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2014 INTERNATIONAL OIL SPILL CONFERENCE

Lessons learned from Offloading Oil from Potentially Polluting Ship Wrecks from World War II in Norwegian Waters.

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ABSTRACT 299921:

Norway has more than 2100 ship wrecks within its territorial waters. They have been classified according to their pollution potential, both from cargo and bunker oils. Most concern has been paid to World War II wrecks with large amounts of bunker oil or oil tankers. 30 high risk wrecks have been monitored since 1993, with concern about corrosion and oil leakage. New knowledge on corrosion status and toxicity of different oil types has radically changed the priority list for which ships will be handled first. The Norwegian Coastal Administration, has conducted oil recovery from eight of these ships (30 – 150 meters depth). The amount of oil had been estimated on all ships based mainly on ships' papers, eyewitnesses to the incident and known damage to ships (hits by bombs, torpedoes, etc).

We have tested different oils for their environmental effects to marine organisms. We have also tested for operational purposes in case we have to handle large amounts of oil after a sudden collapse of one or more tanks. The very high toxicity effects on marine environments from some German oils (coal based) compared to British oils (mineral oils) is important new information that will alter the priority list for oil recovery from World War II ships. The methods for hot tapping have also been developed and refined during the different operations. This brings the time and cost of each operation down significantly. The use of highly experienced personnel and standardized equipment from the off-shore oil industry contributes to the same.

INTRODUCTION:

The Norwegian Coastal Administration (NCA) has the full responsibility for handling all cases of acute pollution on land and in Norwegian territorial waters. This includes pollution from sunken wrecks. Given that Norway has more than 2100 sunken ships wrecks, there is a need to prioritize which are in the most precarious need of attention. Until recently this prioritizing was mainly based on the ships containing the largest amount of oil, an evaluation of their structural integrity and the environmental vulnerability of the waters in which the ships were located. With each action, lessons learned have been used to make improvements to procedures, equipment, use of personnel and policy. This has included launching independent studies to improve operational actions taken when an oil spill from a wreck occurs, and to better understand the environmental threats of different oil types. In a related paper and presentation at this conference (Faksness et. al. 2014, draft), presents findings on the toxicity to marine environment from various types of oil from World War II shipwrecks. New findings in these studies have made it possible to better prioritize among potentially polluting shipwrecks.

WORK DONE IN NORWAY ON PRIORITIZED WRECKS:

Norway has more than 2100 sunken ships (larger than 100 DWT) in its territorial waters. Some are well documented with precise locations, accident reports, cargo lists and fuel content. Others lack almost all information including the precise location of where they sank, cargo information, type and amount of fuel, etc. The latter applies mostly to older shipwrecks (before World War II). These are considered to have a low environmental risk.

Based on the facts that the NCA has about these 2100 ships, their environmental impact has been estimated based on the type and amount of fuel, the cargo and the environmental effects from the ship itself as it deteriorates on the sea bottom. Together, this information provides the basis for ranking the wrecks based upon their expected negative impact on the marine environment.

The first report about sunken ships was made by the Norwegian Pollution Authorities in 1991 (Idaas, K. 1995). The wrecks were categorized based on: the estimated amount of oil products they contained, the cargo and the vulnerability of the marine environments they were situated in. The results were that 1700 ships were categorized as creating no potential pollution risk, 350 ships as having a moderate pollution risk, and 30 ships as having a high polluting risk. The NCA has recently included the environmental hazards resulting from the ship's hull, electronics, paint, etc. into the assessment prioritizing the risk posed by these wrecks (Norconsult, 2009). The following describes the three main threat factors currently being used to generate a prioritized risk assessment list for working on wrecks in Norway.

1. **Environmental impact from the ship itself.** The ships building materials, paints, electronics, etc. from newer ships pose a higher risk than older ones due to use of more synthetic building materials, increased use of technological equipment, electronics, fire fighting chemicals and other toxic and/or bio-accumulating chemicals, etc. However, newer paints and anti-fouling are more environmental friendly. The environmental impact of the vessel's hull, engine room and accommodations (navigating bridge, radio room, galley, etc.) are local and in most cases of low-medium value. (Norconsult, 2009). The breakdown of ships is slow and the leakage of pollutants will be going on for a long time. The Russian war ship, Murmansk (210 meters long), is the only sunken ship that has been completely removed in Norway (in 2012) due to the evaluated pollution risk from the ship itself. Put in a larger perspective, many shipyards and harbors in Norway have higher levels of pollutants originating from ships than the levels found in the close vicinity of sunken ships.

