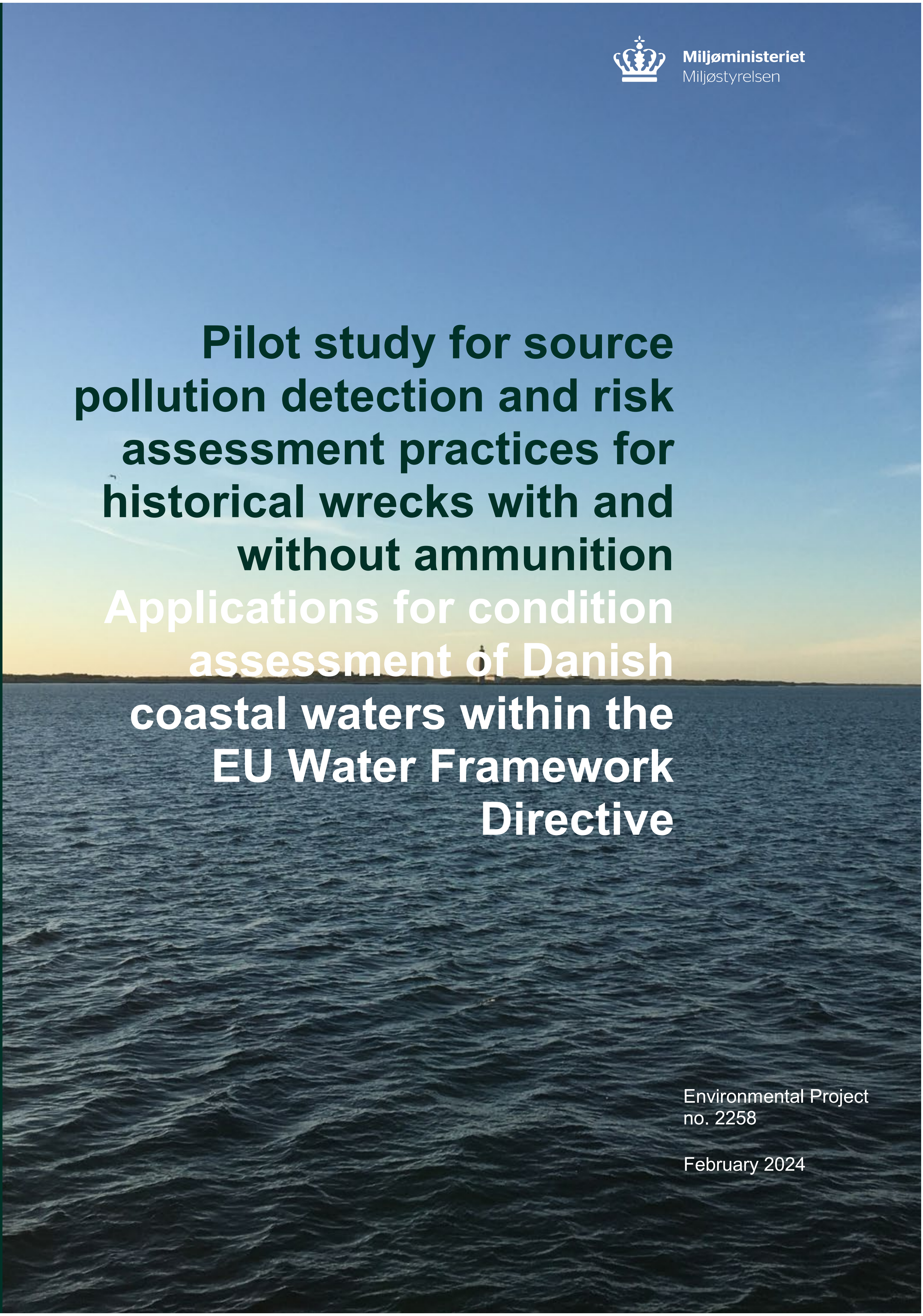

Miljøministeriet
Miljøstyrelsen

Pilot study for source pollution detection and risk assessment practices for historical wrecks with and without ammunition

Applications for condition assessment of Danish coastal waters within the EU Water Framework Directive

Environmental Project no. 2258

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Short summary	Several thousand wrecks occur in the Danish waters. Some of these may pose a risk to the marine and coastal environments if leakage of bunker oil or pollutants from warfare cargo occur. In this pilot project, the purpose is to gather knowledge on how to map wrecks in the Danish waters, and discuss the best approaches for risk assessment of wrecks relative to impact on cumulative effects. It is recommended to add current knowledge of wrecks in the Danish waters to already developed risk assessment tools such as the WRECKNS tool. In such tools, wreck-specific and site-specific information can be added to evaluate the probability of leakage and the effects of leakage, and to guide the integrated decision support system. Furthermore, there is a need for more research on pollution effect distance from wrecks as well as how the risk varies spatially and temporally in the light of climate changes. National collaboration between Danish governmental institutions (agencies, museums, military) and towards private actors should be strengthened as should the transnational collaboration. Hazardous wrecks are a growing global problem that should be remediated and mitigated collectively with widely usable solutions.

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Preface

This report describes the results of a pilot study performed during December 2022. The main aim of the pilot study is to provide information regarding best practice approaches for source pollution detection and risk assessment for historical wrecks with and without ammunition within the Danish territorial waters (i.e., within the 12 nautical mile zone). This is done by evaluating existing literature and approaches related to the topic and by knowledge sharing based on work carried out in the ongoing EU Interreg North Sea Region funded NORTH SEA WRECKS research project (https://northsearegion.eu/nsw/).

Conclusions reached in the study express the opinion of the author.

The pilot study is funded by the Danish Environmental Protection Agency, Ministry of Environment of Denmark.

