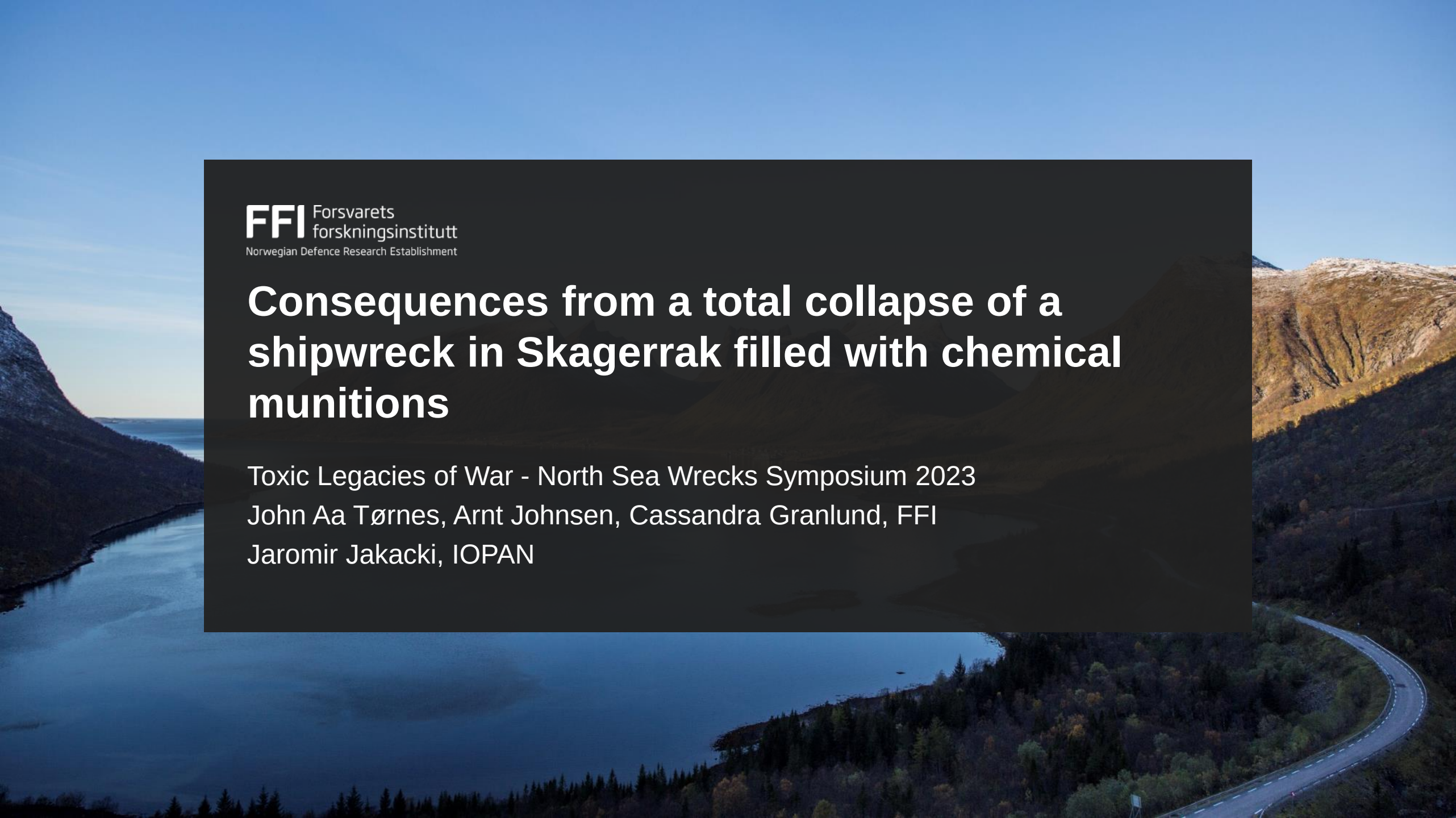

FFI Forsvarets forskningsinstitutt
Norwegian Defence Research Establishment

Consequences from a total collapse of a shipwreck in Skagerrak filled with chemical munitions

