Pre-study of ship wreck assessment and remediation

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assessment and remediation

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Executive summary

In the Skagerrak there are 261 ship wrecks which have been identified as potentially polluting wrecks. Twenty of these are located close to the Swedish coast, within the Västra Götaland County. The majority of the potentially polluting wrecks originate from the Second World War, hence many are heavily corroded and some are already leaking oil. In Sweden this problem has been discussed now and then since the mid seventies, yet there is no legislation regulating the liability for preventive actions to avoid future oil spills from the actual wrecks. This pre-study highlights potentially polluting wrecks in the Skagerrak, but the problem is present along the rest of the Swedish coastline. Therefore, there is a need for the establishment of a national database over recognized potentially polluting wrecks.

Present salvage technology allows for offloading the oil onboard the wrecks, but the remediation operation can be very expensive (about 20-250 million SEK per wreck). This cost has to be compared to the socioeconomic consequences occurring in case of a sudden leak of the corresponding amount of oil along the coast. To ensure that the environmental benefits of a remediation are economically justified, it is of great importance to initially conduct a detailed wreck assessment which in addition to verification of the amount and type of oil onboard, also ascertains that wreck stability will allow remediation. The cost of such an assessment ranges from 0.5-2 million SEK per ship wreck. To finance both ship wreck assessment and remediation of wrecks where no owner can be held responsible, establishment of a fund similar to that intended for remediation of contaminated land sites could be used. Additionally, the formation of a national competence centre to support the fund, gather knowledge in the field of ship wreck assessment and remediation and coordinate actions is recommended.

TABLE OF CONTENTS:

EXECUTIVE SUMMARY **5**

1. INTRODUCTION **9**

1.1 POTENTIALLY POLLUTING WRECKS IN THE SKAGERRAK 10

1.2 PREVIOUS SUCCESSFUL SHIP WRECK REMEDIATIONS 11

2. CONSEQUENCES OF A MAJOR OIL SPILL OFF THE SWEDISH WESTCOAST **12**

2.1 ENVIRONMENTAL IMPACT 12

2.2 SOCIOECONOMIC CONSEQUENCES 15

3. WRECK INSPECTION AND RISK ASSESSMENT **18**

3.1 WRECK INSPECTION 18

3.2 RISK ASSESSMENT 20

3.3 CULTURAL AND HISTORICAL ASPECTS AND RIGHT OF SALVAGE 20

3.4 COSTS OF WRECK INSPECTION 21

4. PRESENT REMEDIATION TECHNOLOGY **23**

4.1 AVAILABLE METHODS 23

4.2 COSTS FOR REMEDIATION 24

5. CASE STUDY OF S/S SKYTTEREN **26**

5.1 CASE STUDY OF S/S SKYTTEREN 26

5.2 INITIAL THEORETHICAL RISK ASSESSMENT 28

5.3 PROPOSED REMEDIATION METHODOLOGY 28

5.4 PROPOSED REMEDIATION METHODOLOGY 32

5.5 BEST AND WORST CASE SCENARIOS OF A SUDDEN MAJOR OIL SPILL FROM S/S SKYTTEREN 32

5.6 EXTRAPOLATION TO OTHER POTENTIALLY POLLUTING WRECKS IN THE SKAGERRAK 35

6. WHO IS RESPONSIBLE FOR THE COSTS OF WRECK ASSESSMENT AND REMEDIATION? 37

6.1 TODAY – NO RESPONSIBLE AUTHORITY! 37

6.2 HOW DO OTHER COUNTRIES TACKLE THE PROBLEM? 38

6.3 POTENTIAL PLATFORMS AND SOURCES OF FINANCING 39

7. CONCLUSION 40

8. REFERENCES 42

Appendix 1: Preliminary risk assessment of S/S Skytteren 47

Appendix 2: Modeled current data at the S/S Skytteren position 51

Appendix 3: Oil spill trajectory models from the S/S Skytteren position 57

Appendix 4:List of contributors regarding cost estimates 61

1. Introduction

For two decades, ship wrecks leaking oil in the Skagerrak have been pointed out as ticking environmental bombs[2-6]. The report Shipwrecks in the Skagerrak[2] from 2005 identify 261 wrecks as potential threats to the environment, of which 20 are located very close to the Swedish coast (Fig 1).

Despite this debate no actions have yet been taken and meanwhile the hulls corrode at the seafloor[7, 8]. In fact, today there is not even a national database in Sweden with compiled information about known ship wrecks. According to Marin Mätteknik AB[3] the known positions for several ship wrecks deviate from the actual positions in the Skagerrak.

From an environmental point of view, there is no principle difference between an oil spill from a leaking ship wreck and a recent spill from a vessel or coastal industrial activity. Hence, the topic has been discussed at International Oil Spill Conferences. The complexity of the problem is well described from an international perspective in the report "Potentially Polluting Wrecks in Marine Waters"[9], which covers both theoretical and practical difficulties regarding leaking ship wrecks.

Technologies of today enable both sea floor surveys to identify ship wreck positions, as well as detailed inspections of individual wrecks.

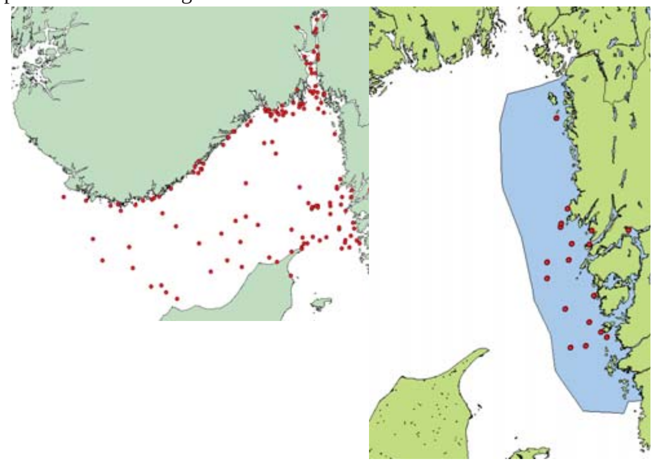


Fig 1. The map above shows potentially polluting wrecks, where approximate positions are available in the Skagerrak. Right: Zoom of the county of Västra Götaland, including 19 potentially polluting wrecks. From the report Shipwrecks in the Skagerrak.

There are also several different concepts to remove remaining oil from ship wrecks and a range of patents[9-14] which are based on pumping of the oil to a container at the sea surface, thereby preventing the oil from polluting the environment.

To summarize; lack of technology is not a valid argument today to further delay the handling of potentially polluting wrecks. Rather there are legal issues regarding responsibility and unsolved financial matters that slow down the proceeding. This report stresses the importance of immediate resolution of these matters and describes possible scenarios and socioeconomic costs if no preventive actions are taken. Available wreck remediation technologies are discussed and finally wreck assessment procedures are discussed in detail as a case study of S/S Skytteren, which rests at 74 m depth off Måseskär since 1942.

1.1 Potentially polluting wrecks in the Skagerrak

The first step towards actions, and possible prevention of future sudden oil spills from ship wrecks, is to map existing potentially polluting wrecks. Through the report Shipwrecks in the Skagerrak[2], the county administrative board of Västra Götaland County have already initiated this inventory with focus on the Swedish west coast. Their report is based on information from Skandinaviskt vrakarkiv, which is a private data base constructed by Mr. Björn Åkerlund. Today there is no national data base available, providing verified information about e.g. wreck identity, position and depth. Fig 2 shows the depth distribution for ship wrecks at recorded depths.

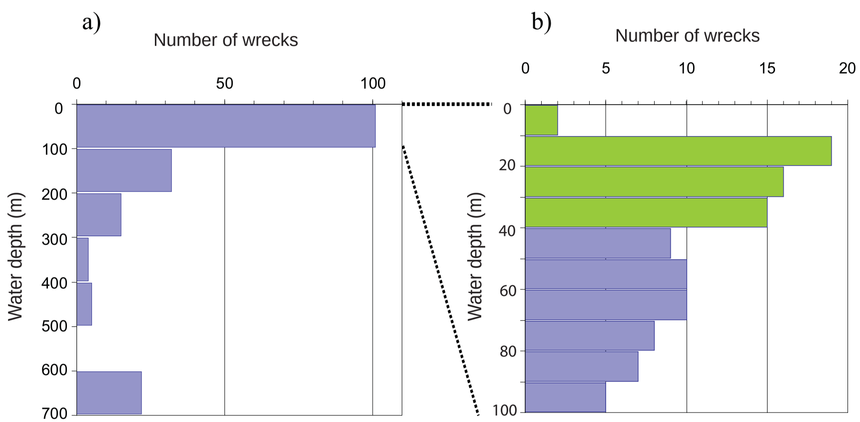


Fig 2. a) Depth distribution of 179 potentially polluting ship wrecks in the Skagerrak. b) Depth distribution of 106 potentially polluting ship wrecks at less than 100 m depth.

To decide whether a wreck should be classified as potentially polluting or not, Lindström[2] used the criteria developed by the Bergen Maritime Museum. These criteria are:

1. A gross tonnage larger than 100GRT
2. The ship should be lost later than 1914
3. The ship should be driven by oil, diesel oil or similar fuel, and thereby accordingly bunkered at the time of sinking
4. Ships that according to the data base carried hazardous cargo at the time of sinking should be included even if they do not fulfill criterion 1-3. Examples of hazardous cargo are petroleum products (e.g. oil and diesel oil), munitions (e.g. ammunition and chemical warfare agents) and other chemicals hazardous to the environment and human health (e.g. arsenic).

From: Shipwrecks in the Skagerrak, P. Lindström, 2005

In the inventory by the county administrative board of Västra Götaland County, there were 453 additional ships, which probably used petroleum based fuel, but were smaller than 100GRT.

1.2 Previous successful ship wreck remediation

Just like the S/S Skytteren, many of the oil leaking ship wrecks date back to the Second World War. Of course this is not only a Swedish phenomenon and around the globe many ship wrecks call for attention when corroded plates suddenly burst and a wreck starts to leak. Norway has come far regarding both legislation relating to responsibility matters[15], as well as detailed wreck assessment. This has led to two major actions of remediation in the Oslo fjord since the mid 1990's, of which the removal of 1600 tons oil and oil mixture from the battle cruiser Blücher is the most commonly known case. The total cost was 90 million NOK.

Across the globe, in the Ulithi atoll, Yap State, Federate States of Micronesia, the US Navy oil tanker USS Mississinewa was sunk by a Japanese submarine in 1944. When going down, USS Mississinewa was fully loaded with a range of different types of fuel and lubricating oils. In August 2001, after 57 years at the sea floor, the wreck was starting to leak heavily. A year later the US Navy began to prepare for a remediation action and in February 2003 the successful removal of almost 7500 m3 oil was finished[14].

Beside remediation of older ship wrecks experiences from remediation of recent ship wrecks, such as the removal of oil from the sunken oil tankers Erika[11] and Prestige[13], can provide valuable information. Erika sank off the coast of France in 1999 and 20 000 metric tons of oil immediately leaked out in the sea. The cost for remediation at sea and along the coast is estimated to correspondingly1.3 billions SEK. Erika sank to 120 m depth and in the late summer of 2000 another 11 200 tons of oil were removed through diver assisted use of specialized pumping equipment. The cost for this remediation was approximately 670 million SEK. Even more remarkable is the removal of 13 400 tons of oil from the Prestige, which sank in 2003 to 3800 m depth off the coast of Spain. The remediation was entirely operated through small Remotely Operated Vehicles (ROV:s) equipped to handle both puncture tanks and attach hoses for pumping of oil to the surface.

2. Consequences of a major oil spill off the Swedish west coast

2.1 Environmental impact

Accounting for time, the probability for leakage of remaining oil in the ship wrecks equals one, i.e. eventually all oil will escape. However, it is far more difficult to predict whether the oil will leak for several years or if a sudden collapse will cause a momentary oil spill. Both scenarios release the same amount of oil to the environment, but the response to the two different types of spill may be very different. According to Swedish law, the Swedish Coastguard is obliged to record oil spills at sea and accordingly take legal action if possible. Further duties include oil spill remediation if the assumed environmental benefits are socioeconomically defensible. Another given prerequisite is that the environmental conditions allows for remediation, which could pose a problem when dealing with leaking oil and periodically rough wind and weather conditions. On the other hand the rate of release of oil does affect natural degradation processes. Oil is degraded in the environment, primarily by microorganisms, and recent studies implies that the recovery is faster than previously thought[16-19]. The effect of an oil spill in a coastal marine environment is affected by several factors[20, 21], such as:

- Oil type
- Amount of oil
- Type of shoreline
- Wind and current conditions

2.1.1 Different types of oil

A very important parameter determining the extent of environmental impact of an oil spill is of course which kind of oil that was spilled. Oil consists predominately of different proportions from three classes of hydrocarbons; alkanes (paraffins), cyclo alkanes (naphtenes) and aromatics[22]. Light oil is generally considered more acute toxic compared to heavy fuel oil, but on the other hand the lighter oil evaporates quicker and is therefore not transported as far in the marine environment as a heavier fraction[20]. Both lighter and heavier oils can deinsulate bird's plumage; either through degreasing or through bsmeared feathers. Especially in cold climates, relatively small amounts of oil can put a bird's life in danger; 2-3cm2 of oil covered feathers may be life threatening for an individual[23].