Summary

In relation to the EU Water Framework Directive, the Danish River Basin Management Plans and the Danish Marine Strategy II, underwater pollution sources as stressors for the marine and coastal environments and the understanding of their cumulative effects have recently gained more attention. The frameworks collectively motivate the Danish government to document, monitor and improve the state of the Danish aquatic environments. For the territorial waters (extending towards the 12 nautical mile boundary), the focus is particularly on a good chemical condition.

The Danish waters host thousands of wrecks from archaeological, historical, and recent time and these wrecks, especially those from the two world wars may represent a point pollution source if leakage of bunker oil or pollutants from warfare cargo occur. However, there is currently only little concrete knowledge about the number of dangerous wrecks in the Danish waters, their specific location, and their state, making risk assessment very uncertain.

The purpose of this pilot project is to carry out a pre-study for mapping and classification of historical wrecks within the Danish territorial waters, prepare an overview of potential pollutants from wrecks, evaluate the best approaches for risk assessment of discrete wrecks, and discuss the cumulative effects from wrecks.

The pre-study shows that mapping and first-hand classification of wrecks can be performed using public available information. Much more information is however likely to exist in restricted access databases currently hold by governmental authorities or private actors.
A selected study area at the west coast of Jutland, covering ca. 900 km^2 and 40 km of the Danish coastline, returned 77 wrecks with 12 of these (ca. 16 %) linked to the two world wars. A total of 4 wrecks (ca. 5%) in the selected study area were classified as having a high significance in terms of potential impact on the chemical conditions, because of a pollution risk related to leakage of pollutants from warfare related cargo (munitions).

To perform a more thorough risk assessment, it is recommended to use already developed risk assessment tools. Such evaluate the risk from wrecks based on wreck-specific and site-specific parameters, the probability of release (caused by an opening of the wreck due to various (human) activities), and the estimated effect of an opening (in terms of the volume of pollutants present on the wreck, such as munitions and bunker oil).

For evaluating the cumulative effects of wrecks, it is important to acquire more knowledge and data on the distance-of-effect as well as how the risk varies spatially and temporally, especially with respect to climate changes. Wrecks should furthermore be treated as a specific stressor in cumulative effect analyses, and if possible, numerical modelling of pollution spreading from wrecks using effect distance and oceanographic and geological parameters should be implemented.

The below specific recommendations can be drawn from the pilot project:
- Wrecks within the 12 nautical mile zone should be mapped using both public and private sources, and information should be uploaded to secure risk assessment tool databases that also have an integrated decision support system, such as the WRECKNS tool. This requires resources but the process can likely be optimized using big data analytics.
- The first-hand classification of the mapped wrecks should focus on whether the wreck holds war-related cargo in the form of conventional munitions or chemical warfare agents (CWAs),

since explosive compounds together with CWA and bunker oil represent the main pollution risk from wrecks.

- The more detailed risk assessment should include wreck-specific (e.g., year of wreckage and cargo at time of wreckage) and site-specific (e.g., sedimentation processes at the seafloor and physical properties of the water column) parameters as well as human and natural activities that influence the opening of the wreck.
- National collaboration between the Danish governmental institutions (agencies, museums, military) and towards private actors should be strengthened to activate all the current information about wrecks in the Danish waters.
- Transnational collaboration should also be strengthened since specific wreck information may reside in foreign historical archive (e.g., German archives) and because hazardous wrecks are a global problem that should be remediated and mitigated collectively with widely usable solutions.

Dansk resumé

I forbindelse med EU's vandrammedirektiv, de danske vandområdeplaner og Havstrategi II, har forurening fra punktkiler under vand på det seneste fået større opmærksomhed. De givne rammer motiverer de danske myndigheder til at dokumentere, overvåge og forbedre tilstanden i det danske vandmiljø. For territorialfarvandet, der strækker sig ud til 12 sømil-grænsen, er fokus især på at opnå og opretholde en god kemisk tilstand.

De danske farvande huser tusindvis af vrag fra arkæologisk, historisk og nyere tid. Disse vrag, og især vrag der stammer fra de to verdenskrige, kan repræsentere en tiltagende punktforureningskilde, f.eks. i forbindelse med lækage fra olietanke eller fra farlig last såsom ammunition. Der er dog i øjeblikket kun lidt konkret viden om antallet og placeringen af farlige vrag i de danske farvande og om sådanne vrags tilstand, hvilket gør den samlede risikovurdering meget usikker.

Formålet med dette pilotprojekt er at indsamle viden om kildeopsporing for historiske vrag med og uden ammunition. Dette gøres ved at gennemføre et forstudie til kortlægning og klassificering af historiske vrag inden for det danske søterritorium, udarbejde en oversigt over potentiel forurening fra vrag, vurdere de bedste tilgange til risikovurdering af diskrete vrag og diskutere hvordan vrag potentielt kan bidrage til kumulative effekter i vandmiljøet.

Forstudiet viser at kortlægning og førstehåndsklassificering af vrag kan udføres ved hjælp af offentligt tilgængelig information. Der forefindes dog sandsynligvis yderligere relevant information om vrag i Danmark hos visse offentlige instanser og private aktører, men denne information er der i øjeblikket kun begrænset adgang til.
For et udvalgt undersøgelsesområde ved den jyske vestkyst, som dækker ca. 900 km2 og strækker sig over ca. 40 km af den danske kystlinje, viste forstudiet at der var 77 vrag, hvoraf 12 (ca. 16 %) havde tilknytning til de to verdenskrige. I alt 4 vrag (ca. 5 %) i det udvalgte undersøgelsesområde blev klassificeret som værende af stor betydning med hensyn til potentiel påvirkning af de kemiske forhold på grund af en forureningsrisiko relateret til lækage fra krigsrelateret last (ammunition).

For at udføre en mere grundig risikovurdering anbefales det at bruge allerede udviklede risikovurderingsværktøjer. Sådanne værktøjer evaluerer typisk risikoen fra vrag baseret på vrag- og stedspecifikke parametre, sandsynligheden for udslip (forårsaget af en åbning af vraget på grund af forskellige (menneskelige) aktiviteter) og den estimerede effekt af en åbning (i forhold til mængden af forurening (eks. fra ammunition og olie) der vurderes at være til stede på vraget.