Toxic Legacies of War - North Sea Wrecks Symposium 2023

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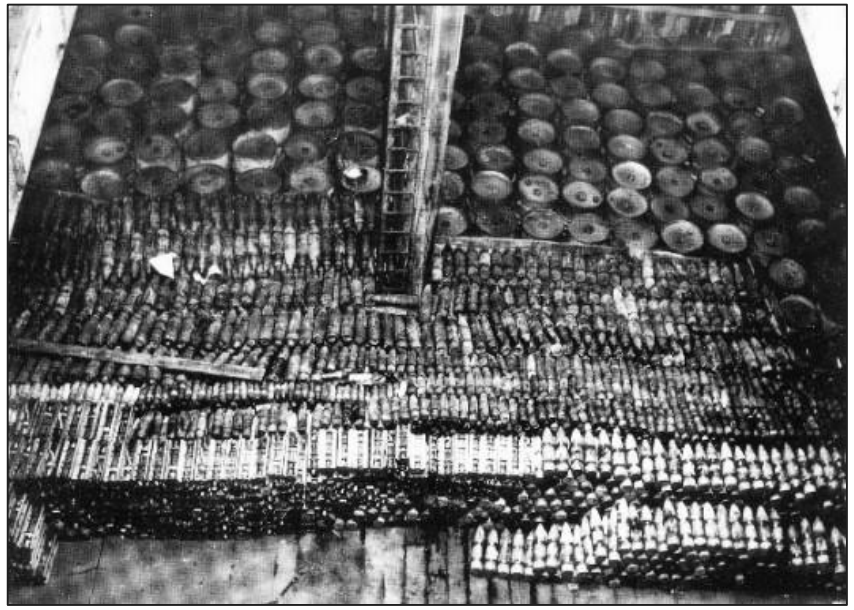
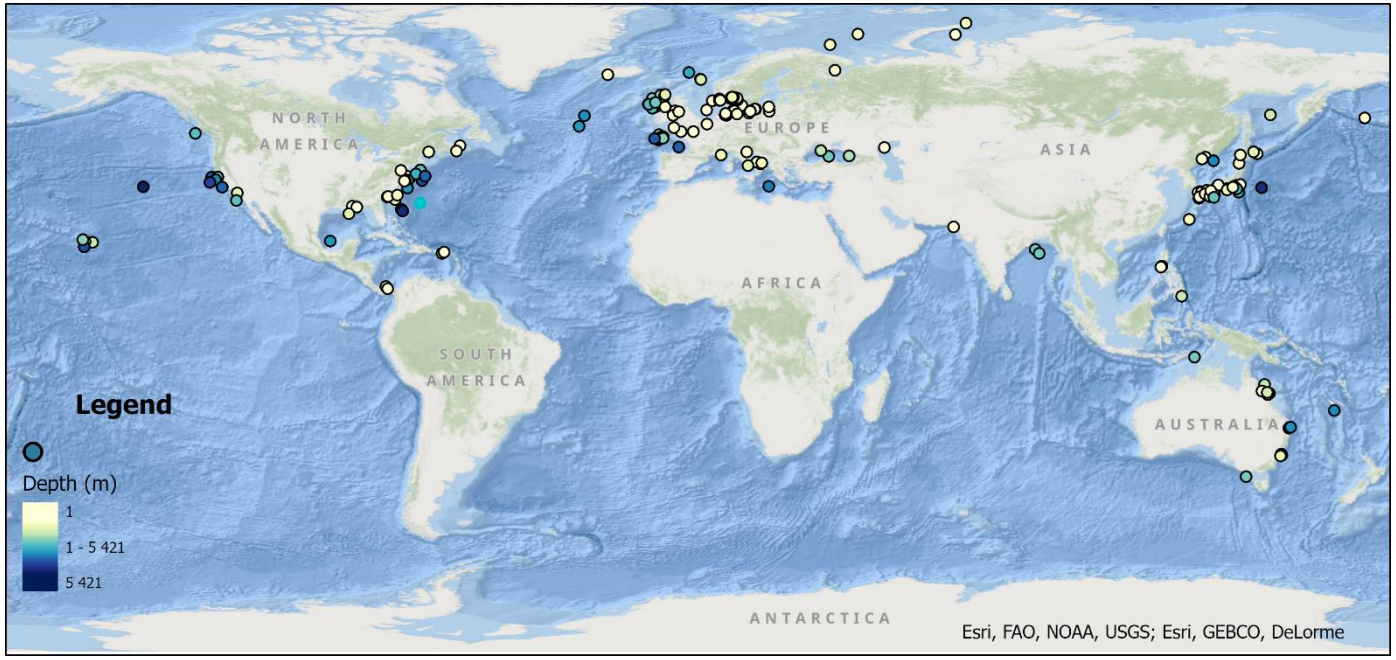
The challenge after World War II



Source: H.L. Arison III (2013)

Large amounts of chemical munitions from several German Army and Air Force munition depots were loaded onto abandoned ships for scuttling at sea when World War II ended

Worldwide there are approximately 150 dumpsites, from very deep water (>1000 m) to shallow water (< 50 m). Most of the German munitions were dumped in Skagerrak and the Baltic Sea