2. **Cargo**. Most merchant ships that sank in Norwegian waters were carrying raw materials (timber, rocks, etc.) and therefore do not present a threat to the environment. During and after World War II, ships loaded with munitions were sunk in Norwegian waters. Conventional ammunition is not considered a major threat to the environment. However, it may become a high risk either during an oil recovery operation or during removal of a wreck.

   In the waters between Norway and Denmark, approximately 38 ships loaded with chemical warfare agents, mainly mustard gas (150 000 tons) and possibly some nerve gas

(Tabun) from German stocks were scuttled after World War II. The sea depth in the area is 600-700 meters. Most of the wrecks have been mapped and sediment samples have been analyzed. The environmental impact so far seems to be low and very local (FFI report, 1907/2002). The main concern is that local fishermen might catch chemical ammunition in their fishing gear. To address this, NCA is planning to expand the mapping of all ships with chemical weapons from World War II. Another identified risk is the environmental problems connected to a German submarine (*U-864*) that was torpedoed outside Bergen in 1945. It went down with 73 men and 67 tons of mercury. The mercury was under transport to Japan, and was to be used in bomb and torpedo production there. We are in the process of collecting information about the status of the wreck in order to come up with the best plan to prevent the mercury from polluting the marine environment.

3. **Oil amount**. Most of the wrecks containing oil in significant quantities in Norwegian waters were sunk during World War II. Based on all available information, the 30 ships ranked as having the highest risk of polluting the environment are followed up on a regular basis. The five top-ranked wrecks were drained of oil products. Two others on the list were handled after they began to leak. In these acute cases, the NCA needed to take immediate action in order to avoid serious environmental impacts on fjords with important marine environments, specially protected fjords for salmon and important seashores for recreational use. Nine of the listed wrecks that were expected to contain large amounts of fuel were found empty upon inspection. One additional wreck handled was the German submarine, *U 864*. It was hot tapped for oil pending additional work concerning mercury removal. Of the original list, 14 wrecks with known locations remain.

LESSONS LEARNED:

This article looks into what the NCA has learned from these operations, with special focus on;

1. Actual amount of fuel found as compared with the amount estimated before the operation began.
2. The state of corrosion of the ship after 70+ years.
3. Equipment for removal and the level of competence of the operation staff.
4. Spill response preparedness during the operation and survey after having finished the oil removal
5. Toxicity to marine organisms of different oil types removed from two German and British ships that sank during World War II.
6. Operational properties of these oil types, should an oil spill occur from World War II ships.

Estimated and actual amount of oil found in the wrecks

Of the thirty shipwrecks on the NCA's prioritized list, 14 remain. These are assessed as posing the highest risk to the marine environment, because they potentially contain large amounts of oil. In addition, we focus on the German submarine *U 864* that may contain as much as 67 tons of mercury. To increase our preparedness to address these situations, we maintain close records of each operation. These are compiled with the intent of learning from past experiences, with the goal of improving future actions.

Since 1994, the NCA has removed oil from eight shipwrecks. Of these eight, five were on the top of NCA's priority list, two of the ships had started to leak and the last one was the mercury-containing submarine. The wrecks were located from the Oslo fjord(59^{o}N) in the South to Vesterålen (68^{o}N) in the North (Fig.1). The operational depth has varied from 20 meters (60 feet) to 152meters (456 feet). The amount of fuel estimated to be contained in a ship is based on information about the ship itself (size, number and volume of tanks) and from information gathered from various sources; survivors, eyewitnesses, oil spills, fires, location of torpedo hits, sinking reports, newspapers, etc.