For at vurdere de kumulative effekter af vrag er det vigtigt at der opnås mere viden og data om effektdistancen samt hvordan risikoen varierer rumligt og tidsmæssigt – ikke mindst set i lyset af de igangværende klimaforandringer. Vrag bør desuden behandles som en specifik presfaktor når de kumulative effekter skal analyseres, og om muligt bør numerisk modellering af forureningsspredningen fra vrag ved brug af effektdistance og oceanografiske og geologiske parametre implementeres.

Nedenstående specifikke anbefalinger kan udledes på baggrund af pilotprojektet:

- Der bør foretages en fuld kortlægning af vrag inden for 12 sømil-grænsen ved hjælp af både offentlig tilgængelige og private kilder. Informationen vedrørende specifikke vrag bør desuden uploades til allerede udviklede og sikre risikovurderingsværktøjer og databaser, der også tilbyder løsninger som kan understøtte en videns- og datadreven beslutningsproces (f.eks.

WRECKNS værktøjet). Dette kræver ressourcer, men processen kan sandsynligvis optimeres ved hjælp af big data analysemetoder.

- Førstehåndsklassificeringen af de kortlagte vrag bør fokusere på om vraget indeholder en krigsrelateret last i form af enten konventionel ammunition eller kemiske krigsførelsesmidler (CWA'er), da eksplosive materialer sammen med CWA'er og olie udgør den største forureningsrisiko fra vrag.
- En mere detaljeret risikovurdering bør omfatte vragspecifikke (f.eks. årstal for forlis samt last på forlistidspunktet) og stedspecifikke (f.eks. sedimentationsprocesser på havbunden omkring vraget og fysiske egenskaber af vandsøjlen) parametre, samt menneskelige og naturlige aktiviteter, der kan medvirke til en åbning (lækage) af vraget.
- Det nationale samarbejde mellem danske institutioner (myndigheder, styrelser, museer og militær) og med private aktører bør styrkes for at aktivere hele den aktuelle informationsmængde, der forefindes om vrag i de danske farvande.
- Det tværnationale samarbejde bør også styrkes, da relevant og specifik information om visse vrag kan være tilgængelig i andre lande (f.eks. tyske historiske arkiver). Yderligere udgør farlige vrag et globalt problem, der bør afhjælpes og afbødes i fællesskab via udvikling af bredt anvendelige løsninger.

1. Introduction

1.1 Background

The EU Marine Strategy Framework Directive from 2008 [Havstrategirammedirektivet] obliges the member states to develop strategies for the marine areas within their economic exclusive zone (EEZ). Such a strategy must ensure that a good environmental status in the marine ecosystem is achieved and maintained, while at the same time, enable a sustainable use of the marine resources.

In Denmark, the first Marine Strategy Act was adopted in 2010, followed by the first Marine Strategy from 2012 to 2018. The second Marine Strategy [Havstrategi II] runs from 2018 to 2024. Each strategy comprises a baseline analysis, a monitoring program, and a programme of measures. For the current marine strategy, 11 descriptors (topics/factors) describe significant characteristics of impacts on the sea and its status [tilstand]. Together, the descriptors provide a holistic assessment of the status of the marine environment.

In addition to the Marine Strategy Framework, the EU Water Framework Directive from 2000, which is transposed into Danish legislation by the Water Planning Act [Lov om vandplanlægning], and the specific Danish initiatives following this directive, have led to the development of river basin management plans (RBMPs) [vandområdeplaner]. These plans inform authorities and the public about the plans to improve the state of the Danish water environment, accounting for water in lakes and streams, groundwater and coastal waters including the territorial waters (with regard to chemical status) to the 12 nautical mile boundary. In principle, the RBMPs also aim to ensure a clean environment for the wider Danish marine waters.
Together, the marine strategy and the RBMPs provide a framework for the Danish authorities and it is within this framework the current pilot project sits.

The environmental status of the territorial waters (i.e. the marine and coastal waters within the 12 nautical mile boundary, cf. definitions in Miljøstyrelsen (2001)) is by nature rather complex to assess, because of the influence by several adjacent environments: - the terrestrial, the fluvial, the atmospheric and the marine environments (e.g. Tørslev & Rasmussen, 2020). Furthermore, since the coastal zone is one of humanity's most valuable assets, there is a variety of human activities (e.g., industry, shipping, fishery, tourisms, and recreation) taking place within these waters and this increases the exposure to and the number of various pollutants.

Pollution within the territorial waters originates from both point and diffuse sources, with point pollution sources (e.g., Andersen et al., 2017b; Tørslev & Rasmussen, 2020) including offshore infrastructure of various kind (e.g. oil and gas platforms), marine sediment dumping sites [klappladser], marine aquaculture, dumped ammunition, and wrecks. This pilot project focus on the potential pollution from wrecks as point pollution sources.

While dumped ammunition has been the target for more investigations and research projects (e.g. DAIMON and DAIMON 2), wrecks have only to a small degree been specifically addressed as point-pollution sources (e.g. NORTH SEA WRECKS; Monfils, 2005; Monfils et al., 2006; Maser et al., 2023). This is problematic since historical wrecks, and in particularly wrecks from the two world wars may pose a further risk due to their potentially dangerous war-related cargo. It thus remains uncertain which pollutants (including priority substances and river basin specific substances) [MFS - Miljøfarlige Forurenende Stoffer]) are to be expected from wrecks and how wrecks may contribute to the cumulative environmental risk. Recently the European Commission recommended that assessment of risks from historical wrecks and dumped ammunition should be carried out in the member states along with an evaluation of how to handle such risks. Together with the Baltic Sea HELCOM strategy (HELCOM, 2021) and the Danish strategy for environmentally hazardous substances (Miljøministeriet, 2021) this inspires authorities to initiate research on these topics.

