring points must be planned by measuring on the blueprints before diving, and stated with horizontal and vertical distance from well-defined points on the wreck, that can easily be found by divers. The positions of the thickness measurements must also be documented precisely by the diver with horizontal and vertical distances—partly to verify that measurements have been performed as intended and partly to be able to locate the positions again for future repetition of measurements. If possible, the surface should be treated first to remove bio-fouling, paint, and corrosion products in order to minimize the measurement error.

Underwater Inspection – report on *in situ* investigation of wrecks

Once the Inspection Information and Description of Assignment have been analyzed, the assignment should be performed and documented according to the Underwater Inspection report. *The diver or diving supervisor can be given a checklist with the following items.*

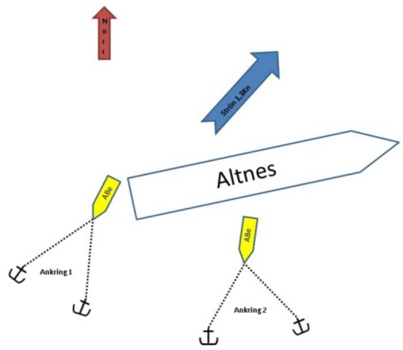
- Report date: *YYYY-MM-DD*
- Report prepared by: name, unit, agency
- Name of wreck: *NN*
- FMIS ID: *xx*
- Position: *N DD MM,mm / E DDD MM,mm*
- Positioning method used: *GNSS with DGPS/RTK, USBL (underwater positioning)*
- Estimated positioning precision: *GNSS, USBL, in meters*
- Type of inspection: *ROV, diving, hydrography, sampling, equipment etc.*
- Inspection equipment/measuring equipment used:
- Vessel: *vessel/boat name*
- Weather: *wind direction, wind strength, wave height*
- Depth, bottom depth: *xxx meters, minimal depth of the wreck/distance above the sea floor, xxx meters*
- Hydrography, collection of depth data:
  - *depth data and topographyof the sea floor at the wreck and in the immediate vicinity of the wreck, radius of about 500 meters.*
  - Orientation of the wreck: Direction, upright, lying on its side, upside down
- Any anchoring next to the wreck or DP:
  - position, direction/distance from the wreck, one/several anchors/crowfeet/stern anchors.
- Measures: *inspection, oil removal/drainage, closing of goose necks, other*
- Water transparency in water column:
- Structural integrity: *broken apart, holes in hull, cargo hold hatches on/off, dispersed parts etc.*
- Wreck sunken or partially sunken in sediment;
- Condition of hull:
  - *condition of paint, corrosion, pitting, bio-fouling: seaweed, barnacles, sea anemone, polychaetes etc.*
- Condition of goose-neck ventilators:
  - *condition of paint, corrosion, pitting, rusted through, bio-fouling: seaweed, barnacles, sea anemone, polychaetes etc.*
- Sampling and measurement of thickness of hull, tanks, goose necks etc.:
  - *Cleaning with hydraulic steel brush/ grinding disc/manually and measuring with ultra sound device designed for underwater use on an ROV or by a diver.*
  - *Systematic investigation with positioned measuring points on the wreck, x/y distance from distinct points on the hull.*
- Obstacles: *trawling/fishing net, broken masts/antennas etc.*
- Condition of any previously used gaskets/seals;
- Type of sea floor around the wreck: *rocks, sand sediment, clay sediment, bio-fouling, etc.*
- Topography of sea floor around the wreck: *hilly, flat, inclined*.
- Videos, photographs/images of the wreck:
  - *Systematic investigation with positioning, stating x/y distance from distinct points on the hull; alternatively, USBL positioning.*