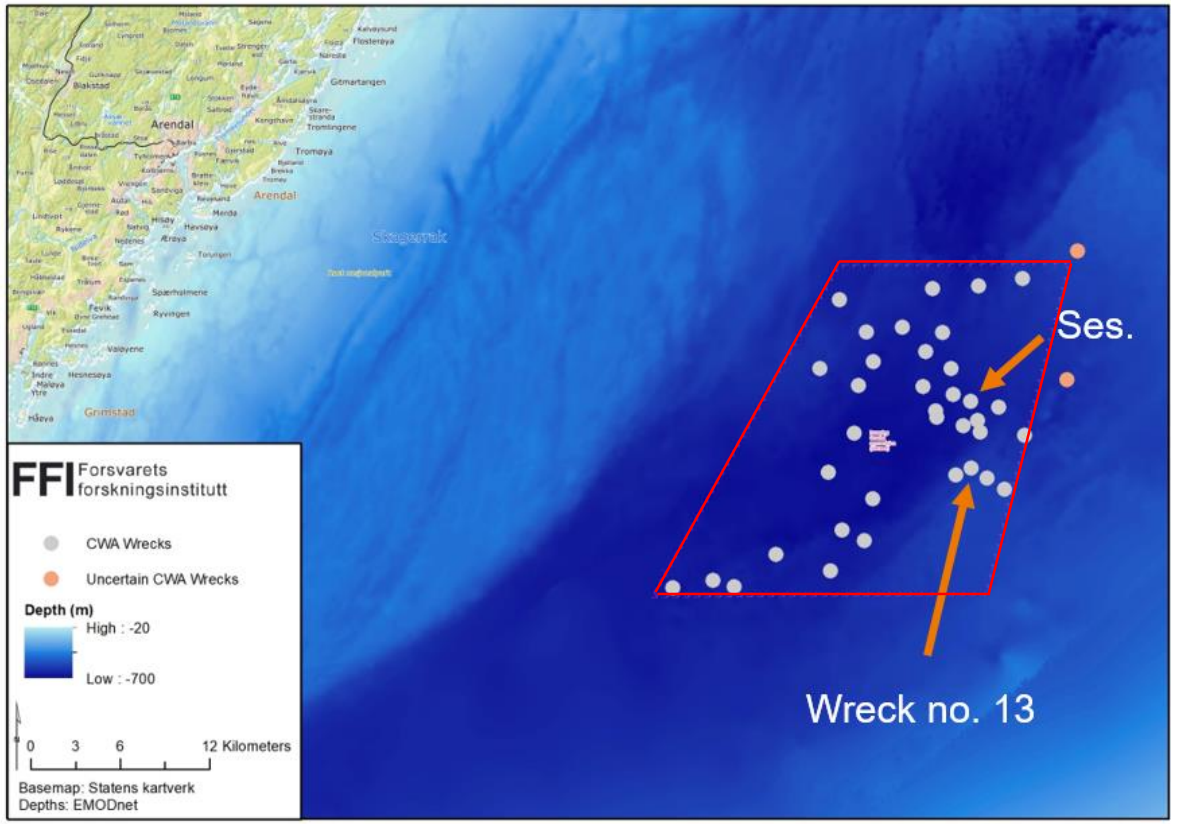


Source: Data from Wilkinson (2017) systemised by North.IO and FFI

Overview of wrecks in the Norwegian part of Skagerrak

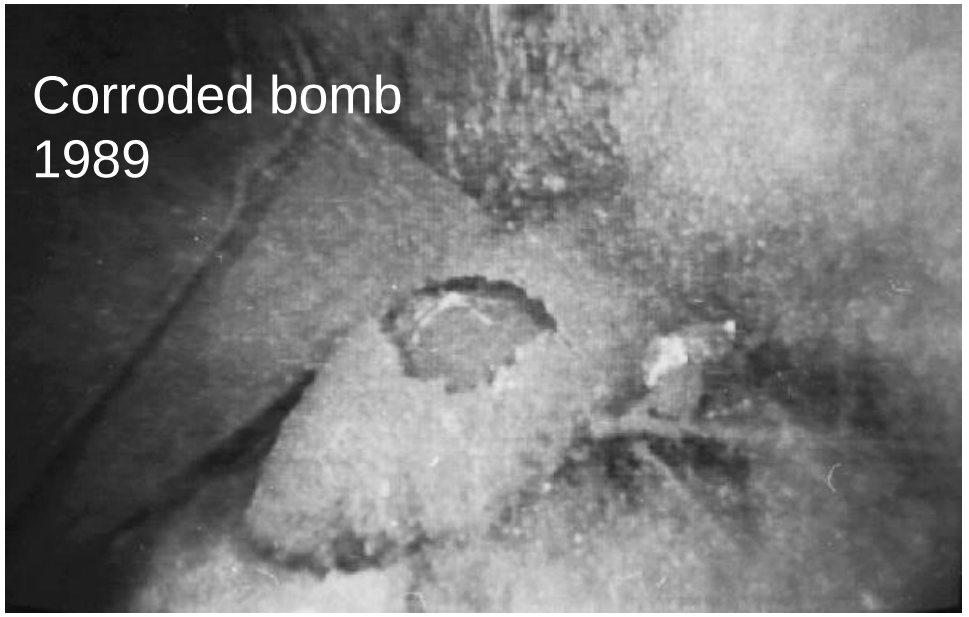
- 36-45 wrecks with 41-48 000 tonnes (net) of CWA were scuttled in Skagerrak in 1945-47
- 36 wrecks classified as possible CW-wrecks have been located by FFIs HUGIN AUV
- Two more possible wrecks were located in 2020 by ship-mounted MBE
- Only one wreck has been identified by name, Sesostris (built in 1918, then Lake Arthur)

Image: www.wrecksite.eu



Red box: Dumping area in Skagerrak (423 km^2) where bottom fishing and anchoring is prohibited