For the Danish waters (including the North Sea, the Baltic Sea and the inner Danish waters), it is estimated that currently more than 10,000 ship, submarine and aircraft wrecks rest at the seafloor (e.g., Slots- og Kulturstyrelsen, 2022), with many of these wrecks originating from World War I (WWI) and World War II (WWII) (e.g., Fig. 1). The war-related wrecks may, in addition to bunker oil and fuel, oil-residues and other specific cargo, contain large quantities of conventional and chemical warfare munitions, hence posing an elevated threat towards people, the marine environment and blue growth operations. There is, however, a general lack of knowledge about the precise number and location of historical wrecks and about the composition of the potentially pollutants from such. All are necessary to understand before assessment of the real source of pollution from sunken historical wrecks, both with and without ammunition, can be completed.

Work towards assessing the risks from munitions in the sea and wrecks is ongoing - both in terms of specific research projects carried out in particularly the Baltic Sea region but also in the North Sea (e.g. DAIMON and DAIMON 2, NORTH SEA WRECKS, CHEMSEA, MODUM), and via the international organisations HELCOM, OSPAR and AmuCad. Denmark has only participated in this work to a limited extent and there is currently only a fragmented effort towards the subject of wrecks and underwater munitions at national level. Munitions in the sea and wrecks require a collaborative and joint (mitigation) strategy across the Baltic Sea and the North Sea. To enter such collaboration, it is relevant that the current state of the Danish waters regarding wrecks and underwater munitions is clarified.

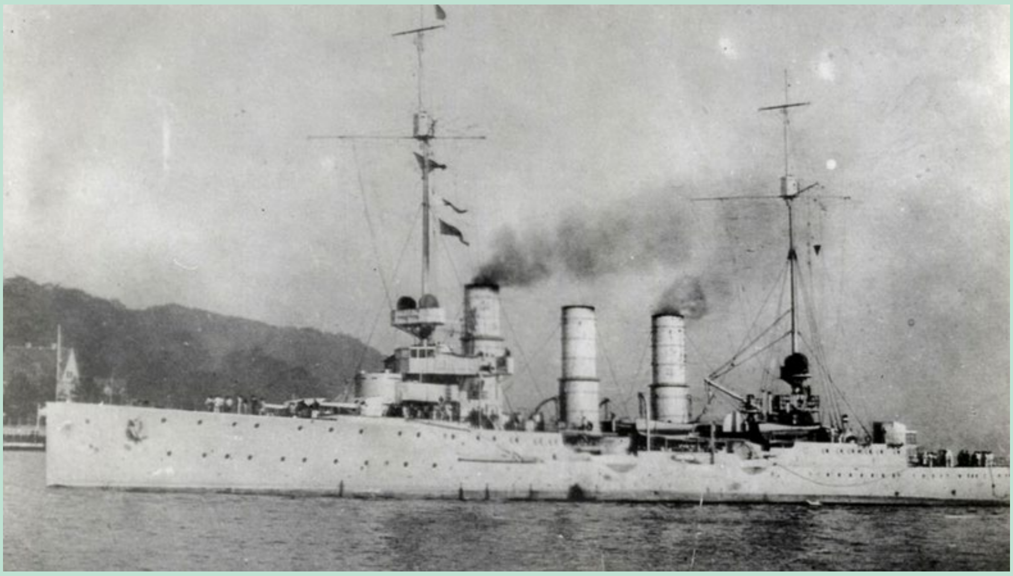


FIGURE 1. German Light Cruiser SMS ELBING that sunk during the Battle of Jutland in WWI in 1917. The wreck resides on the seafloor in the Danish EEZ. Source: Photo Archive, German Maritime Museum.

1.2 Purpose of pilot study

The purpose of this pilot project is to build knowledge for the location and number of historical wrecks, and the risks from these within the Danish territorial waters (waters within the 12 nautical miles zone where a good chemical condition according to the EU Water Framework Directive must adhere (Miljøstyrelsen, 2001)). Additionally, the pilot project aims to assess the cumulative effects from such wrecks and further recommend the best method for risk assessment by identifying possible pollutants, reviewing the literature, and sharing knowledge gained from ongoing research projects (e.g., NORTH SEA WRECKS).

The pilot project specifically has the following objectives:

- Carry out a pre-study for mapping and classification of relevant historical wrecks with and without ammunition, in the area within the 12 nautical miles boundary.
    - Demonstrate how to screen for number and location of wrecks.
    - Demonstrate how to classify wrecks into types in relation to significance for risk.
- Prepare a list of possible pollutants related to historical wrecks including both EU prioritised substances and national specific substances.
- Assess how pollution from wrecks may impact and contribute to the cumulative effects for the relevant waters.
- Assess methods used for designating potential hotspot areas that requires special focus.
- Recommend best available methods for risk assessment of wrecks.

1.3 Methods

The methods used in the pilot study include screening for wrecks via public available databases, literature review, and knowledge sharing.

The pre-study for the wreck screening was carried out in a smaller area along the west coast of Jutland. First, it was tested how much information regarding the specific location of wrecks and their potentially dangerous cargo, could be extracted from public available data including wreck databases. Secondly, it was tested how a classification scheme of the wrecks, based on this type of information could be constructed in a meaningful way. The list of possible pollutants from the wrecks was prepared based on a review of existing literature. Similarly, the evaluation of cumulative effects also relied on literature review. Finally, for the best practice recommendation for risk assessment and hotspot definition, recent results from the DAIMON and NORTH SEA WRECKS projects have been incorporated.

2. Pre-study for mapping and classification of relevant historical wrecks with and without ammunition

2.1 Introduction

One of the most critical elements related to risks from historical wrecks, is the lack of knowledge concerning the number of wrecks, their precise location, and their potentially dangerous cargo. There is additionally a high uncertainty about the state of the wrecks in terms of potential leakage and degradation of the dangerous cargo.