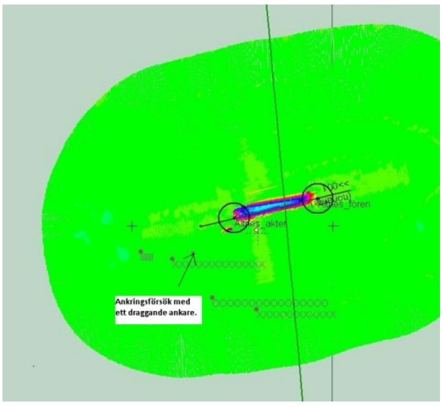
- Leakage from hull/tanks, goose necks, other openings/holes. Positioning of leakage stating x/y distance from distinct points on the hull; alternatively, USBL positioning:
  - From what part of the wreck?
  - DO/HFO/SMO/chemicals, other substances
  - Continuous discharge (l/s, drops /s)
  - Sampling performed
- Documentation with filming, photography/images

Results from collected samples/data are collated in cooperation with the relevant POC:

- The POC for water current measurements collates the current data collected
- The POC for corrosion status collates the results of laboratory analysis of test pieces collected from the wreck
- The POC for environmental data collates the results of environmental ecotoxicological and chemical analyses of sediment, water, and hazardous chemicals discharged from the wreck

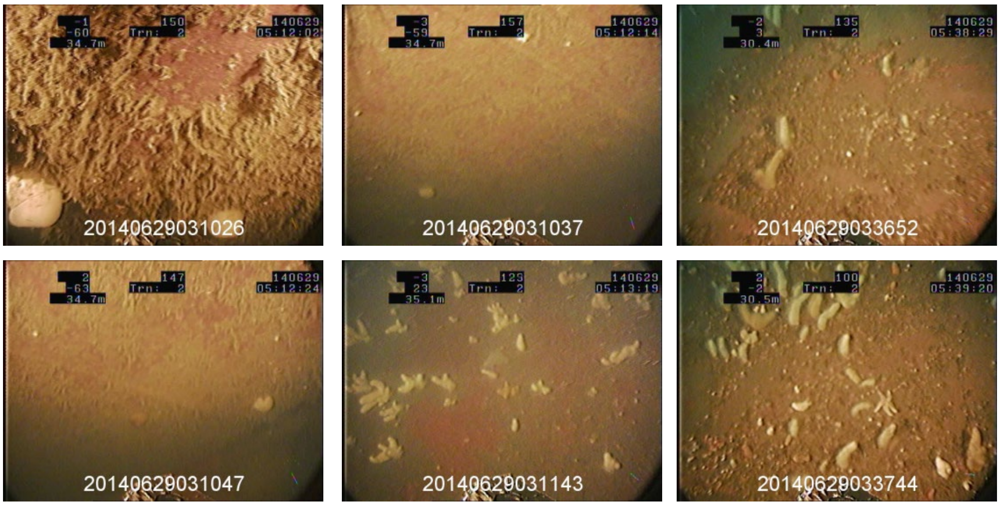
Datum/tid	*Händelse*
2014-06-28/19:00	Avgång lotshamnen Malmö.
2014-06-28/21:20-21:30	Helsingborg, Ulf Olsson anländer för att deltaga.
2014-06-29/01:43-02:30	Sjömätning över vraket och i närområdet.
2014-06-29/02:30-03:00	Ankringsförsök ankarplats 1, draggande ankare.
2014-06-29/03:00-02:30	Ankring ankarplats 1, dubbla ankare.
2014-06-29/05:00-06:00	Rov-körning 1
2014-06-29/06:00-06:40	Hivning ankarplats 1, flytting till ankarplats 2.
2014-06-29/06:40-07:55	Rov-körning 2
2014-06-29/07:55-08:35	Hivning ankare
2014-06-29/08:45-09:05	Komplettering sjömätning över vraket
2014-06-29/09:10	Lämnar vrakområdet
2014-06-29/13:25-14:30	Helsingborg, Ulf Olsson avmönstring
2014-06-29/17:00	Åter Lotshamnen i Malmö.