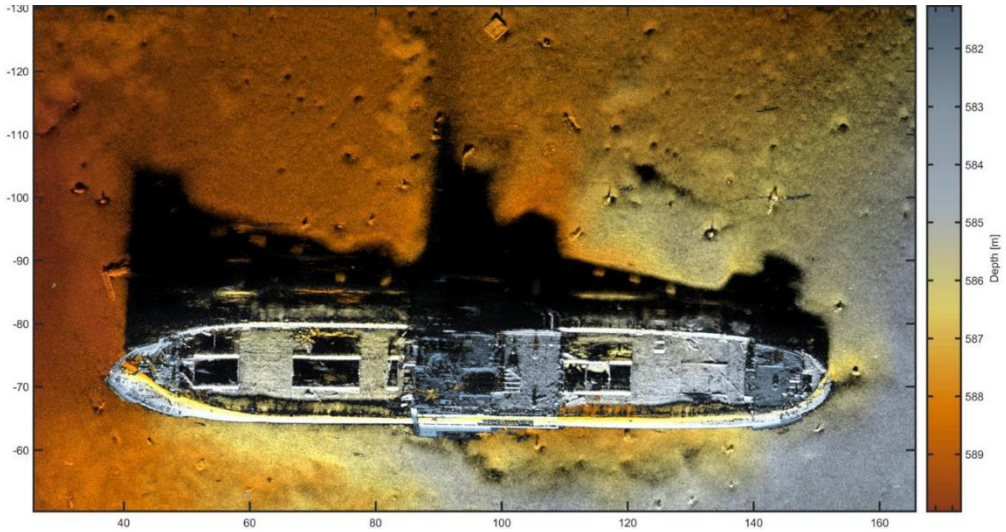
Munitions on the seabed and inside the wrecks



Images: Norwegian Defence Research Establishment, Norwegian Coastal Administration and Spiro Marin

- The wrecks were mainly loaded with sulphur mustard, arsenic containing compounds and tabun
- The chemical munitions found outside the wrecks are heavily corroded and most of the content probably lost, some already in 1989
- The munitions found on the wrecks are better protected against the environment

Conditions of the wrecks

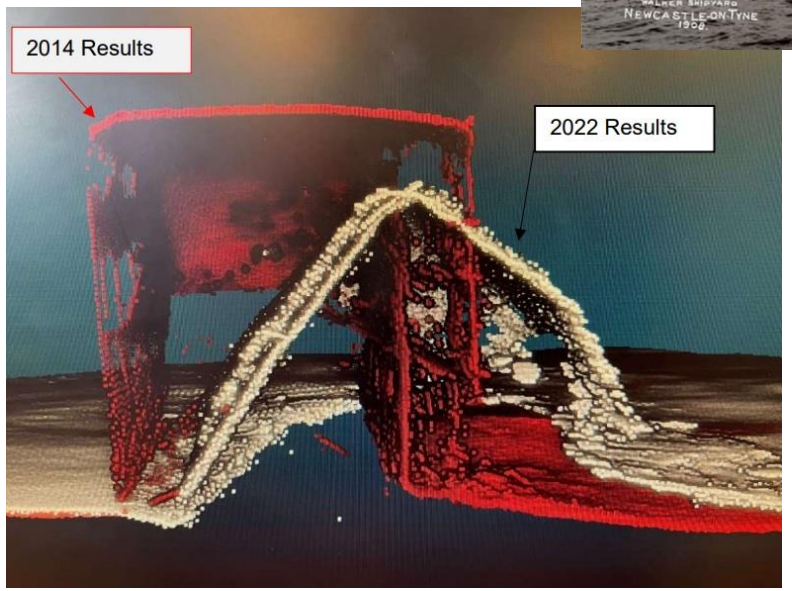


The conditions of the wrecks varies from apparently pristine to broken in several parts, probably at the time of scuttling