This chapter describes a simple approach usable for mapping the number and location of historical wrecks within the Danish territorial waters together with a first-hand classification regarding importance of the mapped wrecks when it comes to impacts on the chemical conditions. The approach is exemplified and illustrated by performing a screening for wrecks within a limited area of the Danish territorial water. The selected study area is located at the western coast of Jutland, near the city of Esbjerg and Blåvandshuk, extending into the Horns Reef in the Danish North Sea (Fig. 2). The area stretches towards the 12 nautical mile boundary and covers in total ca. 905 km2 and ca. 40 km along the coastline.

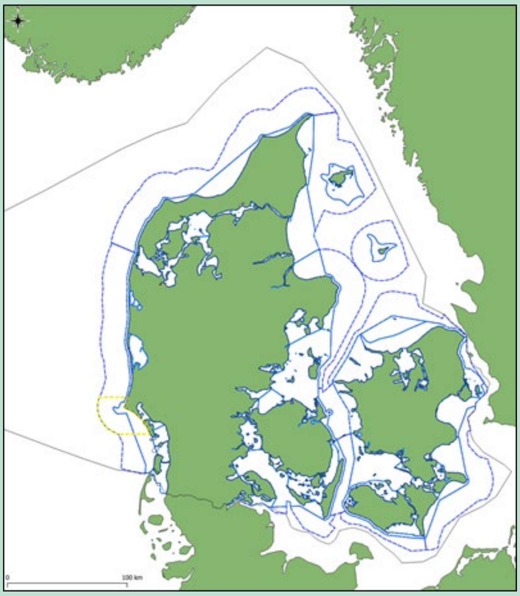


FIGURE 2. Selected study area (yellow dashed polygon) for wreck screening. The blue (dashed and solid) lines show respectively the 12 nautical mile zone and the 1 nautical mile zone (MiljøGIS, 2022).

2.2 Approach for mapping wrecks within the 12 nautical miles zone

When screening for the number and location of wrecks, it is relevant to differ between public available sources of information and restricted-access sources. For this pilot study, as illustrated with the example below, only public available sources have been used.

A much more comprehensive list of wrecks, their precise position and information of their cargo and current state, is likely to exist in in-house databases of relevant public authorities and museums, and the military such as the Environmental Protection Agency [Miljøstyrelsen], the Agency for Culture and Palaces [Slots & Kulturstyrelsen], and the Royal Danish Navy Mine Clearance Unit [Søværnets Dykkertjeneste]. These are restricted-access sources and hence not directly available for the pilot project.

The most comprehensive public available map-based database for wrecks in Denmark can be found at https://www.kulturarv.dk/fundogfortidsminder/ (*Fund og fortidsminder* platform). This database has a record of all cultural heritage objects in Denmark, both at land and at sea and further provides good search and filter options either via lists or maps. The database is maintained by the Agency for Culture and Palaces and should therefore provide a trustable source of information.

Several other privately driven wreck databases (both list- and map-based) exist and can be accessed freely from the internet. For those voluntarily driven by sports divers (e.g., vragguiden.dk), the precision and quality of data may vary depending on the quality of the user-input. The private museum Sea War Museum Jutland has an extensive record of relevant information including wreck positions, geophysical wrecks scans (multibeam echosounder data) and historical documents that can at least partly, be accessed from the museum's website. More survey companies also share information of mapped wrecks to the public (e.g., Sensor Survey).

Naval charts published by the Danish Hydrographic Office within the Danish Geodata Agency, provide another trustable source of information for the location of certain wrecks (e.g. Fig. 3). Similarly, the EU Commission's EMODnet Bathymetry platform provides information of wrecks across the EU. On the global scale there is also the partly user-paid/subscription-based platform wrecksite.eu (Fig. 4).

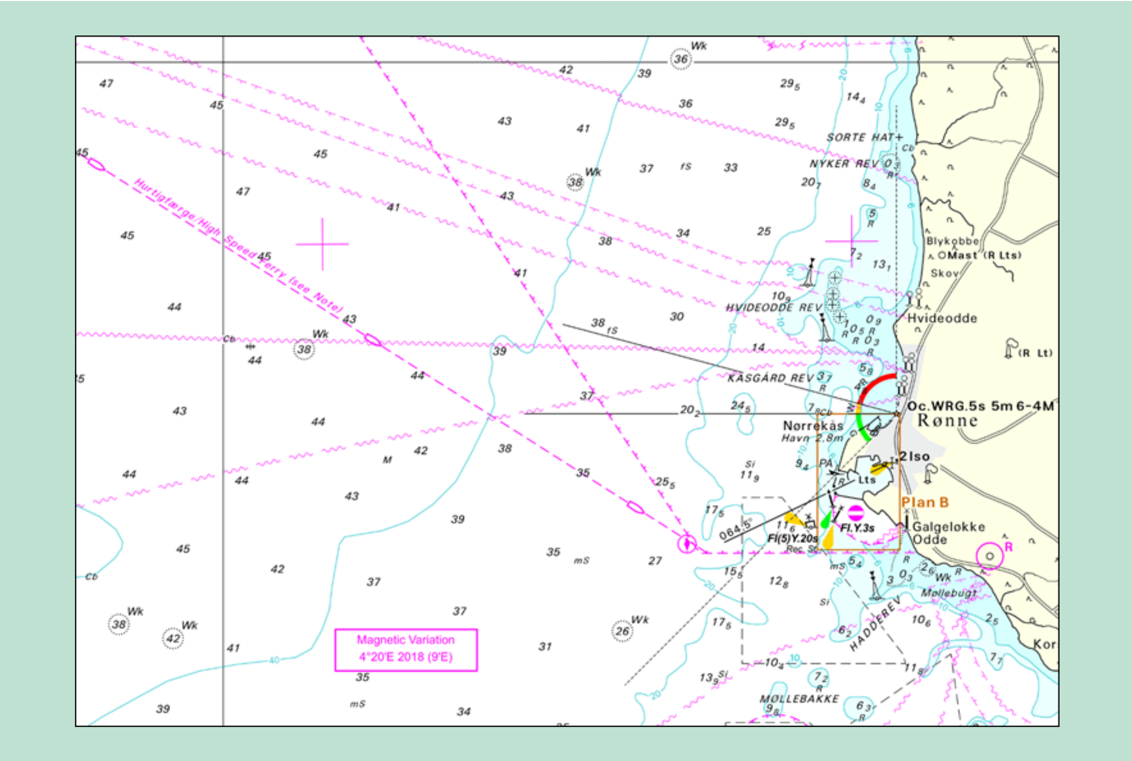


FIGURE 3. Excerpt of naval chart at Bornholm with indications of several wrecks (Wk).