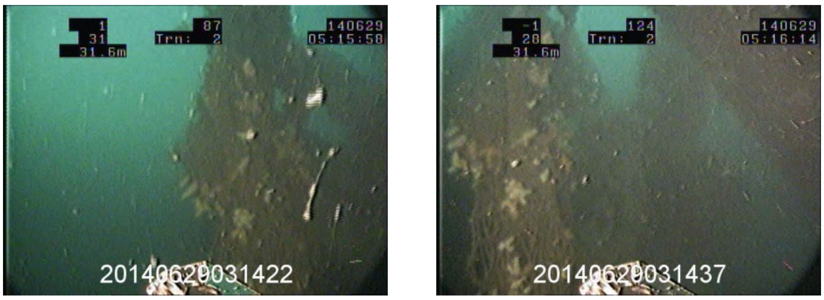


Depth 36–37 meters with sediment of clay and sand. Anchoring in a crowfoot, with the main anchor of Anders Bure (50 kg anchor, about 15 meters of chains and 75 meters of wire, 90 meters in total). Assisted by reserve anchor (25 kg, with 10 meters of chains and 80 meters of tamp, 90 meters in total).

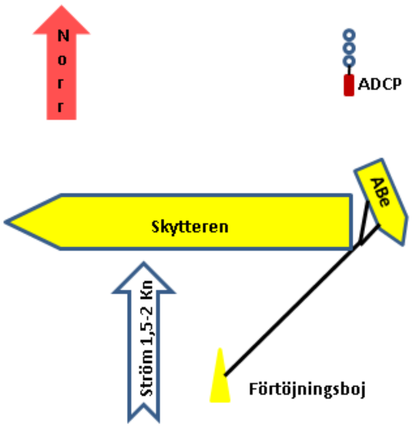
Anchoring in crowfoot with two anchors.

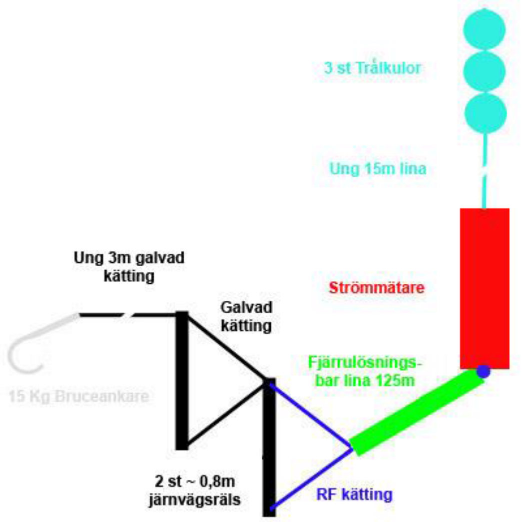


ROV images showing bio-fouling, condition of the bottom paint, and weld seams.
The anti-fouling paint is believed to be intact, and there is minor bio-fouling on the lower vertical parts and those parts where the hull cuts off the light from the surface. There was significantly more bio-fouling on the parts located below 30 meters. In general, there was no extensive corrosion on the visible parts of the hull.



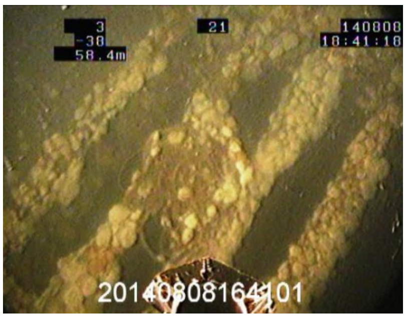
Rudder and propellers, with remains of trawling nets.



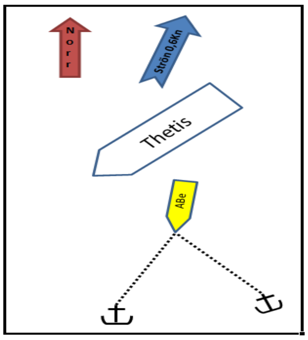


Usually northerly current at about 2 knots. Working vessel Scandica placed a mooring buoy immediately to the south of the wreck.