SAS Images by HUGIN AUV in 2015, Norwegian Defence Research Establishment

Breakdown of the wrecks – Examples

Oil tanker Derbent on sea trials. © Tyne and Wear Archives and Museums G8008G

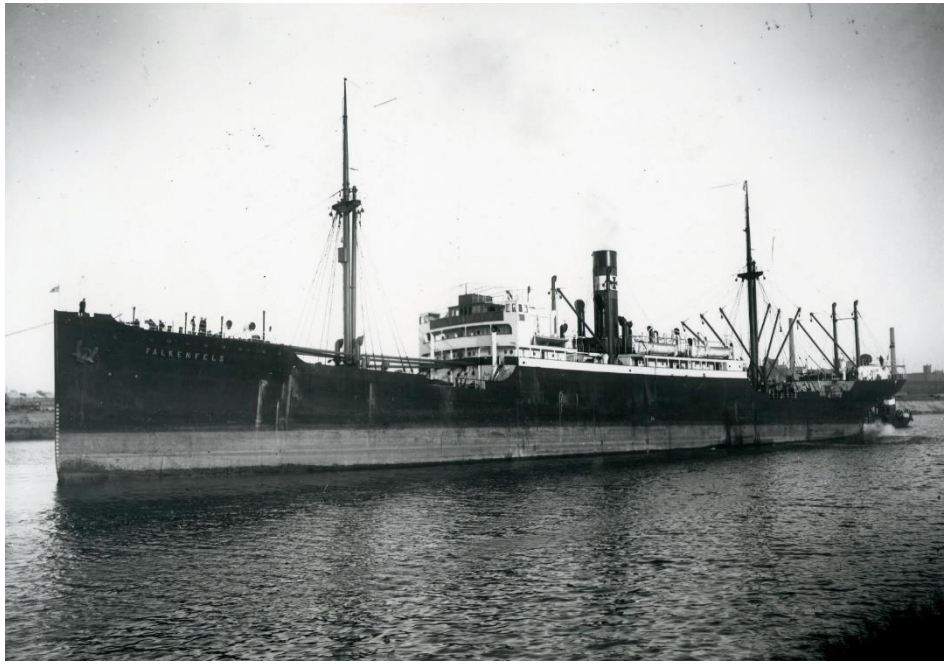


SS Derbent, sunk November 30th 1917 off the Isle of Anglesey, UK
Comparison of 2022 Waves Group Multibeam Echo Sounder (MBES) and 2014 Bangor University MBES. © Crown-owned copyright 2022

MV Lühesand (built 1918) was lost January 19th 1960 between Norway and the Netherlands. Top picture: © German Maritime Museum
Sonar picture below of a wreck found by RNLNavy in 2021 likely to be MV Lühesand. © RNLNavy

A worst case scenario – Total wreck collapse

- The collapse could cause a release of large amounts of chemical warfare agents at the same time
- The wreck with the largest load of chemical munitions in Skagerrak was D/S Falkenfels with 9 000 metric tons of munitions on board
- The type of CWA on board is not known, but is for the simulations assumed to be either sulphur mustard, tabun or Clark I
- The amount of CWA (excluding casings) are assumed to be 2 700 metric tons (30 %)

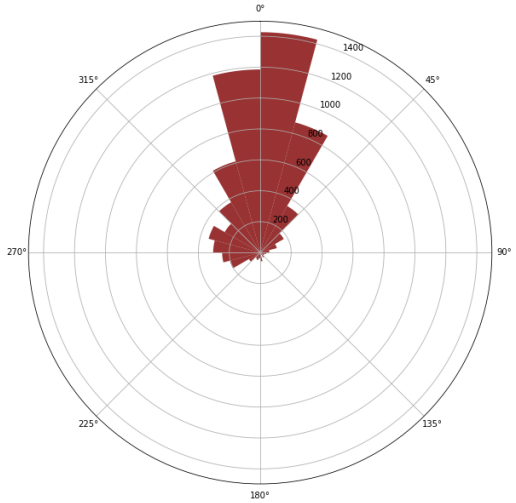


D/S Falkenfels (Image: German Maritime Museum)

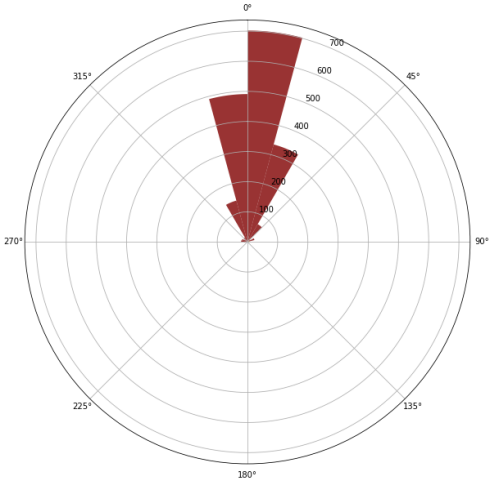
Assumptions used in the simulations

- All the CWA are pure and will leak out to the surrounding water
- The agents have limited solubilities in seawater
- Any movement of bottom particles has been ignored
- The duration of the release will depend on:
  - the duration of the collapse, which is assumed to be fairly quick – hours/days
  - the time to dissolve the agents in sea water, which also depends on the loading conditions and how the wreck collapse
- Bottom currents from marine.copernicus.org are used in the model

CW agent	Solubility in sea water	Density	Half-life
Tabun	98 kg/m^3	1.07 g/cm^3	7.92 hrs @ 15°C
Sulphur mustard	0.6 kg/m^3	1.27 g/cm^3	2.92 hrs @ 5°C
Clark I	0.2 kg/m^3	1.42 g/cm^3	Low (none during model)