When released in water, the chemical and physical properties of oil are altered. The main processes accountable for these changes are:[20]:

- Evaporation, through which the lighter fractions disappear from the sea surface leaving a product of higher viscosity.
- Natural dispersion increases the contact surface between oil and water, which accelerates natural degradation of oil in water.
- Spreading of the oil is depending on the properties of the oil, but also on the prevailing wind and current conditions. According to IVL's (IVL Swedish Environmental Research Institute Ltd's) oljejour, a rough generalization of the distribution between a lighter and a heavier fraction could look like this:

	"Blue shimmer"	Heavier oil
Thickness of the oil-slick	>1µm	1-5mm
Relative volume of the oil-slick	10%	90%
Relative area of the oil-slickläcken	90%	10%

- Dissolution is generally only applicable to a small amount of the oil. When dissolved in the water the oil is no longer a threat with respect to besmeared shorelines. In spite, the bioavailability to aquatic organisms increases and cause enhanced acute toxicity.
- Oxidation is primarily taking place through photo oxidation and is thereby limited to the top layer where the sun light reaches.
- Emulsification can be regarded as the opposite to dispersion, i.e. emulsification means hydration of the oil resulting in enlarged volumes of oil pollution. The volume could easily be doubled in a couple of days and the consequence is reduced evaporation and dispersion. Also spreading of the oil spill will decrease as the emulsion has a higher density and viscosity.

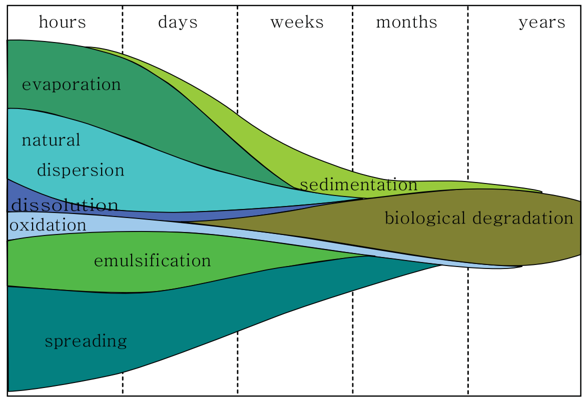


Fig. 3 Overview of the processes involved after an oil-spill. Adapted from IL Oljejouren [20]

Beyond the processes described above, there are other ways in which oil in the tanks of a wreck from World War Two could be altered. The natural mix of different chemical compounds, commonly referred to as oil, implies that e.g. occurrence of density driven stratification of oil in intact tanks could not be excluded in case the tank is relatively still.

2.1.2 Diffrent types of shorelines

Depending on the natural shoreline characteristics, the consequences from an oil spill reaching land can be considerably different. Initial reports from a major oil spill often picture a sense of complete ecological disaster, from which nature will never recover. However recovery will follow according to three distinguished phases, where the first involves the start of recolonization of opportunistic species. The following step describes the time from established recolonization until the third phase, a recovered ecosystem, is established. Phase one and two overlap and the rate of recovery is very variable depending on the type of shoreline that has been polluted[24]. Dean and Jewett[25] compared the recovery the first five years after the Exxon Valdez spill in Alaska, at eelgrass beds compared to sites dominated by kelp following the. The study found much slower recovery at the eelgrass beds, which partly can be explained by generally less exposed localities, but also by community composition dominated by more sensitive species compared to the kelp community. Other studies point out that the acute toxic effects in the water column decline rapidly due to dilution[16, 18, 26]. However, recent experiments in pelagic mesocosms by Hjorth et al 2007[68] showed that single exposure of very low concentrations of pyrene (a PAH model substance), could affect both structure and function of a plankton community. These results are rather controversial as the prevailing opinion has been that the maximum environmental effect from an oil spill is found in the benthic communities as a delayed (in the order of months) response. An example is the Baltic Carrier spill in 2001, when more than 1100 tons of heavy fuel oil polluted Grønsund in southern Denmark. A monitoring program was established following the spill and two and a half months later elevated levels of PAH's traceable to the incident were still measurable. The corresponding figure for the sediments was three years for all but one sampled sites. For that particular site five years were required before the elevated PAH's, originating from Baltic Carrier spill, could not be distinguished from background levels in the sediments anymore[18].

To summarize the recovery of an exposed rocky shore can be estimated to 1-2 years, while the corresponding time required for recovery of a salt marsh can exceed 5-6 years. Paradoxically, the process of recovery is not always facilitated through human actions of remediation, as the initial recolonization phase can be delayed by such an operation 24].

The tool Digital miljöatlas[1] (Digital environmental atlas), developed by IVL commissioned by the administrative county board of Västra Götaland County, can be used to illustrate the distribution of shore lines according to different sensitivity indexes and/or specifically protected areas or natural reserves. This information could be advisory e.g. to limit hazardous activities in especially sensitive areas. Another field of use is rapid identification of where to put maximum remediation effort in the event of a sudden oil spill, in order to minimize the impact at the most sensitive types

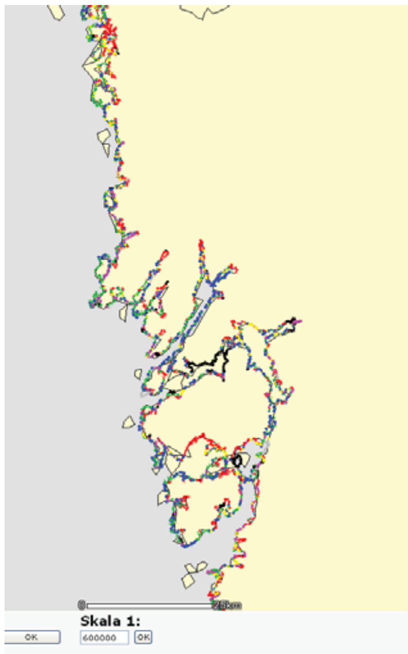


Fig 4. Different types of shore lines registered in Digital miljöatlas [1].

of shore lines, which of course also could be beneficial from an economic point of view. The Digital miljöatlas is yet not complete, but Fig 4 shows an example of present types of shore lines along the Swedish coast of Bohuslän, which could be affected from a sudden oil spill from any of the potentially polluting wrecks in the Skagerrak.

2.2 Socioeconomic consequences

2.2.1 Direct costs

The clean up of a major oil spill is of course costly with respect to both use of special equipment to fight oil pollution (vessels, skimmers etc) and extensive personnel costs. The Swedish Rescue Services Agency has commissioned research regarding identification and quantification of costs associated with major oil spills in Swedish waters[27, 28]. Realistic socioeconomic of this kind can both serve as background information to motivate enhanced precautionary measures to prevent future incidents and also ensure that a correct order of priority in case of an accident[29]. Forsman et al 2002[28] and 2006[27] classify the direct costs as follows:

- National Rescue Services
  - o Oil pollution control at sea
  - o Equipment
- Local Rescue Services
  - o Personnel costs
  - o Equipment
- Transports, logistics and waste disposal
  - o Remediation
  - o Personnel costs
  - o Equipment, transports and waste disposal

According to Swedish law (2003:778) the Swedish Coastguard is responsible for environmental rescue services at sea. Today the Swedish Coastguard has a capacity to handle oil spills in the order of 5000 tons, but during 2009-2012, this capacity will be doubled mainly due to incorporation of three new multi purpose vessels[27, 30]. The level of preparedness and available operational resources has been outlined by the Swedish Coastguard in consultation with the Swedish Rescue Services Agency and the Swedish Maritime Administration. The outline is due the fact that there have only been a few incidents of oil spills exceeding 1000 tons in Swedish waters. The majority of oil pollution clean-ups concern much smaller oil spills. In the event of an urgent situation of a major spill, all potentially useful national resources will be activated. For instance military vessels can assist putting out skimmers and not least transportation of equipment and personnel. The latter could be of great importance in order to increase the efficient time for vessels specialized for oil pollution control. Further enforcement of the Swedish Coastguard's resources can be activated through international agreements such as the Copenhagen Agreement and the European Maritime Safety Agency[27].

If possible, taking control of oil pollution at sea is often considered to be easier, than cleaning up the shoreline[31, 32]. Etkin (2000[31]) estimates the costs related to clean-up of coastal oil spills or spills in harbors to be 4-5 times the costs of corresponding scenario at sea. There are also examples where the clean-up of the shores rather were 15 times the cost (per ton of oil) of clean-up at sea. A Swedish example is the final bill for Operation Fu Shan Hai; the rescue action following the collision between the Chinese ship Fu Shan Hai and the Cypriote vessel Gdynia north of Bornholm in May 2003. During the wreckage of Fu Shan Hai, the Swedish Coastguard took care of approximately 1000 tons of heavy fuel oil at sea to a cost of approximately 10 million SEK. Despite massive efforts, another 100 tons of oil reached the shore and the clean-up costs for the struck districts were approximately 15 million SEK. The total cost, including the loss of cargo and ship, the rescue action and the repair of Gdynia as well as oil pollution control, exceeded 1 billion SEK[33].

In the example of Fu Shan Hai, the oil struck the Swedish Region Skåne at a shoreline dominated by sandy beaches. Such a beach is relatively easy to restore through removal of large volumes of sand. In accordance to the discussion of different environmental impact for different types of shores, the costs for oil clean-up is also variable. A rocky coast is generally much more costly to restore compared to a sandy beach, however if the rocky coast is highly exposed human action for restoration might not significantly accelerate the degradation processes. The far most sensitive type of shoreline to restore is, as mentioned above, salt marshes. This type is also the most expensive to restore. In spite of high costs, successful restoration is not guaranteed. There are studies that human actions in this shore type rather delay the recovery of the ecosystem[24, 29]. Yet, it can be difficult to implement the choice of no action, due to the distrust arising among the public when "no measures are taken".

2.2.2 Indirect costs

So far only direct costs have been discussed, that is costs for equipment, material and personnel involved in a clean-up action of an oil spill. Unlike the direct costs, which are relatively easily quantified, additional extensive indirect costs are much more difficult to distinguish. The indirect costs are primarily due to increased stress of local services and reduced industrial incomes. In the row of entries that brings about increased social expenses there are also a few exceptions. For example large-scale unemployment can be temporarily reduced due to increased need for manpower in the clean-up actions. Forsman 2002[28] och 2006[27] classify the indirect costs as follows:

- Local services
  - o Rescue services
  - o Protection of the environment and human health
- Other local services as health care, school meals and transports
  - o Infrastructure
  - o Harbours
  - o Waste disposal and reloading
  - o Local accomodation of personnel
- Labour-market and employment
  - o Local recruitment of manpower
  - o Unemployment
- Affected branches of industry
  - o Turism
  - o Fisheries and aquaculture
- Real estate market
- Quality of life and inconvenience for individuals
- Accidents
  - o Death and personal injuries
  - o Material damage, fire and ground pollution

From the perspective of ecosystem functioning, there will be additional indirect costs in terms of loss of ecosystem services; that is values supplied by the ecosystem and generally taken for granted by humans as these values by tradition never were priced[34, 35]. The insight that earth's/the ecosystem's resources are not unlimited has driven the development of different methods to assess the value of such goods and services, which can be divided into production functions (e.g. availability of fish), regulating functions (e.g. the remediating function of a wetland regarding nutrients) and finally cultural functions (e.g. the recreational value of a coast line)

In 2002 the Swedish Rescue Agency commissioned a prestudie including a case study of a major oil spill (25 000 tons) at the Swedish west coast, outside Gothenburg[28]. In this prestudie of wreck assessment and remediation, no detailed analyses of socioeconomic consequences for different potential spills from individual wrecks. There are statistical methods to transfer calculations in one specific environment or situation to apply the data in another scenario[32]. None of the recognized potentially polluting wrecks in the Skagerrak are thought to contain oil volumes in the order of 25 000 tons, but as previously pointed out in many reports there are no linearity between the volume of an oil spill and the clean-up costs[9, 32]. To clean up a spill in the order of 100-5000 m3 does not necessarily have to be far less expensive compared to a significantly larger spill[32]. As even a primary analysis of socioeconomical consequences includes a range of factors of uncertainty[27], it is not justified to use a transfer of calculations before the potential environmental threat from a wreck is secured. Instead, we chose to draw a parallel to costs for clean up of a major spill outside Gothenburg (Table 1).