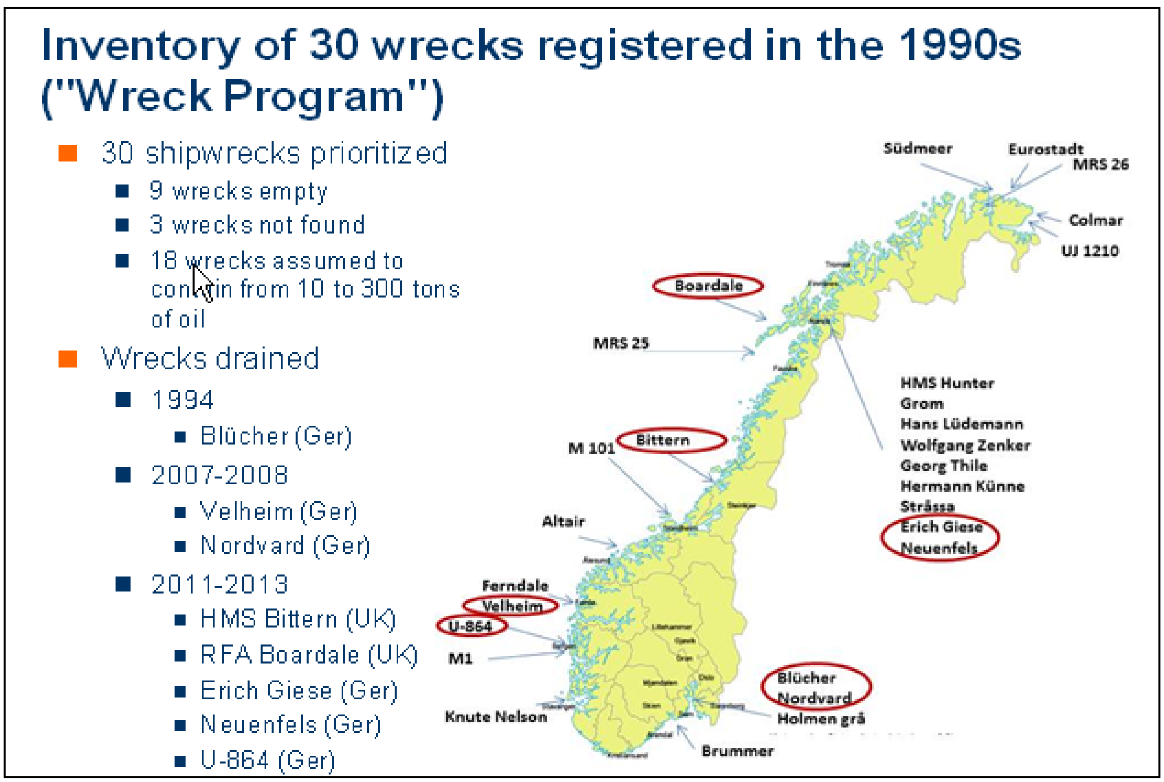

Figure 1. Prioritized wrecks in Norway. Status as of December 2013.

Vessels Name (Year of sinking)	Size DWT, DPL, Brt Length meters	Project Year, Depth meters	Total cost (Norwegian kroner) Number of tanks	Bunker type	Estimated amount	Actual amount
Blücher, cruiser German (1940)	18200dpl 208m	1994 90m	100 mill. 120 tanks	HFO Diesel	1100 tons	1000 tons
Welheim, freighter German (1944)	11200dpl 134,7m	2007 30-65m	24 mill. 31 tanks	Diesel	300 tons	96 tons
Norvard, supply German (1944)	7700dwt 116m	2007 30m	35 mill. 15 tanks	HFO Diesel	173 tons	434 tons
HMS Bittern destroyer, British (1940)	11900dpl 81m	2011 152m	5 mill. 5 tanks	HFO	50 tons	89 tons
RFA Bordale, tanker, British (1940)	11836dwt 142m	2012 67m	4 mill. 2 tanks	HFO	295 tons	201 tons
Eric Giese, destroyer, German (1940)	3200brt 120m	2012 66m	12 mill. 30 tanks	HFO Diesel	300 tons	189 tons
Neuenfels, freighter, German (1940)	14300dwt 143m	2012 20m	3 mill 2 tanks	HFO	50 tons	0 tons
U 864, submarine German (1945)	1640dpl 87,6m	2013 155m	16 mill 8 tanks	Diesel	203 tons	1 tons

Table 1. Wrecks remediation projects, estimated fuel content and actual amount of fuel removed (compiled from NCA data)

As Table 1 shows there have been relatively large variations in the amount of oil that we expected to find as compared with the actual amount we were able to recover. The reasons for this differ. The information we had about the ship before it sank may have been unreliable or wrong. Other wrecks have been found empty, probably due to corrosion of the tanks and resultant leakage of oil over a long period. As of yet we have not found any reliable method to measure oil/water content in the tanks before we have drilled a hole in them.

Figure 2. Blücher was sunk immediately outside Oslo during the German attack on Norway in April 1940. It sank and 1000 tons of heavy fuel oil and diesel was removed in 1994 at a depth of 90 meters (NCA archives).