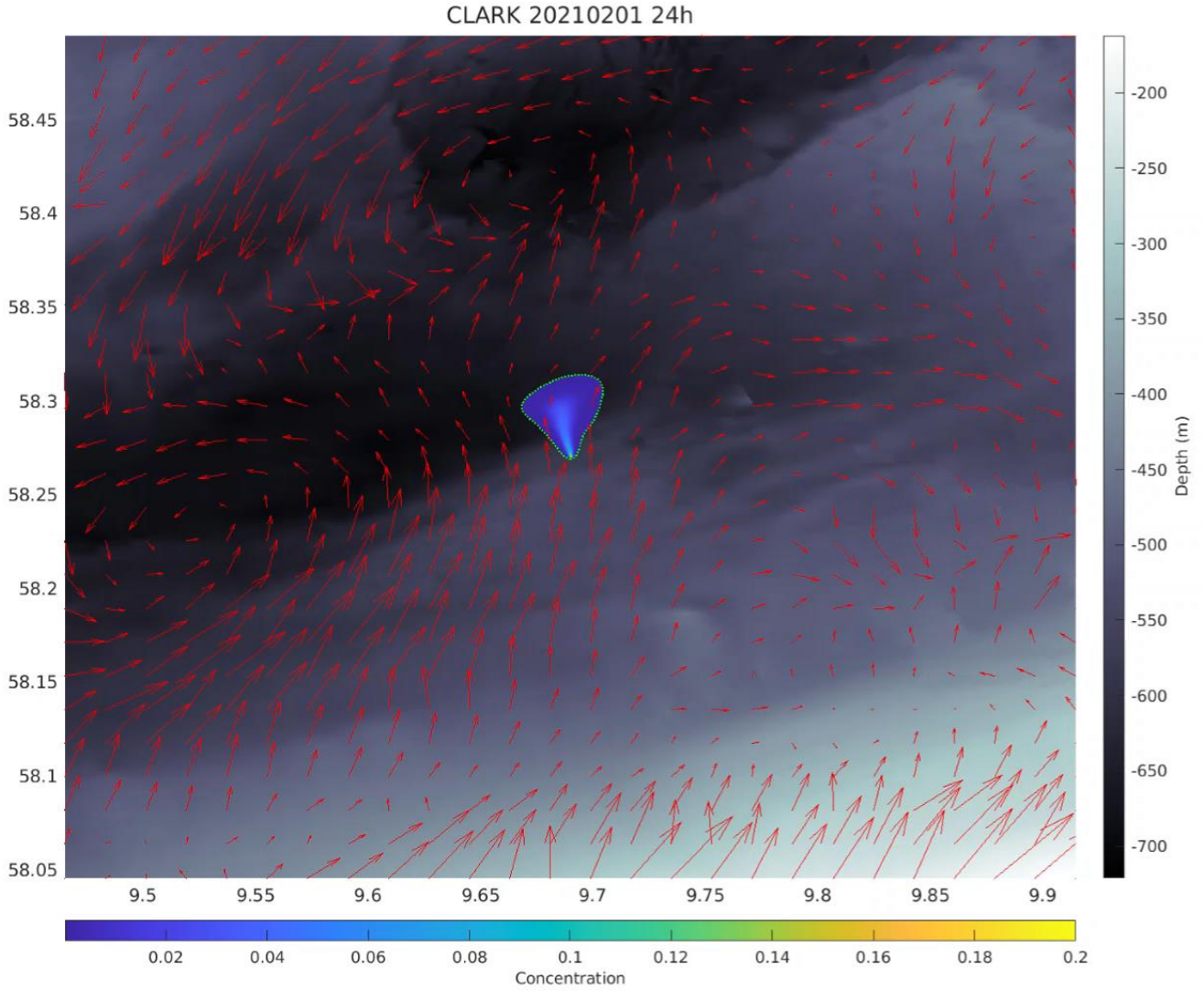


Measured bottom current, Oct-Dec 2022



Measured bottom current > 5 cm/sec, Oct-Dec 2022. Max ~15 cm/sec

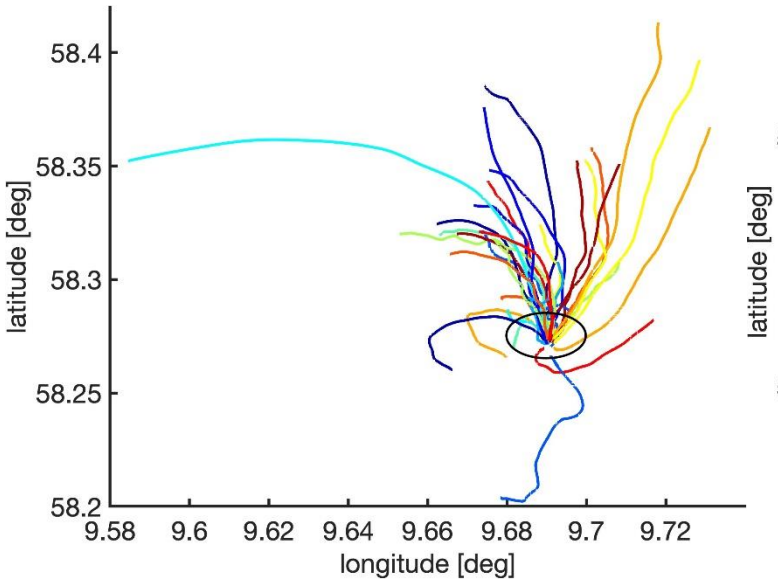
Clark I simulation close to the sea floor