Table 1. Costs related to oil spills

	Estimated volume of oil (tons)	Direct costs (SEK)	Indirect costs (SEK)
1987, Tolmiros*, oil spill outside Tjörn	400	96 millions	No data
2003, Fu Shan Hai, sank north of Bornholm	1100	25 millions	No data
2002, case senario, tanker outside Gothenburg [28]	25000	Some hundred millions	> 1 billion

* Was later cleared of suspicion, but the incident is still referred to the suspected ship's name.

3. Wreck inspection and risk assessment

After mapping the potentially polluting wrecks, followed by listing of their relative priority, the next step is to make a more detailed inspection of individual wrecks (Fig 5). This stepwise procedure has successfully been applied in Norway to handle potentially polluting wrecks in Norwegian waters[36]. A similar way of working, MIFO (Method for Inventory of Polluted Areas) has also been developed by the Swedish Environmental Protection Agency[37, 38] for inventory and classification of polluted ground.

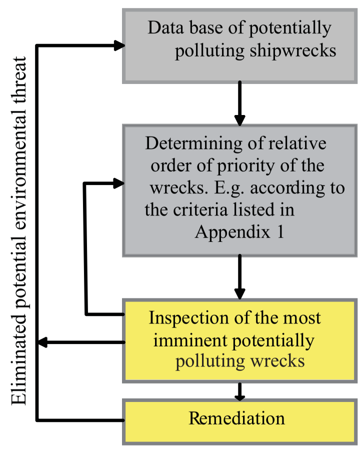


Fig. 5 Proposed organizational chart to ensure resource effective handling of potentially polluting wrecks.

A detailed assessment of the wreck status and its surrounding is crucial to get information about which method to choose for remediation. The assessment should include inspection of the present wreck condition, the volume of oil onboard and where it is located and finally whether or not the oil could or should be removed[9]. The final question includes both the possibility of creating relatively safe working conditions and a risk assessment with respect to plausible consequences of an oil spill from the individual wreck would get.

3.1 Wreck inspection

The wreck inspection is predominately of practical nature, but to facilitate the practical work it is preferential to have as much theoretical information as possible about the wreck. Following data is good to assemble[9]:

- Technical drawings of the wrecked ship construction. In lack of drawings of a specific ship, drawings of similar ships should be studied.
- Eye-witness depictions and/or photos from the point of wreckage
- Documentation from the last journey, such as cargo and bunker reports etc
- Documentation from previous wreck assessments and remediations

A detailed three dimensional survey of the wreck and its surroundings can be made with a multi beam sonar coupled to a GPS. This can provide detailed information on the wreck position, how intact the wreck is, and if technical drawings are available can comparisons between the sonar images and the drawings for example reveal the localization of the tanks. From this information it is possible to conclude where it is likely to find remaining oil and where to look to find them. For instance it is likely that the remaining oil of a wreck that rests more or less intact and up side down is left in the tanks, while a wreck that was severely damaged during the impact and is found with the valves of the tanks upright might have lost more oil since the time for sinking. In general a sinking ship reaches its maximum sinking velocity at approximately 100 to 300 m depth. The span is due to variations in e.g. different hull design, cargo and/or wreckage related damage. The present condition of a ship wreck is, besides damage from the wreckage and impact when reaching the sea floor, also depending on the environmental conditions at the site such as:

- Water depth
- Exposed or protected waters
- Wind and current conditions
- Water temperature
- Biological activity
- Water chemistry

Water depth, in combination with wind- and current conditions can affect the possibility for large scale movement of the wreck, both (as previously discussed), but also later when the wreck rests at the sea floor. Considering an exposed site with hypothetical wave lengths of 75-150 m can scour the wreck through the wave pulses. This can accelerate the degradation of steel as coatings and biological epigrowth. It can also force the wreck in motion, which in turn can cause further damage of the construction or burial of the wreck in the sediment making it more difficult to localize the tanks for sampling and possible removal of the oil. In shallow waters, breaking waves can increase the oxygenation of the water around the wreck, which might contribute to enhanced corrosion of the hull. Especially the oxygen concentration in the water has turned out to be a critical parameter for the corrosion rate[39]. Other contributing parameters are salinity, biological epigrowth and degree of burial in the sediment. These parameters are all more or less interconnected or interdependent. Hence, corrosion rates are difficult to calculate theoretically as reduction of one key parameter might induce increase of another[8]. Beside its effect on corrosion rate, the water temperature also affects the viscosity of oil, which can cause seasonal oil spills. Finally, the water depth governs the choice of method for wreck inspection, either divers and/or ROV:s.

To localize and sample individual tanks is a very time-consuming, yet extremely important moment. This work does not necessarily have to include high technological equipment, but can be made through knocking at the hull to find e.g. bulkheads and frames inside the hull. Sampling could be made with a drill and a thin hose. In case of high viscosity oil, heating might be required to enable sampling. Each tank needs to be frequently sampled along a vertical line to determine the oil level and that it is the same type of oil throughout the tank as gravimetrical stratification may occur. To sum up this implies many holes to drill, why non-destructive methods to identify different liquid layers in closed tanks bring a significant saving of time. There are also ultrasonic devices which can be used to determine the thickness of a hull. However, the ultrasonic instruments are of limited use when trying to find the oil level in a tank. Instead there are today neutron backscattering technologies[40] available to provide information on the position of an oil-water interface with less than 5 cm resolution. These detectors have also successfully been used in combination with a ROV.

If available, or if the condition of the wreck allows for, another option is to use existing valves or piping to sample the oil. For more recent wrecks this can be a possible way to go, also for removal of oil. When it comes to older wrecks from the Second World War it is unlikely that this approach will work[7, 8], mainly due to corrosion related changes.

Previous wreck remediations have pointed at extremely slow corrosion of oil containing tanks where the bottom paint outside the tank is intact underneath marine epigrowth. This phenomenon has been observed both in cold and warm waters, down to 50 m depth[41]. Hence, it is of great interest to check the status of the bottom paint, especially on and close to the tanks. This in combination with measurement of the galvanic potential of the hull, are two important pieces to enable a proper risk assessment and the probability for the tanks to collapse.

3.2 Risk assessment

Beyond the necessity to assess wreck stability to assure safe working conditions during an eventual remeditiation, it is also desirable to make a detailed risk assessment with focus on possible consequences of a sudden spill of all the verified remaining oil volume onboard the wreck. Today environmental issues are hand-in-hand with socioeconomic issues[42] and the risk assessment that was started when mapping the potentially polluting wrecks has to be more detailed prior to remediation. Before discussion of suitable remediation technique, the environmental benefit of a remediation must be economically defensible, in other words; is it possible to verify that the socioeconomic consequences of a major spill from a specific wreck is severe enough to call for remediation?

This work should also include comparisons between available drawings, information about cargo and bunker, and also existing munitions or other dangerous goods, if any. Even though the focus of this report is at the environmental threat posed by oil spills and not munitions such as ammunition or chemical warfare agents, it is important to remember that presence of the latter may interfere with the possibility to remove remaining oil from a wreck. It is a major safety hazard to remove oil from a wreck if there is an elevated risk of explosion onboard or risk of deliberation of war gas during salvage work. For example during the remediation of the battle cruiser Blücher in the Oslo fjord, it was concluded that 30-40 tons of oil were too risky to remove as it was located in spaces next to ammunition storage[10].

3.3 Cultural and historical aspects and right of salvage

Another aspect of the potentially polluting wrecks is their cultural and historical importance. Wrecks older than are 100 years are protected by museum laws administrated by the National Cultural Heritage Agency. However, these laws are not applicable to wrecks younger than 100 years, which in many ways is an unfortunate and irrelevant division[44]. For instance wrecks from the Second World War can definitely be as interesting as older wrecks from a military historical point of view. Hence it is of great importance to involve marine archaeologists at an early stage of the planning of a remediation. Observations from the wreck inspection can also be of interest for the marine archaeologists. Finally, one has to consider that many wrecks are graves and should be treated with respect.

Each year, the marine archaeologists at the Bohuslän's museum in Uddevalla and the Swedish Coastguard assist the county administrative board of Västra Götaland County by giving their respective opinions in the handling of applications for exclusive right to salvage according to the Act (1984:983). The establishment of this law was thought to protect the rightful owners to proceed with salvage without interference from the many eager salvers that usually show up in case of wrecked goods of considerable value. This poses probably not a major problem regarding the potentially polluting wrecks as the costs for retrieving the oil onboard is most likely exceeding its intrinsic value. On the other hand, if any parts of the wreck or wrecked goods are of considerable value, it could be used to reduce the costs for remediation. However, this brings the discussion of protection of cultural and historical values, versus the reduction of costs to prevent a potential environmental threat. During 2007 the administrative county board of Västra Götaland rejected the Swedish society of marine history's application för exclusive right of salvage to seven (7) wrecks that sunk between 1940 and 1945, of which three (3) are on the list of risk potentially polluting wrecks in the Skagerrak.

Finally, the broad public interest regarding wrecks suggests continuous documentation for possible later exposure of the history of the wrecks to the public[44].

3.4 Costs of wreck inspection

Detailed inspection of the wreck is extremely important to verify the theoretical assessment. Further, the provided information facilitates the preparations of a remediation and enables smoother operation e.g. if the location of the oil to be removed is known and whether the condition of the wreck allows for attachment of a pumping equipment or not. If the decision to realize a remediation is based solely on the theoretical assessment of the wreck, the result might be an unreasonable remediation and a hard-earned experience. One example is the remediation of the wrecked tanker M/T Solar 1, which sank off the coast of the Philippines in August 2006 and the removal of the remaining oil onboard began in February 2007. The cost per cubic capacity was very high (in the order of 4 million SEK per m3) as it turned out that the wreck already was more or less empty (~9 m3 left instead of the estimated 700 m3)[45]. Considering older wrecks, e.g. Skytteren, where no reliable information about the type and amount of oil onboard at the time for sinking, it is inevitable that the initial assessment will be speculative or as a best case educated guesses. To verify the basis and validity of such speculative information, it is necessary that the detailed wreck inspection is comprehensive enough to serve as guidance whether remediation is required or if the potential threat can be canceled without further attention. The cost of detailed wreck inspections includes, in addition to the in-situ inspection, also the mobilization cost that is the transport of equipment, personnel and possibly also mooring of a working platform. Depending on the duration of the mobilization and the depth at the wreck site the mobilization cost can represent a significant part of the total cost for the inspection. On the other hand, the mobilization cost per wreck is likely to decrease if inspections of wrecks located within relatively short distances from each other could be inspected in connection to each other at a stipulated price. The cost for a single wreck inspection along the Swedish west coast is in the range 0.5-2 million SEK.

4. Present remediation technology

4.1 Available methods

Following the localisation and sampling of the oil in the wreck, it is time to choose a suitable remediation technique. The choice is primarily dependent on the wreck condition e.g. if it allows for attachment of flanges to pump up the oil, the position of the wreck and the type of oil. In the case of relatively intact wrecks, especially in shallower waters, it may be preferable to salve the entire wreck. In many cases however, this is not practically feasible and today there are many alternate approaches that enable removal of oil from the wreck.

There is a range of different patent based on pumping of the oil. The advantages of these methods are that they are relatively controlled, with little risk of uncontrolled spill and they also offer a definite alternative; once a tank is emptied this way the threat is removed. Even if tanks are successfully emptied there may be some oil left e.g. in piping or between the hull and the tank. Flanges can either be welded or bolted to the tank. After attachment of a flange, with further possible connections of hoses or pumping equipment, low viscosity oils can be directly pumped through a vacuum pump and a long hose. Problems may be encountered in case of clogging of the pump or hose by contaminants or if the viscosity is too high.

Another attractive alternative suitable for light oils is centrifugal pumps; in spite of their relatively low weight they offer large pumping capacity. A disadvantage is the enhanced risk for emulsification, which significantly reduces the commercial value of the oil in case of planned sale of the salved oil. The method was successfully used at the removal of oil from the USS Mississinewa[14].

When dealing with oils of higher viscosity positive-displacement pumps such as screw pumps can be used. Modified version of these pumps have even been used for pumping of bitumen, with a viscosity exceeding 100 000 cSt. Generally, the higher viscosity the more difficult it is to use pumps, if it is not possible to reduce the viscosity. In the tanks of newer ships there are already heating coils in the tanks, as heating of the oil is required during operation prior to combustion. If the heating coils are intact and in such position that the remaining oil will be heated, they provide a relatively easy approach to reduce the viscosity. However, the heating coil piping are generally not as rigid as hull plating and are therefore also more sensitive to corrosion. In the absence of (intact) original heating coil it is also possible to introduce an extern heating coil. It is also possible to introduce steam directly into the tank, but then the condensation water will be wasted in the tank. Another way of reducing the viscosity is addition of low viscosity oil such as diesel oil. This procedure facilitates pumping but still thorough mixing is required in the tank to make it work accurately.