For all databases, the specific position of the wrecks may be enclosed in various formats and be more or less precise and/or correct. The search and filter functionality of the databases are also highly variable making it relatively difficult to find the relevant information in some cases. In addition, all databases may suffer from incomplete/outdated records; and it should also be considered that all wrecks are likely not located/found yet. The number of wrecks that can be extracted from the available databases may thus underestimate the actual number of wrecks in the Danish waters.

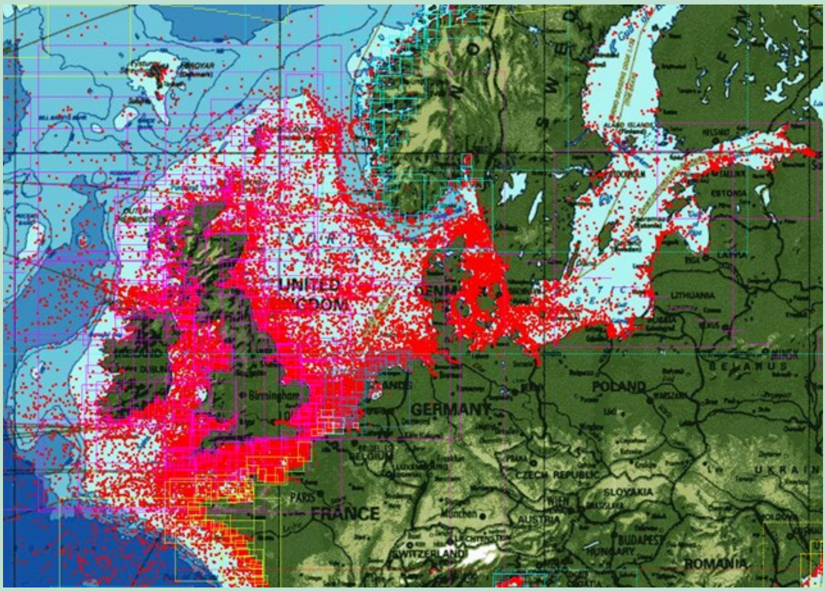


FIGURE 4. Screen-dump from the map service at wrecksite.eu [accessed 21 December 2022] showing the position of wrecks (red dots) in the northern European waters. For Denmark, Kattegat and the Danish straits appear highly populated with wrecks.

2.3 Exemplified wreck screening in selected study area

In this section, the approach for mapping wrecks in the Danish waters are exemplified by performing a wreck screening in the selected study area (Fig. 2). The main database used is the *Fund og Fortidsminder* platform, with secondary mapping using the alternative *vragguiden.dk* platform and *naval charts* for comparison.

By searching the *Fund og Fortidsminder* platform it is possibly to download a list (ESRI-shape or .csv file format) of cultural heritage objects within the Danish waters (filter by 'Water areas' [Farvandsområder]). This list contains for each object an attribute table with 18 parameters (Table 1). The list comprises a total of 14083 objects, of which 10127 (72 %) is categorized as wrecks [Vrag] (Fig. 5) and 236 (1.7 %) as wreck-remains [Vragdel] (Fig. 6) when filtering by the 'Object type name' [anlaegsbetydning] attribute.

TABLE 1. Overview of available attributes in the *Fund og fortidsminder* databse.

Attribute name	Description
systemnr	Number of object within the database
stednr	Number of place
loknr	Number of locality (site)
sbext	Unknown
frednr	Number of protection (relevant for protected [fredede] objects only)
stednavn	Name of place
stednavnsb	Categorized place (e.g., 'buildings, ports and industrial facilities' [Byggeri, havne og industrianlæg], 'water areas' [Farvandsområder], and 'unspecified')
anlnr	Number of general object type (range from 1-7)
anlaegstype	Number of object type
anlaegsbetydning	Name of object type (e.g. 'wrecks' [Vrag] and 'wreck remain' [Vragdel]
dateringskilde	Source of dating (10 varying sources)
datering	Dating of object (categorized into 10 periods: [Stenalder, Bronzealder, Jernalder, Vikingetid, Middelalder, Efterreformatorisk tid, Nyere tid, Oldtid, Historisk tid, udateret])
fra_aar	Start of absolute age range
til_aar	End of absolute age range
kommunenavn	Name of municipality (only relevant for objects on land)
kommunenr	Number of municipality (only relevant for objects on land)
sevaerdighed	Tourist attraction (only relevant for objects on land)
url	Link to further description of the specific object