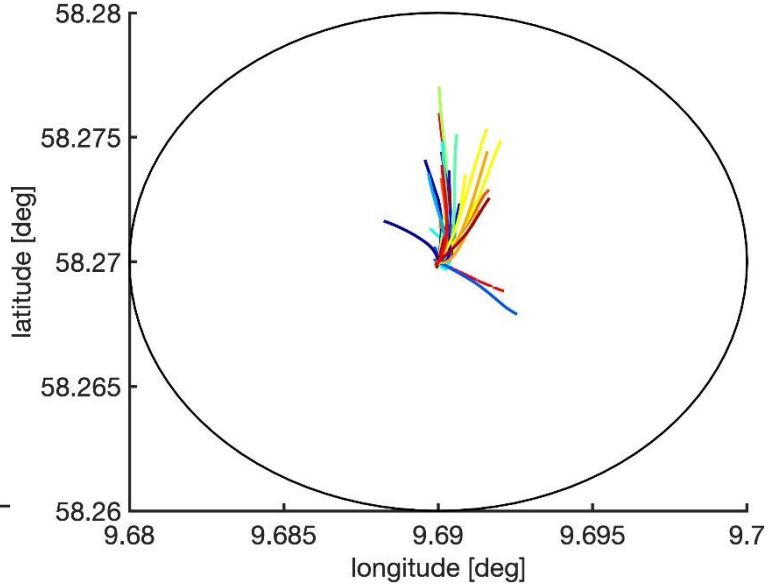


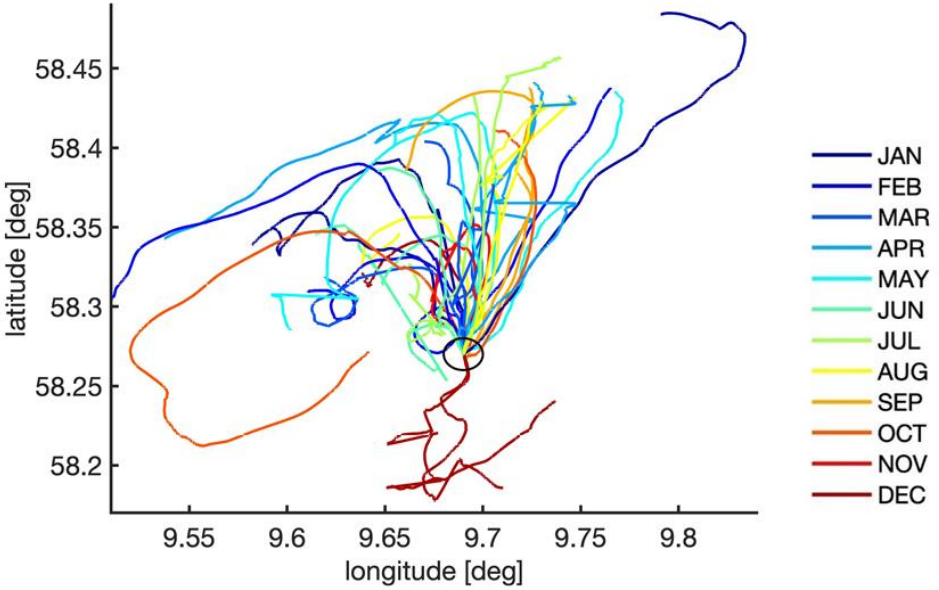
A two-dimensional modelling system called High Resolution Dispersion Model (HRDM) was used to simulate the spread(Jakacki et al. 2020)

Toxicological limit: LC_{50} (fish) = 0.29 mg/L
Outside green line: Concentration below toxicological limit

Simulation results







Tabun:
Maximum distance 16 km
Time to empty: ~ 10 hrs

Sulphur mustard:
Maximum distance 0.78 km
Time to empty: ~20 hrs

Clark I (no decomposition):
Maximum distance 28 km
Time to empty: ~70 hrs

The figures give trajectories of maximum concentrations until the toxicological limits LC_{50} are reached. Each colour represents a simulated release in a given month, repeated in three consecutive years (2019, 2020 and 2021)