State of corrosion

The state of corrosion on wrecks has varied from total to almost no corrosion. Some of the hulls have been open or have been so thin that it has been impossible to hot tap them. The difference seems to be linked to ocean currents and to oxygen levels in the water. The corrosion seems to be heaviest in the parts of the ship where oxygen rich currents have been in direct contact with the hull. In areas with low or no currents, and with less oxygen, the state of corrosion is often very low. The NCA has also found that the quality of work and/or the construction method used by the ship builders is important for the condition of the hull and tanks. Metal plates in tanks and hulls tend to be rather intact, with a low degree of corrosion. However they have often opened up along welding seams, or as a result of totally corroded rivets.

Cost, experienced crews

The cost of oil removal has declined during the period that NCA has carried out this type of work (1994 – present). The work requires different kinds of expertise. While the planning and operational leadership are carried out by the NCA, the actual removal of oil has been contracted out. Originally, we used salvage companies, but these companies rarely operate the type of equipment used in these operations. Recently, we have found that using companies and personnel that operate ROV’s daily in subsea operations, has given better and faster results. Together with a private Norwegian company we are trying to develop more universal hot tapping equipment that can be operated from the most common equipment (ROV's) currently being used in the oil and gas industry. Beside the practical issues, NCA has also learned a lot about contracting issues which are important for bringing overall costs down.

Spill preparedness, surveillance during the operation

During oil removal it is important to have necessary spill response equipment available at the site. Aerial surveillance during an operation is important because leakage of oil at great depths may show up at the surface far from the wreck's location. After the oil removal operation relatively small amounts of oil will normally rise to the surface. It is important to monitor this, and be ready to act if necessary. It is nearly impossible to completely empty/offload a wreck from all oil residues. Structures may collapse, and oil will shift location within a wreck after oil and water have been pumped to the surface. Minor leakage may continue for weeks or months. Information about the different World War II oil's weathering properties, viscosity etc. is of great importance when it comes to response strategies to these spills. Until now we have been missing this type of information about oil from wrecks that sank during WWII. The results of the studies NCA contracted to SINTEF have given NCA important information. For practical operational properties of different oils we have tested a mix of the same type of oil from both within and between tanks. It will be included in our database for Oil Weathering Modeling.

Toxicity of different oils on marine organisms.

NCA made a decision to investigate the operational properties and environmental effects of different type of oils from World War II wrecks in Norwegian waters. The work was done by SINTEF (Faksness.2014. draft paper to this conference). The oils studied for toxic effects were from four World War II wrecks; two British wrecks (the frigate *HMS "Bittern"*, and the carrier tanker *RFA "Boardale*") and two German wrecks (the destroyer "*Erich Giese*" and the German cargo ship *MS "Nordvard*"). The oil from the British ships were classic bunker oil (IFO 20-30), the oil from the German *MS Norvard* was a blend of synthetic and natural diesel while *Eric Giese* (German) carried lignite oil (synthesized from lignite or brown coal).

The toxic effects of the different oils were tested as a growth inhibitor on an alga (*Skeletonema Costatum*) and the mortality rate on a copepod (*Calanus Finmarchicus*). The latter being a key species in the arctic eco-system. The results, shown in Figure 3 were surprising and provide important information not previously known by the NCA. The results show that the mortality rate for the copepod, *C. Finmarchicus,* is much higher when exposed to the German oils as compared to the oils from the British ships. Most toxic is the oil made from lignite (Brown coal) taken from *Erich Giese*. For the highest concentration, the copepod died immediately (indicative of the condition just after the release of oil and before any major spreading has occurred). Even with the lower concentration, we see that the test results indicate total mortality after 72 hours when exposed to oil from *Erich Giese*. From the other German ship, *Norvard*, we find a mortality rate of 95% after 96 hours. The British oils show a mortality rate of 20-25 % after 96 hours (Faksness, L.G., 2014).

These results about the highly toxic effect of oil on the marine environment from German ships sunken during World War II have already altered NCA's priority list for oil removal from wrecks. German ships, especially those known to contain petroleum products synthesized from brown coal, will be prioritized with the intention to minimize the overall negative effect on marine organisms.