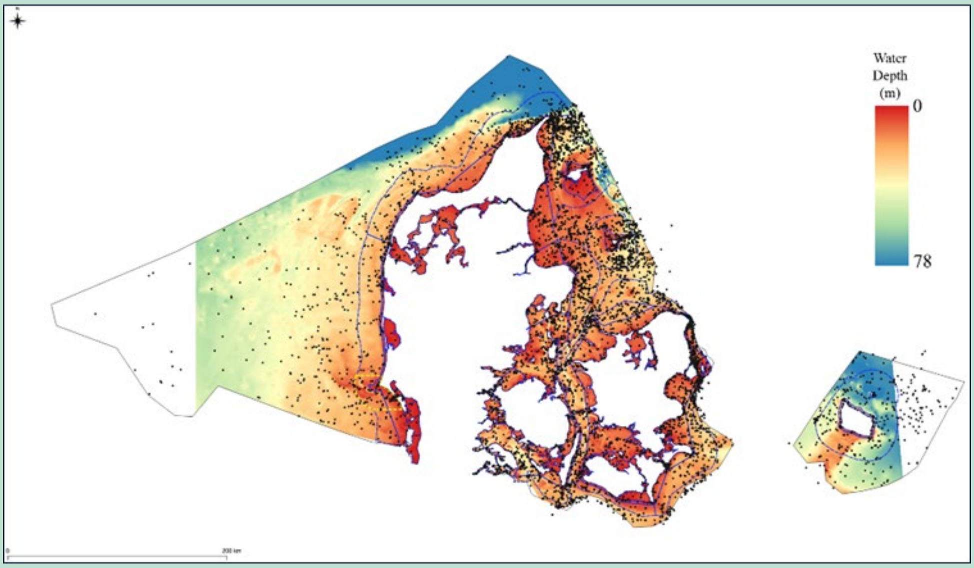


FIGURE 5. Overview of 'wrecks' in the Danish waters included in the *Fund og fortidsminder* database. Bathymetry from EMODnet. Blue lines show the 12 and 1 nautical mile zones and yellow dashed polygon indicate the selected study area. Wrecks are scattered across all the Danish waters, generally with a higher occurrence in the Kattegat, the straits, and the Baltic Sea, and with specific hotspots in terms of abundancy in the Øresund, offshore Anholt and offshore Skagen.

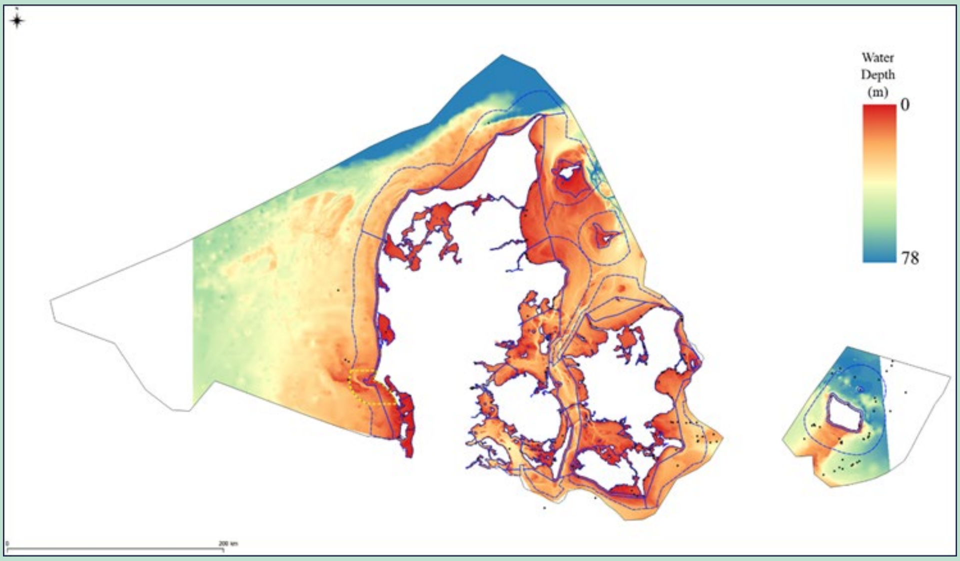


FIGURE 6. Overview of ‘wreck remains’ [vragdel] in the Danish waters included in *the Fund og fortidsminder* database. Bathymetry from EMODnet. Blue lines show the 12 and 1 nautical mile zones and yellow dashed polygon indicate the selected study area. Most wreck remains are found around the island of Bornholm.

Using the ‘dating’ [datering] attribute it is possible to narrow the search of wrecks for specific periods (Table 2). Of all the wrecks, 97 % is dated as either ‘historical time’ [historisk tid] (from year 1050 AD to present) (1.5 %) or ‘recent time’ [nyere tid] (from year 1660 AD to present) (95.5 %). The absolute age attributes (‘from_year’ [fra_aar] and ‘to_year’ [til_aar]) further allow a search for wrecks from specific years. Such a search shows that 46 % of all wrecks are dated to the period from 1900 AD to present day, 3.4 % of all wrecks are dated to the period 1910-1920 AD (including the WWI period 1914-1918), and 11 % of all wrecks are dated to the period 1940-1945 AD (WWII). Table 2 provides an overview of the performed searches with numbers for all Danish waters and numbers for the selected study area.

TABLE 2. Search returns for various filters using the *Fund og fortidsminder* database.

Filter	Objects in Danish waters	Objects in study area
No filter besides 'Water areas' [Farvandsområder]	14083	103
Anlægsbetydning = Vrag	10127	77
Anlægsbetydning = Vragdel	236	0
Anlægsbetydning = Vrag AND Datering = Stenalder	13	0
Anlægsbetydning = Vrag AND Datering = Bronzealder	0	0
Anlægsbetydning = Vrag AND Datering = Jernalder	3	0
Anlægsbetydning = Vrag AND Datering = Vikingetid	4	0
Anlægsbetydning = Vrag AND Datering = Middelalder	52	0
Anlægsbetydning = Vrag AND Datering = Efterreformatorisk tid	15	0
Anlægsbetydning = Vrag AND Datering = Nyere tid	9668	77
Anlægsbetydning = Vrag AND Datering = Oldtid	3	0
Anlægsbetydning = Vrag AND Datering = Historisk tid	147	0
Anlægsbetydning = Vrag AND Datering = Udateret	222	0
Anlægsbetydning = Vrag AND Datering = Nyere tid AND Fra_aar >= 1900	4666	66
Anlægsbetydning = Vrag AND Datering = Nyere tid AND Fra_aar >= 1946	1444	26
Anlægsbetydning = Vrag AND Datering = Nyere tid AND Fra_aar >= 1910 AND Til_aar <= 1920	340	6 (incl. UC30)
Anlægsbetydning = Vrag AND Datering = Nyere tid AND Fra_aar >= 1914 AND Til_aar <= 1918	132	2 (incl. UC30)
Anlægsbetydning = Vrag AND Datering = Nyere tid AND Fra_aar = 1940 AND Til_aar = 1945	1128	10
Anlægsbetydning = Vrag AND Datering = Nyere tid AND Fra_aar = 1946 AND Til_aar = 1949	264	2