To alter the oil viscosity has also been discussed for other solutions than pumping of the oil. Another strategy that has been suggested is to add something that completely solidifies the oil, after which the oil is left in the wreck. As mentioned above when discussing ways to reduce viscosity, thorough mixing is required, which can be difficult to achieve.

A completely different approach is the use of microbial degradation of the oil. Oil spills in nature are degraded in course of time, especially by micro organisms. The idea to use micro organisms for large scale degradation has been investigated for a couple of decades, but the predominant conclusion has been that the processes are too slow to be applicable in-situ[46]. Recent experiments have reported significantly improved degradation rates[47, 48]. The break through is due to addition of other limiting nutrients in combination with pure cultivation of bacterial strains specialized in degrading solely the desired petroleum product[49]. A sample of the oil is sent to a lab, which isolate the bacterial strain. By letting the microbes getting in contact with the oil and at the same time have unlimited supply of other essential nutrients, the potential environmental threat is converted to (from the perspective of oil pollution) harmless components carbon dioxide and water. The temperature dependence implies slower degradation in cold waters. Further, different types of oils require different bacterial strains which brings new isolation procedures for each wreck. This could be laborious if it is not the same oil throughout the tanks.

Finally, if the wreck is in poor condition and does not allow for drilling or welding without immediate risks for the construction to collapse, construction of a large tailored tent or umbrella over the entire wreck could be used to trap the leaking oil. It is also possible to accelerate the leakage through additional holes, after putting the construction in place. The oil is trapped at the top of the tent, form where it can be pumped to a container. This method requires calm conditions and relatively small wrecks without too many protruding details. One lesson of how expensive a misjudgment can become, is the stainless steel umbrella tailored for the wreck after HMS Royal Oak in Scapa Flow, Orkney. Despite investments exceeding 2 million SEK only for the umbrella, the construction did not work at all due to strong tides and currents[9]. This example again highlights the importance of a detailed inspection of the wreck and its surroundings. As the tent construction needs to be tailored to the wreck to improve the chances of successful operation, there is no substantial reduction of costs if many wrecks are handled in the same way.

4.2 Costs for remediation

It is difficult to definitely predict generalized costs of wreck remediation, in other words than that the costs generally are high. Partly this is explained by involvement of methodologies developed within off-shore industry. Through information provided by a detailed wreck inspection, remediation costs can be reduced as in the case of Solar 1 (see section 3.4), and misjudgment in terms of capacity of the authority or contractor performing the remediation. The latter can be illustrated through the problem faced during the removal of the oil from the RoRo ship Finnbirch, which sank between Öland and Gotland on November 1st 2006. After twelve days of work to remove the remaining oil, it was stated that one of the tanks still was intact, but impossible to empty with the equipment obtainable by the actual contractor. Of the estimated 230 m3 oil that went down with Finnbirch, a little less than 100m3 is most likely left onboard[50]. According to Michel et al[9] (2005) the main costs during a wreck remediation are:

- •Mobilization costs, that is the time and cost required to co-ordinate the operation and transport equipment and personnel to the wreck site and back.
- •Equipment, tools and diving operations. This cost will be affected by:
  - o Viscosity of the oil determine whether heating is required or not
  - o Water depth affects the type of moorings required and the need for divers and/or ROV:s
  - o Sea and weather conditions determine what size of vessel required
  - o Wreck construction and condition affects the complexity of the work under water
  - o Volume of oil;affects the number and size of oil transport vessels
  - o Number of tanks; a greater number of tanks require more drilling procedures etc
  - o Extent of necessary back-up preparedness in case of failure causing an unplanned major oil spill
- •Total number of days on-site includes both efficient work-days and also waiting time, e.g. waiting for decent weather conditions.
- •Net disposal cost for removed oil; the total removal cost may exceed the intrinsic value of the oil unless the oil is of good quality.

To illustrate the relative differences between remediation costs for different wreck categories, Michel et al[9] (2005) estimate the range according to Table 2. Converted to Swedish conditions the remediation costs of a single wreck is in the order of 5-650 million SEK.

Relative complexity	Factors affecting the cost	Cost range (US $ million)
Simple	Shallow water (<20 m) Low viscosity oil Protected site Local mobilisation	<1-3
Moderate	Moderate depth (20-50 m) Moderate viscosity oil Some weather restrictions Regional mobilization	2-5
Complex	Deep water (50-250 m) High viscosity oil Poor wreck condition Open water Weather conditions Remote mobilisation	5-20+
Highly complex	Extreme water depth (>250 m) High viscosity oil Poor wreck condition Open water Weather conditions Remote mobilisation	20-100+

Table 2. Cost assessment for remediation of wrecks of different relative complexity regarding site, wreck and oil characteristics. [9].

5. Case study of S/S Skytteren

5.1 The history of S/S Skytteren

The destinies of many wrecks often constitute a fascinating story attracting a broad public from people of a general interest in history to scuba divers with wrecks as special interest. The choice of S/S Skytteren as case study in this report was mainly due to the fact that she today is recognized as the largest oil leaking wreck in Skagerrak (Fig 6) and her position is such that a major spill could have severe consequences along a large part of the coast of Bohuslän. As a bonus, the history of S/S Skytteren is lined with drama[51-53].

5.1.1 S/S Suevic - "The longest ship in the world"

S/S Skytteren was originally named S/S Suevic and she was built 1899-1900 for the fine White Star Line, recognized for another giant ocean liner, namely the RMS Titanic. Suevic was built as a combined passenger and refrigerated cargo ship for use on the route Liverpool-Sydney, but shortly after her maiden voyage she was called up for military service transporting troops in the Boer War.

Her first six years passed without any serious incidents, but in 1907 she was the centerpiece in one of the most remarkable groundings in maritime history. On March 17th, carrying 382 passengers, 141 crew and fully loaded on her way back from Australia, Suevic approached Plymouth. Due to the dense fog and navigational difficulties the ship entered waters normally avoided by ships. Despite the fog, the ship's officers relied on their estimations of the distance to the lighthouse on Lizard Point, Cornwall without even using soundings to verify their calculations. As the ship violently ran aground the ship were almost 14 nautical miles closer to the coast than calculated. Suevic was, like all White Star Line's ocean liners, constructed with watertight compartments as a safety precaution. Sixteen hours after the accident, all passengers and crew were saved and the redistribution of Sue Vic's cargo into smaller boats began. If the ship got lighter it was thought to be lifted off the ground with the incoming tide. This did not occur, and a week and many failed attempts to get Suevic off the ground, the ship-owner decided to use dynamite to carefully split the damaged bow and the intact ster. After this unconventional, yet successful, salvage the stern was towed to Southampton. A new bow was ordered from Belfast and before the arrival of the new bow, Suevic was renowned as the longest ship in the world; with her bow in Belfast and the stern in Southampton.

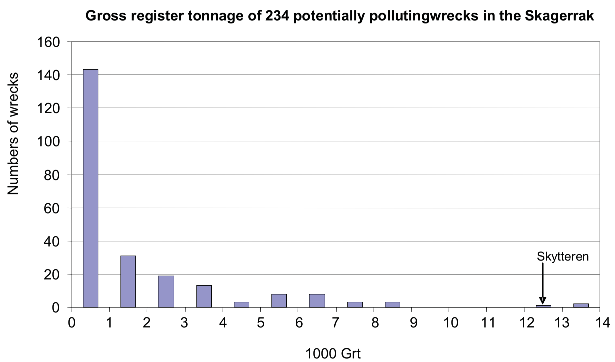


Fig 6. Of the 261 potentially polluting wrecks in the Skagerrak, Skytteren is the third largest recognized (27 of the wrecks lack information on GRT), and the largest with a recent documented leak.

5.1.2 The whaling vessel S/S Skytteren

During the First World War, Suevic was once again called up for military services in the British Navy and after the war she was rebuilt to increase the passenger capacity on her route to Australia. In the late1920's she was already considered old and after more than 50 voyages between England and Australia Suevic was sold in 1928 to the whaling company Yngvar Hvistendahls Finnvahl A/S. The purchase-sum was £35.000 and the ship was immediately sent to Germaniawerft in Kiel, where she was reconstructed to a floating whaling factory named S/S Skytteren (Fig 7).

Fig 7. Skytteren in Gothenburg harbor 1932. Photo used with kind permission from the Maritime Museum of Gothenburg.

During the Second World War, Skytteren was interned in Gothenburg harbor, but the 1st of April 1942 she participated in "Operation Performance" together with nine other Norwegian ships in an attempt to escape to the Allies[52]. Outside Swedish water, the German fleet was waiting and when passing Måseskär, Skytteren were warned by two other blockade-runners, Lind and Rigmor, which had headed out an hour earlier than Skytteren and now were returning towards the Swedish coast. The warning was too late as Skytteren was disabled, most likely through sabotage, and when the German warship fired and hit the target below the bridge the captain, William Wilson decided to sink the ship himself. According to eyewitnesses onboard, the captain activated a series of explosions from a control in his cabin without previous notice to the men. One person lost his life in the explosions. The lifeboats were launched and the other 110 persons onboard started to row toward the Swedish coast. Then the Swedish ice-breaker Göta Lejon arrived from north and the fugitives thought they were going to be rescued. An intense exchange of signals with the German vessel followed and afterwards the Göta Lejon returned to the north, while everybody in the four lifeboats were imprisoned by the

Germans. Only two of the ten ships participating in Operation Performance reached the Allies. On fire, and with a heavy list to port, Skytteren drifted northward before sinking to her final rest with starboard side upward and the bow pointing to the west[51-53] (Fig 8).

5.2 Initial theoretical risk assessment

Based on a form from the report Potentially polluting wrecks in marine waters[9], an initial theoretical risk assessment of the S/S Skytteren was made (Appendix 1). As this prestudie only includes theoretical evaluations, the risk assessment is incomplete, yet it provides a clear indication that Skytteren demand immediate attention including an in situ inspection.

5.3 Proposed remediation methodology

5.3.1 Site description

Skytteren rests at approximately 74 m depth west off Måseskär. The bottom at the site is dominated by glacial clay[54] and the bottom water temperature is between 5 and 7°C depending on the seasonal variations[55].

There are very few observational current data available from the site and an upcoming wreck inspection should include measurements of current velocity and direction. In the lack of data, oceanographers at the Swedish Hydrological and Meteorological Institute (SMHI) were asked to model possible current conditions with depth. To do this, HIROMB (High Resolution Model of the Baltic Sea) was used and the results at 60 and 75 m depth are presented in Fig 9.

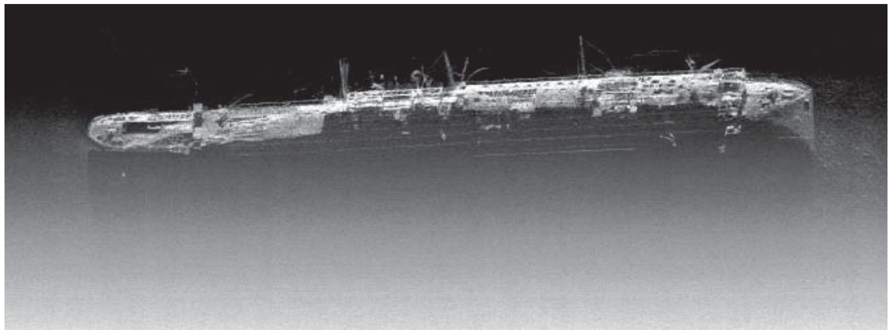


Fig 8. Side Scan Sonar Image of Skytteren, produced by Marin Mätteknik AB. According to MMTAB present side scan sonar techniques can provide images of further enhanced quality compared to the image above [3].

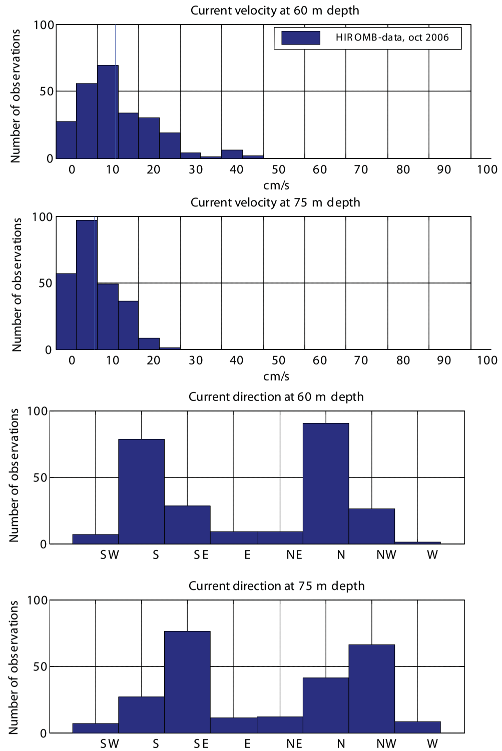


Fig 9. Modeled current direction and velocity at the position of Skytteren during the month of October 2006, at 60 and 75 m depth respectively. Modeled data for shallower depths are available in Appendix 2. Source: SMHI.