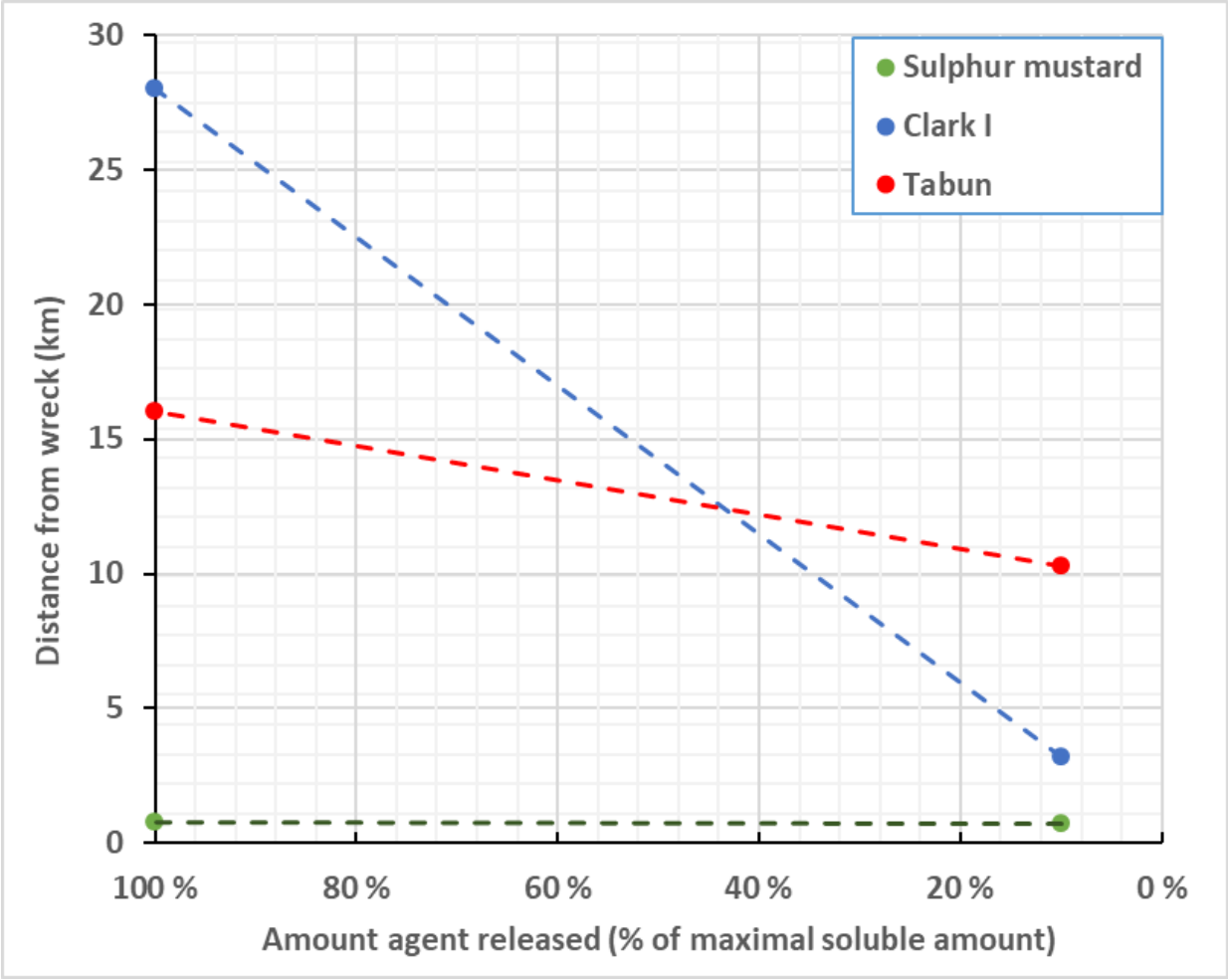
Limitations

- The scenario represents a “Worst-Case” where
  - All agents are pure and not mixed with other compounds
  - All soluble agents are available for spreading (not covered by the wreck, sediments, etc)
  - All soluble agents are immediately transported away from the wreck by advection and diffusion
  - The agents do not settle to the seafloor or bind to the sediments

- All agents are transported away from the wreck in less than three days
  In reality the dense agents like sulphur mustard and Clark I will bind to sediments and stay at the seabed for several years
  - The maximum concentration in the water close to the wreck will be lower
  - The maximum distances before reaching the toxicological limits will be shorter

Distance from wreck until concentrations fall below LC_{50}

- 10 % of the initial amount released from the wreck has been simulated
- For tabun, the maximum distance until LC_{50} was reduced to 10 km
- For Clark I, the maximum distance was reduced to 3.2 km
- For sulphur mustard, the distance is still short
- The simulations give the concentration of soluble agents in the water phase. Settling to sea floor and binding to sediments has not been accounted for



Potential toxicological effect on marine life

- Very little is known about the effects on marine biota from dumped chemical weapons
- The effects could be divided between
  - Effects from water-soluble agents
  - Effects on benthic organisms from agents remaining on the seafloor
- The effects from water-soluble agents on fish in the area will be short-term since the dissolved agents will be diluted fairly rapidly to non-toxic concentrations
- The benthic organisms habiting the area could be chronically exposed, potentially causing chronic toxicity or cumulative effects and adversely affect biodiversity and abundance
- A recent literature review on toxicological data has been published by Joao Barbosa et.al. (Ghent University). Marine Pollution Bulletin 187 (2023) https://doi.org/10.1016/j.marpolbul.2023.114601

Conclusions

- We have simulated the dispersion of soluble agents in sea water close to the bottom after at theoretical collapse of a shipwreck containing 9 000 metric tons of one of CWA (tabun, sulphur mustard or Clark I)
- The time before start of collapse is very difficult to predict – similar wrecks in other parts of the world have already started to fall apart
- The duration of the collapse is assumed to be relatively short (hours/days)
- The maximum theoretical distance from the wreck with concentrations of Clark I above LC_{50} for fish has been estimated to 28 km
- More realistic maximum distances are estimated to 3 km for Clark I and 10 km for tabun for 10 % released compound
- The toxicological effects from water-soluble agents on fish will be short-term
- The benthic organisms habiting area close to the wreck could be chronically exposed and adversely affect biodiversity and abundance.
- Further research is necessary to better understand the effects on deep-water marine life

Acknowledgement

Part of this work has been financed by the Interreg Baltic Sea Region project – DAIMON and Interreg North Sea Region project – North Sea Wrecks