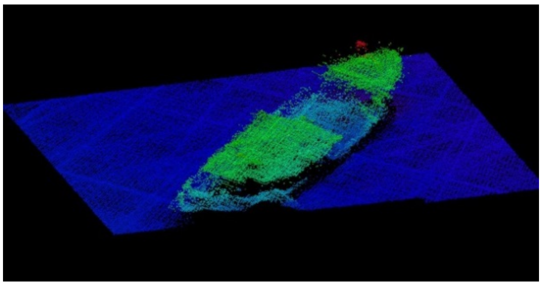
ROV-based salvaging of ADCP with a hook and salvaging rope on the right-hand side of the picture. The acoustic release was somewhat bio-fouled after about three months in the water. Due to strong current, it was necessary to use almost 300 meters of cable for the ROV.

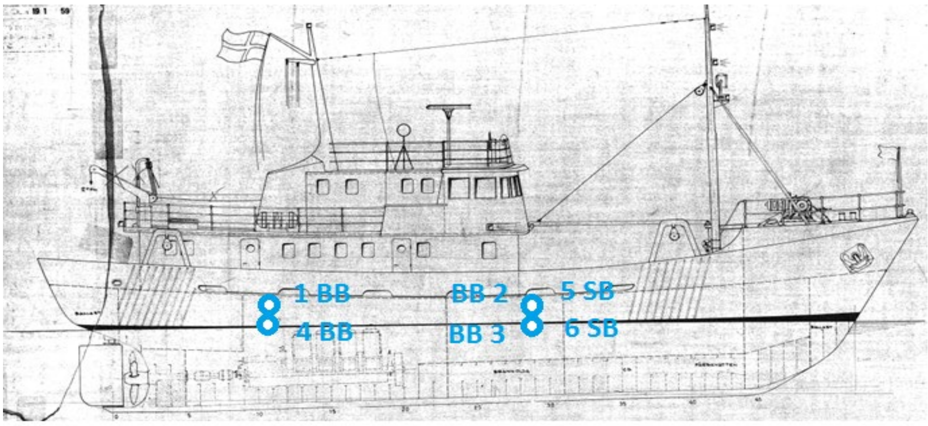


The remains of the fishing gear are located next to the bow on the port side.

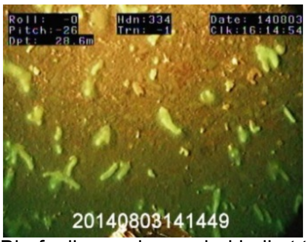


Anchoring in “crowfoot”





Thetis 2014-10-01 mätning av skrovtjocklek vid bunkertankarna								
Fartygs	Position mätpunkt		Avstånd	Mätpunkt	Uppmätt skrovtjocklek i mm			
sida	Längsled	Höjdled	dm från däck	Nr	1	2	3	4
BB	För om bygget	övre	9	2	5.3	6.4	4.9	7.2
BB	För om bygget	under (havsbotten)	14	3	5.7	8.8	8.9	9.1
BB	Akter om bygget	övre	10,5	1	5.3	6.9	4.9	5.3
BB	Akter om bygget	under (havsbotten)	14	4	9.9	6.2	7.1	9.2
SB	För om bygget	övre	1	5	8.1	6.8	7.5	6.4
SB	För om bygget	under (havsbotten)	4,5	6	10.4	10.3	13.0	12.8



Bio-fouling and corroded hull at the port bow close to the bottom. No remaining paint is visible on the hull.

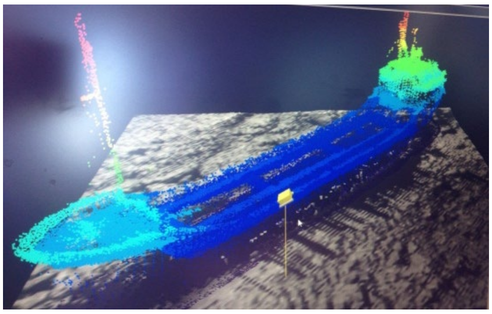
Bulwarks in the fore section

A crab on the port bulwark next to the cargo hold

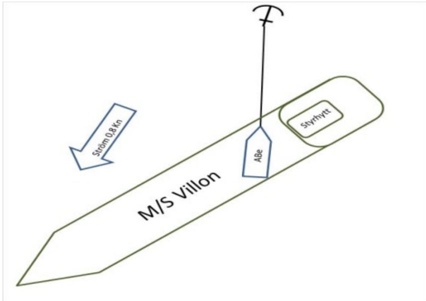
The wheelhouse is missing from the bridge