The model is not completely validated e.g. regarding bottom currents and therefore the uncertainty increase at the endpoints (i.e. the extreme velocities). This implies that a satisfactory level of conclusion is that the bottom conditions most likely are dominated by relatively moderate current velocities. In comparison current velocities of 3-5 cm/s are enough to resuspend sedimentary material[56].

5.3.2 Oil onboard – amount and type of oil

The estimated bunker capacity of Skytteren is 6000m3 [2]. According to the technical drawings of the ship, Skytteren also had a large number of tanks onboard intended for storage of whale oil. Skytteren went down during the failure of Operation Performance, which were preceded by the successful Operation Rubble (January 1941), when five Norwegian ships managed to transport munitions to the Allies from Sweden. To my knowledge, there are no information or documentation regarding bunker or cargo at the time for sinking, but the prevailing situation of war and the fact that she was a blockade-runner, open the door to speculation. The only way to close that door is realization of a detailed in situ inspection of the wreck to reveal what was left onboard.

During the period 2005-02-05 – 2005-06-14, the Swedish Coast Guard made ten (10) calculations of the oil spill that was regarded to originate from Skytteren. The calculations point at spills in the order of a few deciliters to some hundred of liters (Fig 10 & 11).

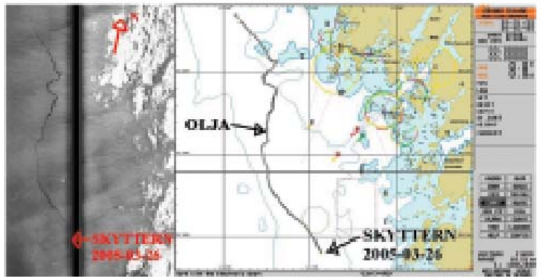


Fig 10. a) SLAR image, Side-Looking Airborne Radar of the suspected oil spill from Skytteren on 2005-03-26. The oil is shown as a black streak to the left of the image. To the right of the black field, which is the "blind spot" of the method, is the light coast line. b) Information from the SLAR image (a) transferred to a nautical chart of the corresponding area. Source: The Swedish Coast Guard.

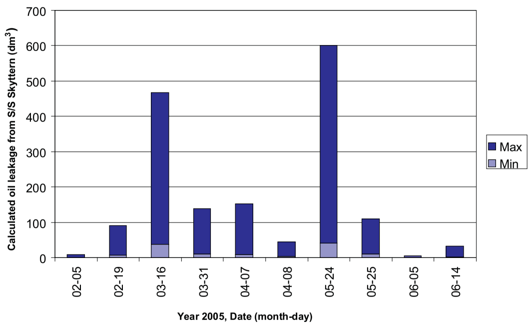


Fig 11. Calculated oil volumes that most likely originated from Skytteren during the spring 2005. Source: The Swedish Coast Guard.

Fig 12. Evidence of the oil leaking Skytteren, recorded from the ROV of the Swedish Naval Forces in 2005. Source: The Swedish Coast Guard.

In March 2005, the 41st division of mine-clearance of the Marines was commissioned by the Swedish Coast Guard to perform an initial in situ inspection of Skytteren using a ROV. At least four different leaks were identified close to the starboard bilge keel. (Fig 12).

In late May 2005, the Swedish Coast Guard sampled the oil slick off Måseskär (Fig 13) which was thought to originate from Skytteren. The chemical analysis showed that the oil was a lighter kind of diesel oil.

Fig 13. Oil probably originating from Skytteren, sampled at the sea surface outside Måseskär. Source: The Swedish Cast Guard.

In spite of these results, there are no scientific evidences that confirm the oil sampled at the sea surface close to the wreck of Skytteren to be identical to the oil remaining in the tanks. Skytteren had a large number of tanks onboard and it is uncertain whether all tanks were filled and further if the type of oil varied between the different tanks. Furthermore there is no reliable documentation available regarding the type and amount of bunker or information about the cargo at the time for sinking. Beyond these factors of uncertainty, oil may also change characteristics over time. For example there might be a gravimetrical stratification of the oil causing initial leakage of lighter fractions.

In the end of 2006 repeated calculations pointed at leakage in the same range as in 2005. Due to technical problems no repeated flights were made until September 2007 and during the period 2007-09-22 – 2007-10-01 seven (7) flights could not detect any oil traceable to Skytteren. If this implies that all oil onboard already is emptied or if only those tanks that were previously leaking are emptied or if it is variations in the rate of leakage is impossible today from present knowledge.

5.3.3 Possible techniques

If there is any oil left onboard Skytteren and if that oil is of the same kind as the fraction sampled at the sea surface by the Swedish Coast Guard, the prospects of a fairly easy remediation, as it would not require heating of the oil before pumping. However, until proved it can not be assumed that this is the case and the picture could be far more complex if the oil have started to mix with water[14, 20],making it more viscous and difficult to handle.

The method based on microbial degradation is in a hypothetical case of Skytteren estimated to take between two and six months. The work could be more difficult in case of many different tanks containing different types of oil. Even if the method implies a substantial improvement of the natural rate of oil degradation, the estimated time might still be too long with respect to a possible collapse of the tanks during operation if the tanks are in poor condition. As the technique of microbial degradation has to be regarded as relatively new[49], a proper approach could be to use the remediation of Skytteren as a small scale test of the method in Scandinavian water. For instance it would be possible to evaluate the methods suitability on the remaining volumes of oil after removing the major part through pumping. Such a field of application allows for reduced need for frequent monitoring and thereby reduced costs.

Considering Skytteren's size and prevailing current conditions, the use of a tailored tent is to be regarded as less suitable.

5.4 Estimated costs for wreck assessment and remediation

From a given set of data about S/S Skytteren a handful contractors with competence in wreck assessment and remediation business, were asked to give a rough hypothetical estimate of the costs involved in an assessment and a remediation of Skytteren respectively. Initially it should be stressed that this is no tender for a contract, but the provided numbers are thought as a hint to what the total cost of an assessment and remediation of Skytteren could sum up to.

The cost of a detailed assessment including localization, sampling and determination of the remaining volumes of oil onboard are estimated in the range 0.5-2 million SEK. The cost of a remediation involves more uncertain moments of both theoretical nature (limited available information about Skytteren) and practical kind as the remediation for instance is highly dependent on favorable weather conditions during the time for operation. Most uncertainties should fall within the span 20-250 million SEK for a remediation, irrespective of choice of method.

5.5 Best and worst case scenarios of a sudden major oil spill from S/S Skytteren

As previously discussed there are many factors of uncertainty regarding available data about Skytteren. The lack of scientifically supported and validated information regarding the remaining volume of oil, and what kind of oil that can be found onboard, makes it difficult to identify the real environmental threat posed by the potentially polluting wrecks. Despite these difficulties we chose to make three scenario calculations simulating instantaneous release of 3000 m3 oil from the position of Skytteren, which could be a realistic scenario if the hull would collapse. The dominating factor determining the distribution of the oil spill along the coast is the prevailing wind conditions and therefore wind statistics from a thirty year period at Måseskär were examined (Fig 14). From these data three commonly occurring wind direction and velocities were chosen; westerly wind 13 m/s, southerly wind 7 m/s and finally easterly wind 7 m/s. As there are indications that the oil onboard Skytteren is of lighter kind, such as diesel, the correspondingly scenario at the different wind conditions are shown below. To give a comparative picture of the behavioral differences of different types of oils, oil spill scenarios for two additional types of heavier oils are modeled in Appendix 3. According to expectations, pure easterly winds do not result in any oil reaching the Swedish west coast, while both westerly and southerly winds do distribute the oil spill along the coast of Bohuslän (Fig 15). A severe oil spill along the coast of Bohuslän could involve costs related to fisheries of nearly 100 million SEK. The corresponding worst case scenario as regard tourism could be close to 1 billion SEK, as all communities along the coast are having tourism as an important source of income[28]. This, in addition to the heavy clean-up costs that has to be considered as the coast of Bohuslän is extremely lacerated and thereby very long. Furthermore geographical areas of significant value (at least in a Swedish perspective) are at risk, like the Gullmar Fjord, Sweden's most distinctive fjord with a unique flora and fauna.

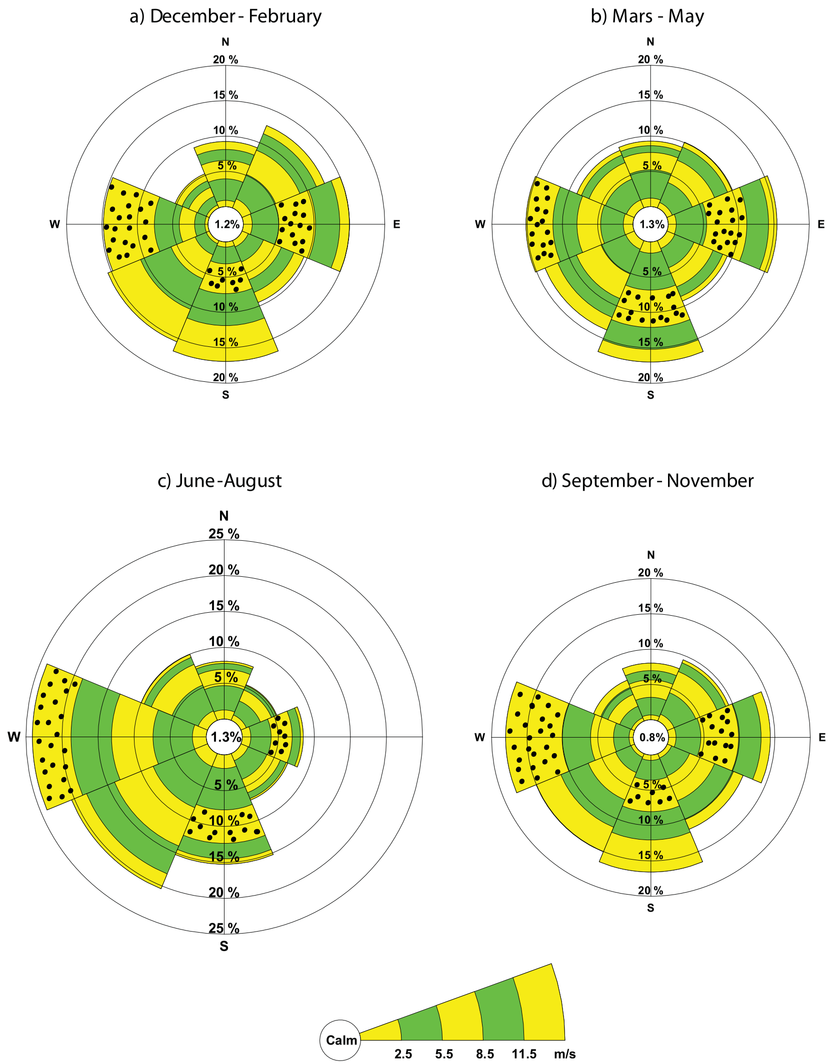


Fig 14. Wind conditions at Måseskär. Statistical distribution 1977-2006. The black dotted areas indicate chosen categories used in the operative oil spill model. Sea Track Web. Source: SMHI.