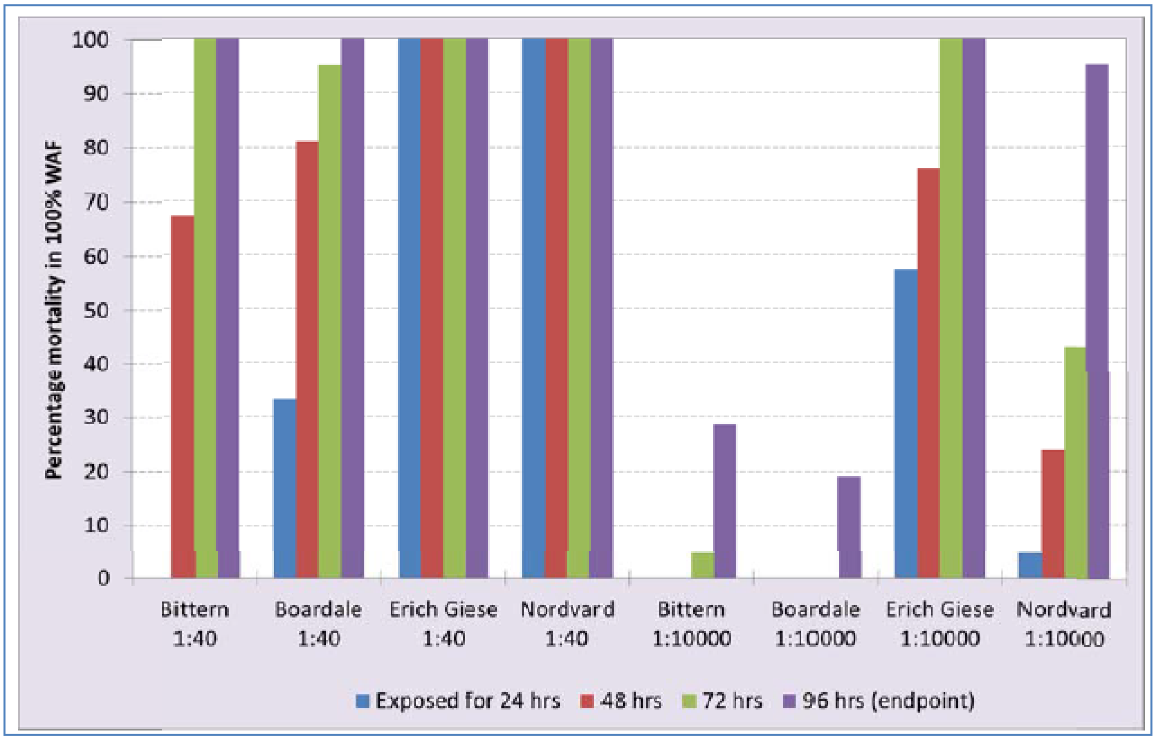

Figure 3. Acute toxicity expressed as percentage effect on the organisms in non – diluted WAF (100%): percentage mortality for C .finmarchicus at 24,48,72 hours and at test endpoint (96 hrs). No bars indicate absence of observed mortality effect on the test organisms. (From SINTEF, 2013)

Operational properties of the oils

NCA is expecting to experience more oil leakage from World War II wrecks in the future. There may be small quantities that leak over a long period or there may be a sudden collapse of tanks that can cause larger oil spills. To be better prepared for the operational handling of oil spills from such wrecks in the future, we needed more information about the properties of the oil. SINTEF was given the job to analyze the oil properties from, *HMS Bittern, RFA Boardale* and *Erich Giese*. They tested emulsifying properties, viscosities of emulsions, dispersibility, oil spreading properties and created oil weathering curves for different temperatures and wind velocity. This data is presented in the SINTEF 2013 report (draft).

These data will be important for deciding what sort of action needs to be taken. For example what sort of dispersant, booms, pumps, etc will work best on the specific type of oil when an unexpected oil leakage occurs from a known wreck. The NCA uses oil weathering model (OWM) that predicts, among other properties, the evaporation rate and natural dispersant rate of different oil products. This is a very important tool when we make decisions about how to handle oil spills. Incorporating World War II oil properties into the OWM database improves NCA's oil spill preparedness significantly. Figure 4 illustrates how the OWM can predict that the highly toxic lignite-based oil will disperse quickly in the sea. After 12 hours, most of the oil will be dissolved, while the remaining (lighter components) will have evaporated. That means that the operational window is very short under these conditions with this type of oil. The British oils are less toxic, and also have a slower rate of evaporating and slower rate of naturally dispersing under the same weather conditions. That gives a larger operational window for an oil spill response.