Tank cap of bronze at the port bulwark next to the cargo hold

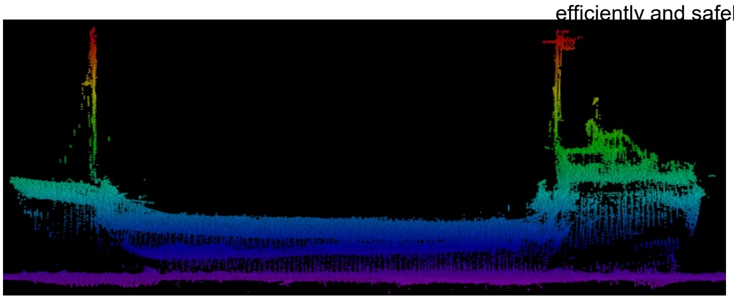
Starboard cargo hold



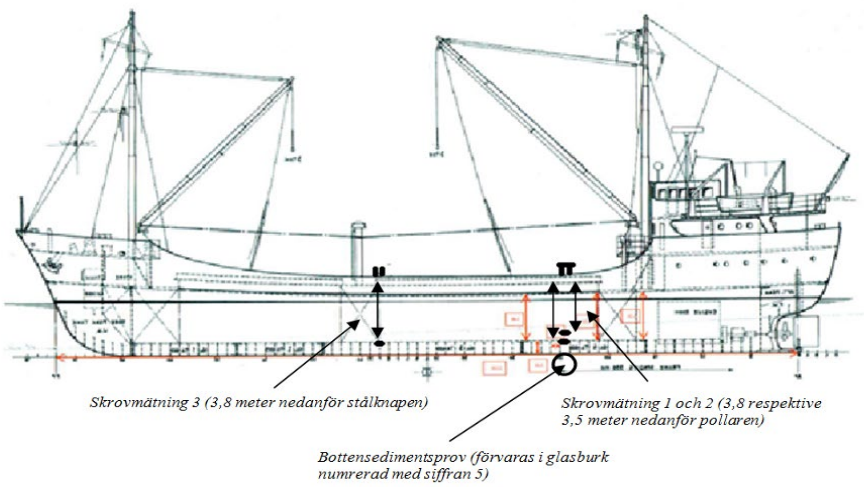
ROV visible on point-mapping data from Villon.



Anchoring with only one anchor. If current and winds are stronger, two anchors are required to maintain a stable position and to avoid drifting sideways, to be able to maneuver the ROV efficiently and safely.



Depth of about 36.5 m. Villon's shallowest depth is about 17.4 m from the front mast and about 17.7 m from the after-mast. The vessel is about 54 m long and about 9.5 m wide. The hull is intact, except that the hatches of the cargo hold are missing.



Tjockleksmätning i mm av skrovet på lastfartyget Villon						
Skrovmätning 1 Babordssida	Vid första pollarparet på relingskanten, för om brygghuset – gick dykarna ner till slingerkölen (3,8 meter nedanför själva infästningen av pollaren).	9,4	8,7	8,8	8,1	9,0
Skrovmätning 2 Babordssida	Åter igen vid första pollarparet på relingskanten, för om brygghuset – gick dykarna nu ner till 3,5 meter nedanför själva infästningen av pollaren.	8,7	8,4	8,9	9,9	8,5
Skrovmätning 3 Babordssida	Vid stålknapen uppe på relingen – ungefär halvvägs längs med fartygslängden gick dykarna ner till slingerkölen (3,8 meter ner från själva relingskanten)	8,9	7,9	8,5	8,3	8,3