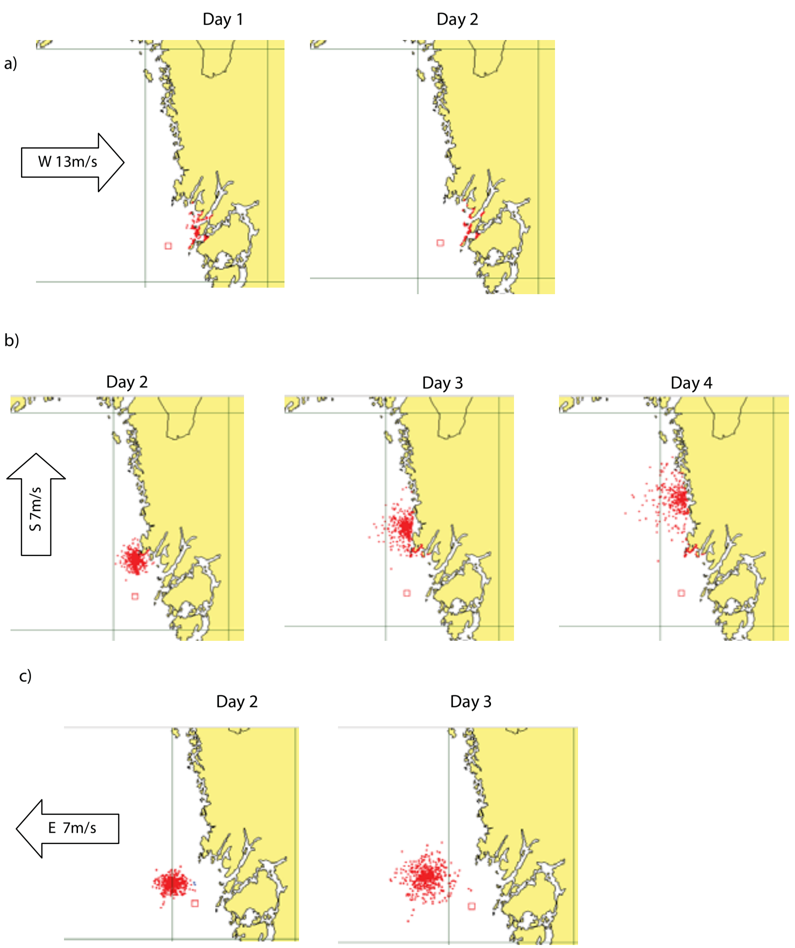


Fig 15. Oil spill trajectories modeled in Sea Track Web developed by SMHI. Three different scenarios of an instantaneous oil spill of 3000m3 light diesel oil during three different wind conditions. a) Westerly wind 13 m/s could give a severe oil spill primarily at the Skaftölandet and Lysekil within 3 days. b) Southerly wind 7 m/s could give a corresponding result all the way from Sotenäset in the south to Koster in the north. c) Continuous easterly wind would not result in any direct oil spill along the Swedish coast; instead the time for possible clean-up at sea would be prolonged. It should be mentioned that in addition to the uncertainty of the estimation of the remaining oil volume, the modeled scenarios are a simplification of natural conditions as the wind is constant throughout each run. To give a hint about the scale on the map, Orust is approximately 25 km in east-westerly direction.

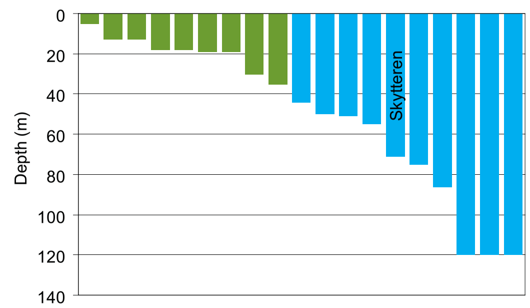


Fig 16. Water depth for 19 of the recognized potentially polluting wrecks off the Swedish coast from Marstrand to Strömstad [2]. The depth information refers to the surrounding seabed and for example the uppermost parts of Skytteren are approximately 20 m above the seabed. Green color indicate (as regards depth) relatively routine depths for certificated diver.

5.6 Extrapolation to other potentially polluting wrecks in the Skagerrak

As previously pointed out it is hard to give more accurate information than rough estimates, both regarding individual wrecks and for a number of wrecks. A cost that is likely to be affected by the number of wrecks that are possible to inspect in connection to each other is for example mobilization costs. The same should be applicable also for remediation, with some restriction due to possible deviation in choice of remediation technology among different wrecks. To conclude, there is not a linear relationship between costs and the number of wreck to handle, but as the estimated costs are rough this will not be paid any further attention.

In an attempt to give some kind of interval for possible costs for remediation of all the recognized potentially polluting wrecks off the Swedish west coast, the estimations for assessment and remediation of Skytteren is combined with the relative scale described in Table 2. The result is as follows regarding the recognized potentially polluting wrecks along the Swedish coast from Marstrand to Strömstad (Table 3):

Group	Remediation cost (million SEK)	Number of wrecks
1	5-20	7
2	10-50	5
3*	20-250	7

Table 3. Cost assessment for remediation of 19 of the potentially polluting wrecks within the Västra Götaland County.

*This group was used to check the assessed cost of remediation of Skytteren and the classification of group 1-3 according to the model in Michels et al 2005[9]

The sum of the average remediation cost of every wreck in respective category exceeds 1.1 billion SEK. If the upper limit of the range is considered to represent some kind of worst case scenario, the total cost will almost be doubled, 2.1 billion SEK. However, this estimate does not include any potentially reduced costs, which could be a result of acquired experience after finishing a number of wrecks, or reduced mobilization costs if many wrecks can be handled in connection to each other. It should also be kept in mind that the potentially polluting wrecks are potential threats to the environment and out of present knowledge it is impossible to make a realistic measure of the number of wrecks that can be removed from the list after the wreck assessment. If the other 243 recognized potentially polluting wrecks in the Skagerrak, turn out to be in need of immediate remediation, the total cost will of course will be enormous. For many reasons, including the possibility of co-financing of the remediation, it is desirable to engage the other countries concerned as the majority of the wrecks are not resting in Swedish waters.

6. Who is responsible for wreck assessment and remediation?

6.1 Today – no responsible authority!

Without any doubt, the total costs for clean-up of a sudden major oil spill from wrecks in many cases are likely to exceed the cost of a well planned remediation was realized. Another aspect, which has gained international attention, is that today lack of technology of both detailed wreck inspections and remediation no longer constitutes a valid argument for further delay of wreck assessment and remediation[59]. As discussed in the introduction there is a legal loophole with respect to the lack of a responsible party entitled to order preventive measures. Furthermore there is presently no special funding available intended to cover neither wreck assessment nor remediation. The lack of clearly assigned areas of responsibility regarding abandoned potentially polluting ship wrecks was pointed out already thirty years ago in the governmental commission on hazardous wrecks (Farliga vrak SOU 1975:81). However no legislation was appointed through this commission and despite recurring discussions in the Swedish Parliament regarding the problem of potentially polluting wrecks[4-6], yet no legislative action has been taken in the matter.

Today the Swedish Maritime Authority is responsible for removal of wrecks that pose an obstacle for shipping, for instance in harbors and fairways. The Swedish Coast Guard are responsible for handling of oil spills at sea including evaluation of the possible environmental benefit in relation to the socioeconomic costs of a clean-up action. In the event of a major spill there are also organized plans of action for possible utilization of other resources such as the Swedish Naval Forces and Rescue Services[21, 29]. During the summer of 2007 the non-governmental Swedish Sea Rescue Society[60] obtained equipment for oil control, such as skimmers. The SSRS also participated in exercises under the management of the Swedish Coast Guard, to enable efficient assistance in the event of future oil spills. The question of responsibility concerning potentially polluting wrecks in Swedish waters was recently discussed in an essay by O. Ekström at the Department of Law at Göteborg University[61]. Ekström make comparisons to existing laws concerning polluted ground and the handling of wrecked cars respectively. A non-strictly juridical reflection is that it appears to be easier to realize legislation in areas where the problems are visual, as in the comparison between wrecked cars ashore and submerged ship wrecks. This natural behavior, to prioritize tackling of problems in the immediate vicinity, is of course strengthened through the cost of a remediation or salvage of a shipwreck is far more extensive operation compared to the removal of a wrecked car. Traditionally, shipwrecks are also regarded as graveyards and therefore treated accordingly

The Swedish Naval Forces has most likely the operative capacity required, at least to perform detailed wreck inspections. For example the four mine-sweepers of model Styrsö built in 1996-1997, are well equipped and prepared for management of future types of ROV:s[62]. Even if environmental operations are part of the mine-sweeping divisions' duties, as clearance of previous military artillery ranges and ammunition disposal sites, they are not responsible according to existing legislation to participate in precautionary actions to avoid future oil spill from shipwrecks.

An important juridical issue discussed by both Ekström[61] and Tiberg[63, 64] is the definitions of when a ship becomes a wreck and who the rightful owner of wreck and wreckage is? The interpretation by Tiberg is that according to existing laws, it is possible to put an owner of a ship responsible for environmental damage due to spilled oil, even if the damage occurred after the ship went down. This is very interesting also from a financial perspective as it brings that recent wrecks, where the owner can be identified and found, are covered by the owner's liability insurance. Probably it is not economically defensible to remove the oil from all older, small wrecks today. Concerning recent wrecked ships, where the matter of ownership and thereby also insurance do not necessary has to be such a juridical challenge as for older wrecks, it is always the owner's responsibility to remove the environmental threat. If the owner refuses to do so, the Swedish Coast Guard can make sure the work is properly done and later on the owner will be charged the cost.

6.2 How do other countries tackle the problem

The US is frequently depicted as one out of few countries that has an existing legislation concerning potentially polluting wrecks[9, 31]. The system is based on identification of an owner that could be held responsible for the wreck and the owner will have 30 days to accomplish his task. If the wreck is considered to pose an imminent environmental risk, the time assigned is reduced to 24 hours. In the event of authoritative action, either the owner or the owner's insurance company are forced to pay remediation costs. Sometimes part of the cost or the entire cost could be covered through sale of the wreckage and or cargo left. Hence the US suffers from the same problem as other countries in case no owner or responsible party can be held responsible, which is the case for several of the many potentially polluting wrecks from the Second World War, the financing of remediation remains unsolved.

Norway has acted in a way worthy of imitation since the Norwegian Pollution Control Authority (SFT), in 1992 commissioned the Bergen Maritime Museum to compile a data base of wrecks along the Norwegian coast. Both public and private archives were searched for wrecks according to the criteria that the ship should have been larger than 100 GRT and sunk after 1914. Today it is the Norwegian Coastal Administration that is responsible for the data base presently containing 2300 wrecks. During the period 1993-2000, a national program of wreck assessments started and 36 potentially polluting wrecks of high priority were assessed. The initial assessments were followed by more detailed inspections of wrecks thought to be in need of immediate attention. As previously mentioned the battle cruiser Blücher in the Oslo fjord was emptied in 1994 within the framework of this program[10, 36, 65].

IMO is working on a convention regarding the handling of wrecks (DWRC, draft wreck removal convention)[66]. The convention aims at regulate the handling of wreck on international water, for example a obligatory system for reports of new wrecks and specifications on their position, cargo, cause of wreckage etc is suggested. However, before the financial matters are resolved, the importance of the proposed convention is unfortunately restricted. Suggested solutions of co-financing have so far required ratification by the majority of the member states, partly to avoid states that do not ratify the convention to still allow ships to be registered under their flag, partly because the pot will be smaller the fewer the states that participate.

6.3 Potential platforms and sources of financing

Preventive actions concerning potentially polluting wrecks are costly, but as discussed previously, the cost has to be compared to the corresponding cost if no measures are taken. A potential track for further investigation is the possibility to use funding from the liability insurance of environmental damage (miljöskadeförsäkringen), to which all industries dealing with processes or products of possible harm to the environment are obliged to contribute according to Swedish law (1998:1473).

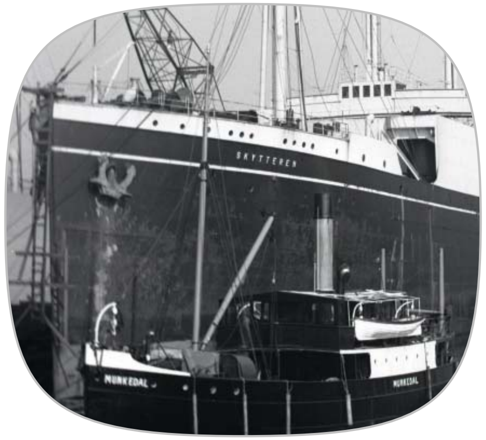
Another possible alternative for financing of handling of wrecks in Swedish waters is establishment of a national fund, similar to the one for polluted ground (2004:100). In connection to the fund it would be advisable to start a center of competence to ensure efficient use of resources through co-ordination of actions and feedback of experiences to improve and facilitate future actions. Hopefully, this assurance of competence could also lead to reduced costs in the future.

To resolve handling of wrecks on international water and/or wrecks on other nation's water, yet posing a threat to Sweden, it is important to find ways of smooth cooperation. The question has been raised in a working group of the Copenhagen Agreement[67], but was postponed after the annotation that Norway is in the front line regarding wreck assessment and remediation while Sweden and Denmark still lack any plans of action. Yet, this annotation has to be considered as a step in the right direction as it opens the discussion of the problem in a forum of existing documented co-operation within an adjacent problem, namely oil pollution control in the occurrence of major oil spills.

Even if the work of IMO aiming at regulation of the problem concerning potentially polluting wrecks at an international level, it is probably too optimistic to believe in a near smoothly operated financial plan to be ready within the next few years. Probably, it would be more realistic to increase co-operation within Europe, initially maybe in the form of a couple of EU-project to reinforce regional co-operations and not least find models for both strategically and practical work within concerned countries.