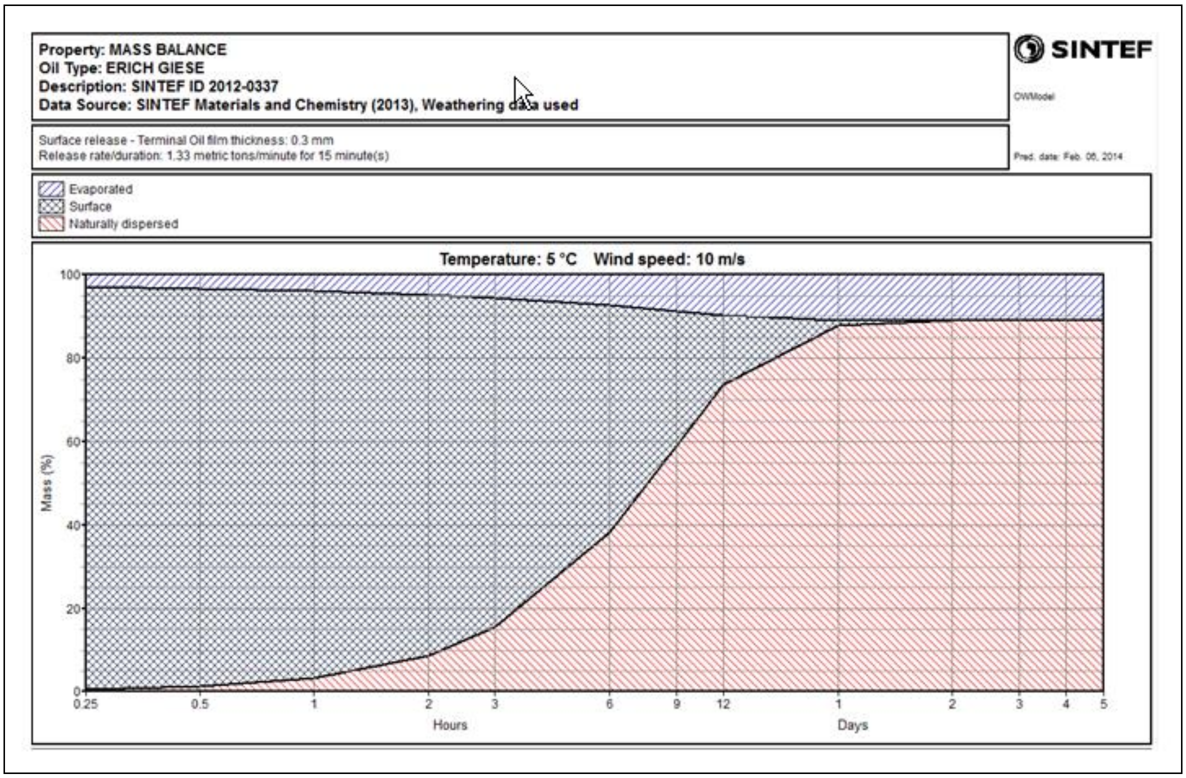

Figure 4. Mass Balance, from German lignite oil – from Erich Giese, predicted at temperature: 5 ^{o}C and wind speed: 10 m/s, at surface (From SINTEF 2013)

SUMMARY AND CONCLUSIONS:

Shipwrecks from World War II are a major problem for many nations around the world. Many of the ships that were sunk during this period contained large amounts of oil. As time goes by, corrosion will lead to small and large oil spills from these ships. At the wrong place, and at the wrong time, they may cause severe damage to the eco system. Since 1994 Norway has worked with a list of 30 prioritized wrecks considered as posing a severe risk to the environment. As of today we have offloaded oil from 8 wrecks, and continually monitor the remaining 22. Lessons learned from this work are incorporated into our monitoring and removal efforts.

New knowledge and technologies continue to affect how we work and they improve the basis for prioritizing which wrecks need to be handled first. Important findings relate to corrosion, oil properties and oil toxicity. The state of corrosion has been found to be strongly affected by ocean currents and oxygen content and workmanship by the shipyard. This makes it hard to predict the actual condition of the ship's hull and tanks. The consequence is that on-site inspections are necessary before an operational plan can be worked out. Knowledge about the properties of oils is important for all types of oil spill response. Properties of oil from World War II shipwrecks have been largely unknown, including the chemical effects of being submerged for 75 years. Properties such as evaporating rate, dispersing rates, pour point, oil film thickness, spreading properties, etc. have been estimated for German and British oils. For example the rapid dispersing rate of German lignite based oil gives a limited window of opportunity for response to an oil spill. Toxicity test carried out on different World War II oils gave us new, unexpected and important information. Extremely high toxicity found in lignite based oil from German shipwrecks has altered the priorities about which wrecks to attend to first. The German lignite oil has a much more severe effect on the marine environment and must be prioritized.

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