7. Conclusion

There is an immediate need for a long-term plan of action, including clearly identified areas of responsibility, regarding assessment and remediation of potentially polluting shipwrecks. The majority of the recognized potentially polluting wrecks date back to the Second World War and hence it is time to act now as some wrecks have corroded to the extent that they are already leaking. Prior to any remediation, it is of great importance to make detailed inspections of the wrecks both to verify the potential threat and to facilitate a potential remediation. Concerning wrecks on Swedish water establishment of a fund, similar to the existing model for handling of polluted ground, could be a possible solution. Regarding wrecks outside Swedish water, yet posing a potential environmental threat to Sweden, it would be preferable to co-operate with the other concerned countries that are Norway, Denmark and the countries of the Baltic Sea. The imminent situation regarding S/S Skytteren should not await a protracted commission, but as soon as possible be inspected in situ to verify whether she is a substantial threat or not.



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Appendix:

Appendix 1: Preliminary risk assessment of S/S Skytteren

Appendix 2: Modeled current data at the S/S Skytteren position

Appendix 3: Oil spill trajectory models from the S/S Skytteren position

Appendix 4: List of contributors regarding cost estimates

Appendix 1
Preliminary risk assessment of S/S Skytteren

Example of assessment and rating of wrecks to use for evaluation of the relative order of priority. The form is reproduced according to Michel et al[1] (2005) and is completed with present information about S/S Skytteren.

Site Assessment Criteria

Risk Assessment Criteria and Questions	High Risk	Medium Risk	Low Risk
What is the size, type, and construction of the sunken vessel?	>10000 tons	1000-10000 tons	<1000 tons
What is the likely quantity of oil on board?	High; >1000 tons	Moderate; 100-1000 tons	Low; <100 tons
How accessible is the wreck to shore?	Near shore or Lagoonal	Offshore but accessible	Open sea
How deep is the water where the wreck rests?	Access by conventional SCUBA	At limit of diving capability	Deep water Submersible access only
Has the wreck a history of previous oil releases?	Documented history of oil leaks	Occasional oil leaks or not known	None
What oil types are contained in the wreck? Are they persistent oils once spilt at sea?	Very persistent oil	Medium grade oils	Non-persistent oil
Is the wreck subject to severe weather events, such as storms, monsoons, hurricanes, typhoons?	High degree of severe weather possible	Moderate degree of severe weather possible	Low degree of severe weather possible
What is the stability of the seabed and what are the sediment effects on the wreck movement and integrity?	Unstable and/or high degree of movement	Relatively stable or not known	Known to be a stable seabed
What is condition of the wreck, degree of deterioration, and its fragility to natural disturbance effects?	Significant deterioration	Moderate deterioration	Mostly intact
Is the wreck subject to high level of hydrodynamic forces on the seabed?	High level of sub-sea currents	Medium level of hydrodynamic forces	Low level of currents and driving forces

Environmental Assessment Criteria			
Risk Assessment Criteria and Questions	**High Risk**	**Medium Risk**	**Low Risk**
Are there areas of high environmental sensitivity in the region? Consider distribution of sensitive habitats such as marshes, mangroves, sea grasses, coral reefs, mud flats, and kelp beds.	High level of environmental sensitivity	Medium level of environmental sensitivity	Low level of environmental sensitivity
Does spill trajectory modeling indicates significant environmental resources at risk from oil releases?	High probability of impact	Moderate probability of impact	Low probability of impact
How unique, rare or diverse is the ecology of the area likely to be affected?	High	Medium	Low
Are rare or endangered wildlife located within the region or potential spill impact zones?	High level of protected species in region	Low level of protected species in impact zone	No protected species in impact zone
What sensitive wildlife species are at risk? Consider the diversity, number, locations, and seasonality.	High number and diversity	Medium number and diversity	Low number and diversity
Are there routes for transitory species, such as migratory birds and marine mammals?	High abundance	Occasional	None
What is the preservation or protection status of the area at risk? Considerations include: marine park, wilderness, world heritage, and conservation status?	High level of protection and preservation	Moderate level of protection and preservation	Low or no level of protection and preservation
Are there any historical, cultural or archaeological resources in the area at risk, including war graves?	Significant resources and high value	Moderate level of resources	Low level or not present
Does the area at risk have subsistence fishing, traditional hunting/gathering or fish traps in the wreck area?	High degree of subsistence living in region	Medium level of dependency on subsistence	Low level or no dependency on subsistence
What is the extent of scientific, educational, or research interest in the area at risk?	High degree of interest	Occasional interest	Low or no interest

Economic Assessment Criteria			
Risk Assessment Criteria and Questions	**High Risk**	**Medium Risk**	**Low Risk**
Are licensed commercial fisheries, fish farms, aquaculture, pearl farming etc in the area at risk?	High level of economic value	Moderate level of economic value	Low level of economic value
What other significant industrial uses, economic resources or important uses of the sea are present in the area at risk (e.g., water intakes, aquaria, salt-pans)?	High level of economic use and dependency	Medium level of economic use and dependency	Low level of economic use and dependency
What important recreational or tourism activities are carried out in the area at risk (e.g., sport fishing, diving, snorkeling, boating, sightseeing, surfing, coastal recreational use)?	High level and/ or high degree of economic value	Medium level and/or moderate degree of economic value	Low level and/or low degree of economic value
What level of marine use occurs within the area of the wreck?	High degree and range of marine uses	Medium degree and range of marine uses	Low degree and range of marine uses
Is the region used as a marine transport corridor?	High degree of use	Medium level of use	Low level of use
Does the wreck contain sufficient quantities of unexploded ordnances (UXOs) or other dangerous goods (DGs) that would pose a safety hazard or require exclusions zones near the wreck?	High quantities of UXOs and/or DGs known on wreck	Moderate or unknown quantities of UXOs and/or DGs on wreck	Low or no UXOs/ DGs on wreck

?

Reference:

Michel, J., D.S. Etkin, T. Gilbert, R. Urban, J. Waldron, and C.T. Blocksidge, Potentially polluting wrecks in marine waters, in International Oil Spill Conference. 2005.

Appendix 2
Modeled current data at the S/S Skytteren position

Summary

Statistics of current velocity and direction from the operational ocean circulation model HIROMB at the position of S/S Skytteren October 2006 are shown. Model data every 3rd hour were analysed from the surface down to 75 m depth. The analysis shows that the currents at the position are predominately in the north-south direction throughout the larger part of the water column. At the surface, where the currents are more influenced by prevailing winds, the current directions are more variable and the north going current is dominating.

The current velocity is highest at the surface and decrease with increasing depth. It is known that the model tend to over estimate extreme velocities at the surface implying that the shown maximum velocities might have occurred less frequently than shown. The extremes constitute an upper limit of what to expect from observational data.

The model has never been validated with depth. The accuracy of the modeled bottom current data is therby uncertain.

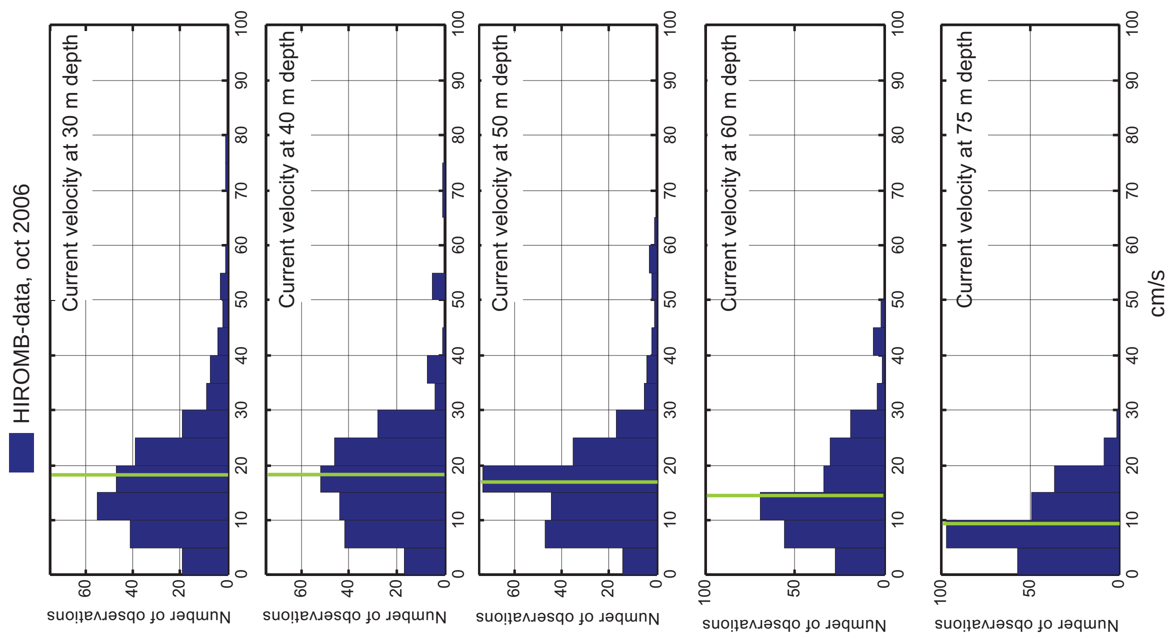
HIROMB

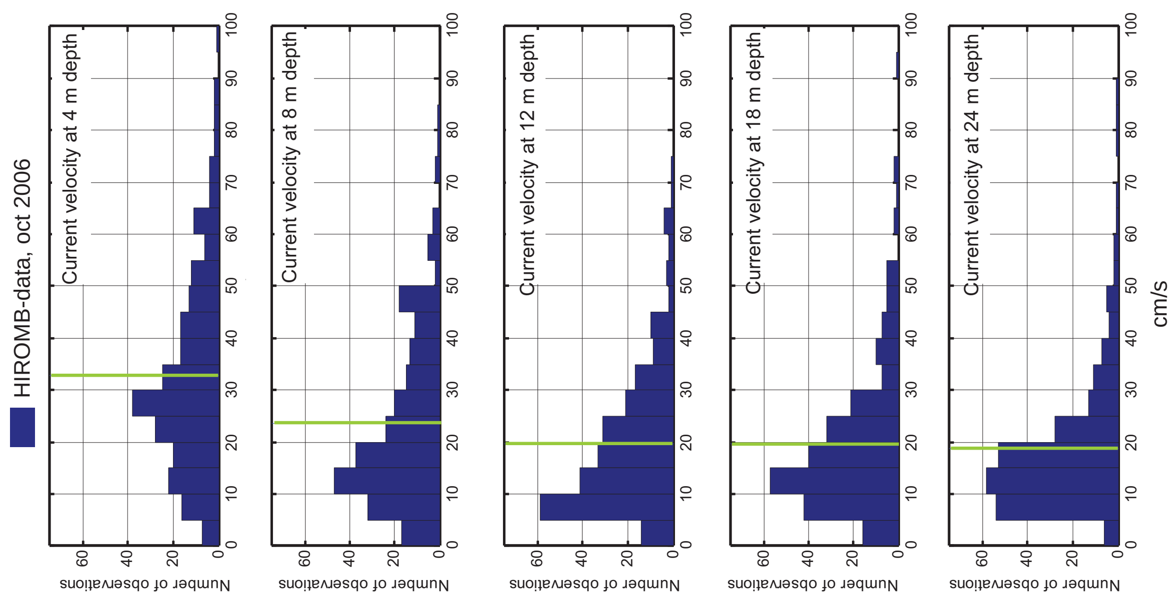
The operational ocean circulation model HIROMB (High Resolution Model of the Baltic Sea) is developed by SMHI and is used for calculations of parameters such as currents, salinity and temperature. In the Baltic Sea, the Kattegat and the Skagerrak the horizontal resolution is 1 x 1 or 3 x 3 nautical miles. The model has been operational since February 2002. In 2005 the model was updated to version 3.0. The extensive update to v 3.0 significantly improved layers and resulted in higher currents.

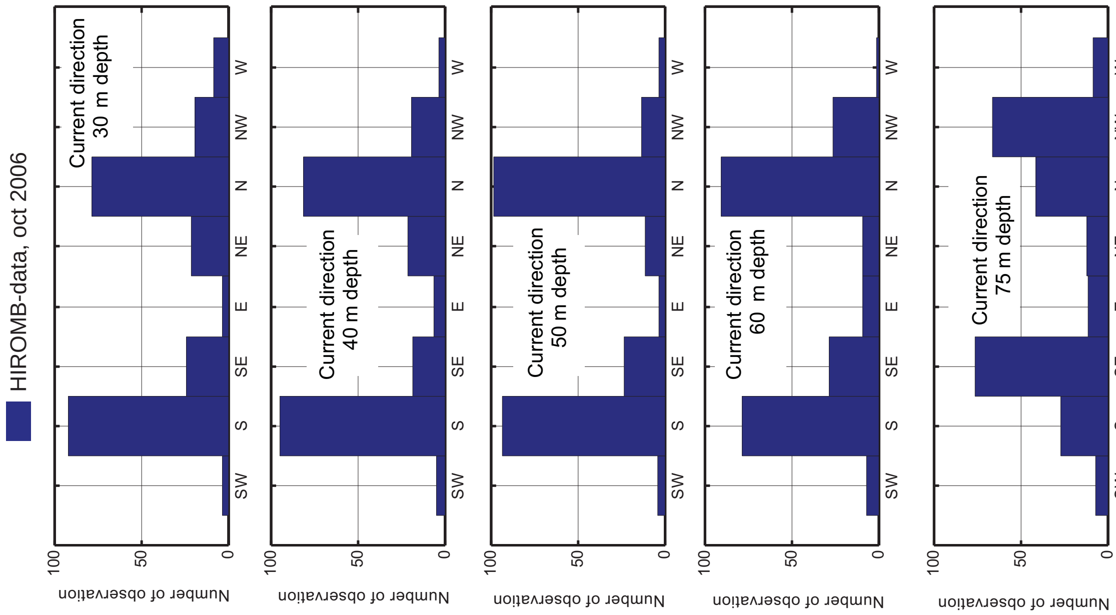
The results from HIROMB are delivered in a grid of 1 x 1 NM. The thickness of the cells varies. At the surface the thickness is 4 meters, i.e. the velocity represents the (mean) velocity between 0-4 m, 4-8, and 8-12 m. Below 12 m the resolution is increased to 6 m deep cells, giving following cell thicknesses: 12-18, 18-24 and 24-30 m. Between 30 and 60 meter depth, the cell depth is 10 m .

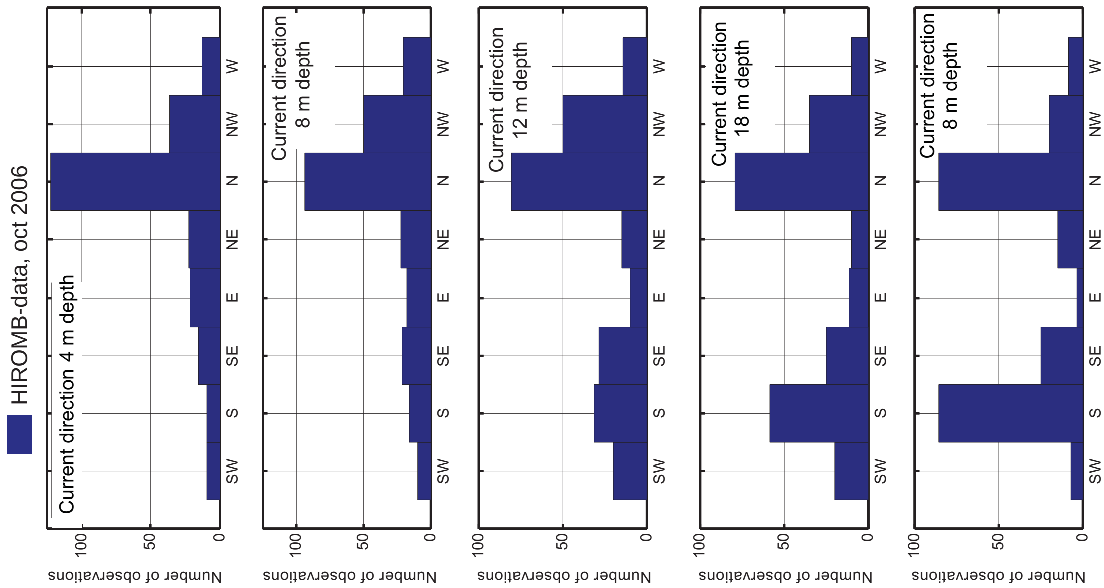
In 2006 a three month validation study of HIROMB, with focus at current velocities, were made through comparison of observational and model data in the Hanö Bay. The results showed that current velocities generally are underestimated. The velocity in the model was periodically higher than corresponding observational data. The velocity distribution showed too many occasions of high current velocities. At the same time, the magnitude of the highest observed velocity in the same order as for the model data during the same period. The figures below show distribution of current velocity and direction in HIROMB for the grid closest to the position of S/S Skytteren. October 2006 was choosen as an example of autumn conditions. During the summer, the current velocities will most likely be some what lower.

In the figures showing current velocity, the mean velocity is also marked.


HIROMB-data, oct 2006
Current velocity at 30 m depth
Current velocity at 40 m depth
Current velocity at 50 m depth
Current velocity at 60 m depth
Current velocity at 75 m depth
Number of observations
cm/s


HIROMB-data, oct 2006
Current velocity at 4 m depth
Current velocity at 8 m depth
Current velocity at 12 m depth
Current velocity at 18 m depth
Current velocity at 24 m depth
Number of observations
cm/s


HIROMB-data, oct 2006
Current direction 30 m depth
Current direction 40 m depth
Current direction 50 m depth
Current direction 60 m depth
Current direction 75 m depth
Number of observation
SW S SE E NE N NW W
0 50 100


HIROMB-data, oct 2006
Current direction 4 m depth
Current direction 8 m depth
Current direction 12 m depth
Current direction 18 m depth
Current direction 8 m depth
Number of observations
SW S SE E NE N NW W
0 50 100

References

Mattsson, J. (2006) HIROMB validation in the Danish Sounds. Presentation at the 9th HIROMB Scientific Workshop 28-31 August 2006, SMHI, Gothenburg: http://www.environment.fi/download.asp?contentid=56262&lan=en

Nerheim, S. (2006) Results from the Hanö bay validation project

Presentation at the 9th HIROMB Scientific Workshop 28-31 August 2006, SMHI, Gothenburg: http://www.environment.fi/download.asp?contentid=56267&lan=en

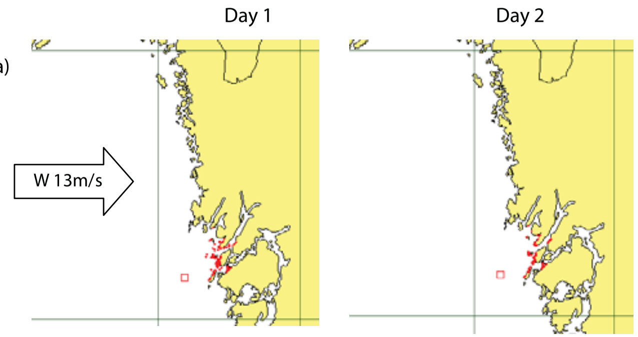
Appendix 3
Oil spill trajectory models from the S/S Skytteren position

Hypothetical oil spill trajectory models from the S/S Skytteren position, modeled in Sea Track Web, developed by SMHI. The following conditions were used:

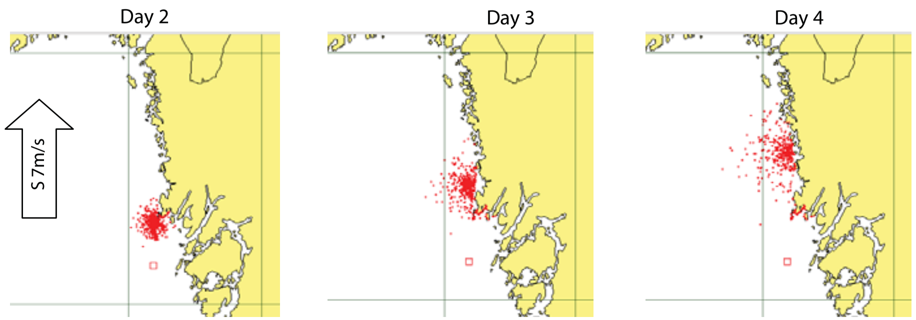
Variables:		
Oil types	**3 different winds:**	**Prerequisites:**
Medium Heavy	High W 13m/s, toward 90 degrees Moderate S 7 m/s, toward 0 degrees Moderate E 7 m/s, toward 270 degrees	Northerly current, 5 cm/s=0.1 knot, toward 0 degrees The wreck rests at 74 m depth. Instantaneous spill of the entire volume Extra uncertainty included Calculation period 2-3-4 days Volume of oil: 3000 m^3

Medium oil:

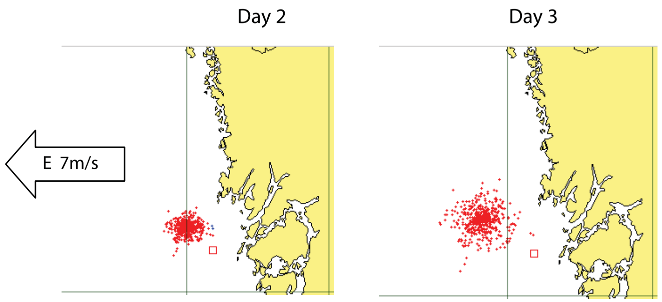
a)



b)

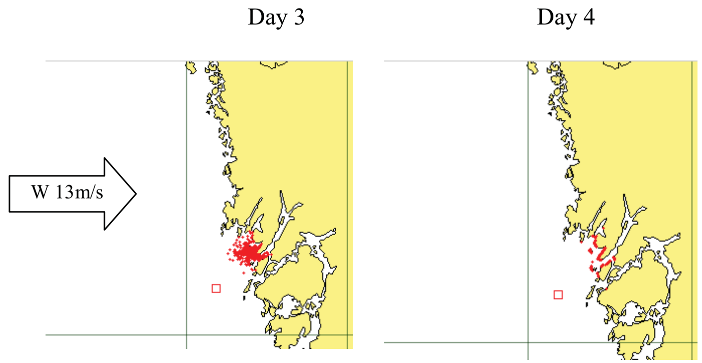


c)

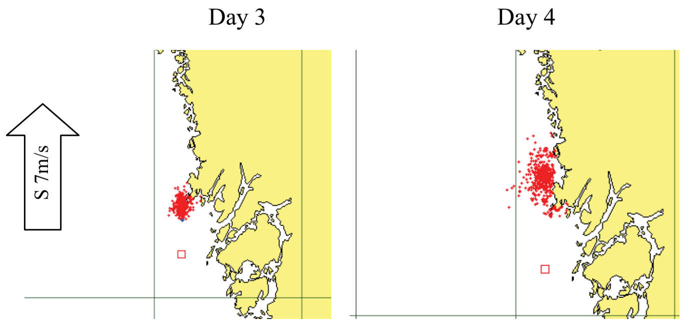


Heavy oil:

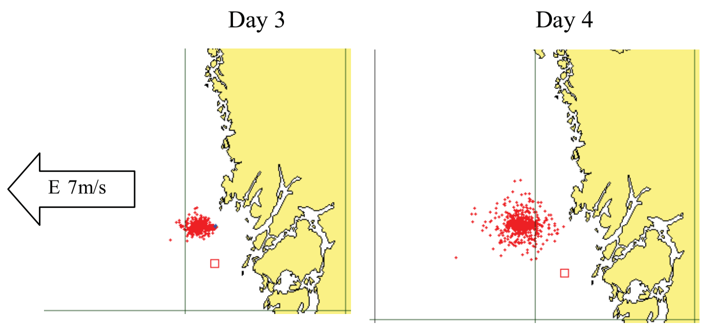
a)



b)



c)



Appendix 4
List of contributors regarding cost estimates:

List of contributors regarding cost estimates (in alfabetical order):

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In the Skagerrak there are 261 ship wrecks which have been identified as potentially polluting wrecks. Twenty of these are located close to the Swedish coast, within the Västra Götaland County. The majority of the potentially polluting wrecks originate from the Second World War, hence many are heavily corroded and some are already leaking oil. In Sweden this problem has been discussed now and then since the mid seventies, yet there is no legislation regulating the liability for preventive actions to avoid future oil spills from the actual wrecks. This pre-study highlights potentially polluting wrecks in the Skagerrak, but the problem is present along the rest of the Swedish coastline. Therefore, there is a need for the establishment of a national database over recognized potentially polluting wrecks.

Present salvage technology allows for offloading the oil onboard the wrecks, but the remediation operation can be very expensive (about 20-250 million SEK per wreck). This cost has to be compared to the socioeconomic consequences occurring in case of a sudden leak of the corresponding amount of oil along the coast. To ensure that the environmental benefits of a remediation are economically justified, it is of great importance to initially conduct a detailed wreck assessment which in addition to verification of the amount and type of oil onboard, also ascertains that wreck stability will allow remediation. The cost of such an assessment ranges from 0.5-2 million SEK per ship wreck. To finance both ship wreck assessment and remediation of wrecks where no owner can be held responsible, establishment of a fund similar to that intended for remediation of contaminated land sites could be used. Additionally, the formation of a national competence centre to support the fund, gather knowledge in the field of ship wreck assessment and remediation and coordinate actions is recommended.

The AGS is a collaboration of four universities that brings together world-class expertise from the member institutions to develop research and education in collaboration with government and industry on the challenges of sustainable development.

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