To assess the importance of the wrecks, a more specific investigation of the discrete wrecks from the *Fund og fortidsminder* database in the selected area study area is performed. Table 2 shows that there are in total 77 wrecks in the study area all of which is dated as 'recent time' with 66 wrecks (86%) dated from 1900 AD to present day. The narrow absolute time searches showed that there are six wrecks (7.8%) from the period 1910-1920 AD including two wrecks (2.6%) specifically from the period 1914-1918 (WWI), and ten wrecks (13%) from the period 1940-1945 (WWII) (see Fig. 7).

By using the available url-links for each wreck, it was possible to extract additional relevant information (Tables 3 and 4). Of the six wrecks from the 1910-1920 period (Fig. 7B; Table 3), there are one German trawler, one German submarine (identified and named as UC30), one steamer (flag state not specified) and three unspecified wrecks. Two of the six wrecks are from the 1914-1918 (WWI) period; one of these is the German submarine UC30, which has been further investigated in the NORTH SEA WRECKS project (Fig. 8).

TABLE 3. Overview of the six wrecks from 1910-1920 in the study area. Information from the *Fund og fortidsminder* database.

Object nr	Absolute dating	Name of place	Additional information
177616	1910-1919	Skallingen	Likely year of wreckage is 1919
178974	1914-1918	Grådyb	Likely year of wreckage is 1916
184542	1910-1919	Slugen	Steamship, shipwrecked in 1919
185704	1910-1919	Skalingen	German trawler, shipwrecked in 1919
186758	1910-1919	Nordsøen SØ	Wrecked in 1911
227837	1917	Slugen	German named submarine (SM UC30), wrecked in 1917. Classified as restricted access area

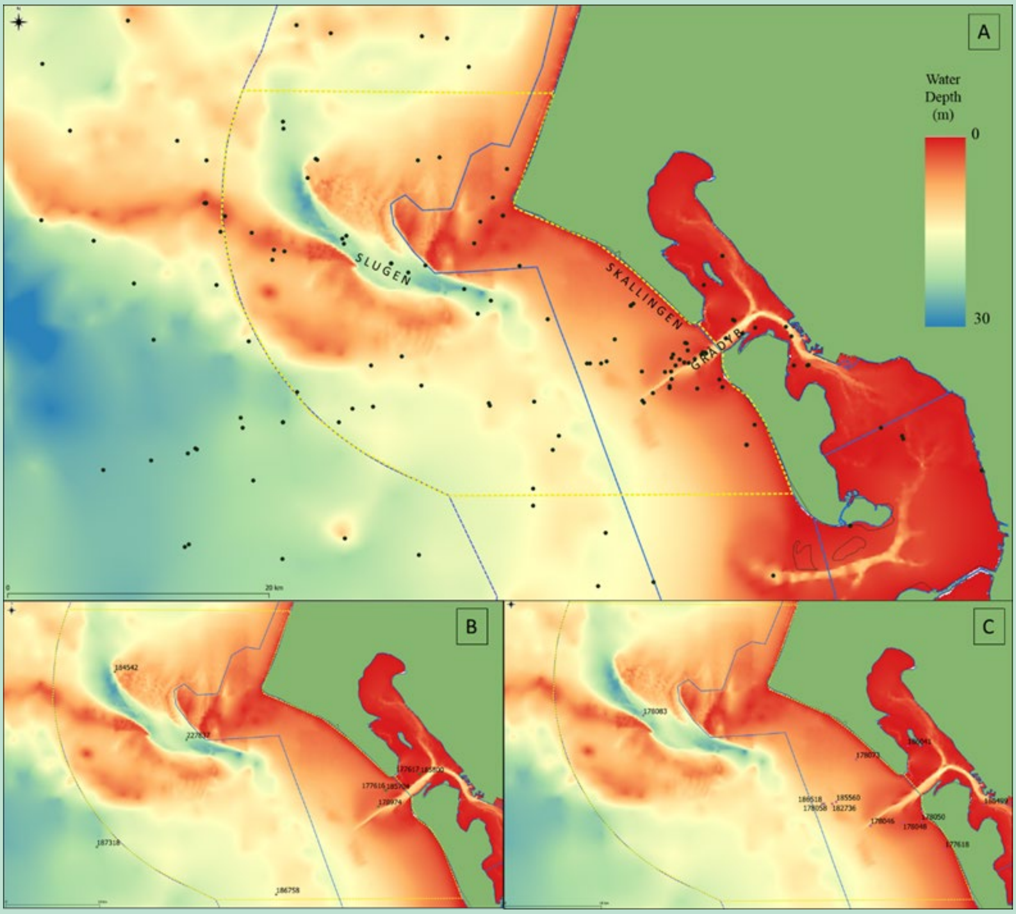


FIGURE 7. Overview of wrecks in the selected study area (yellow dashed polygon) in the *Fund og fortidsminder* database. Bathymetry from EMODnet. Blue lines show the 12 and 1 nautical mile zones. A) The total number of wrecks (black dots) in the study area is 77. B) Six wrecks (green dots) within the study area are dated to the period 1910-1920. C) Ten wrecks (purple dots) in the study area are dated to the period 1940-1945.

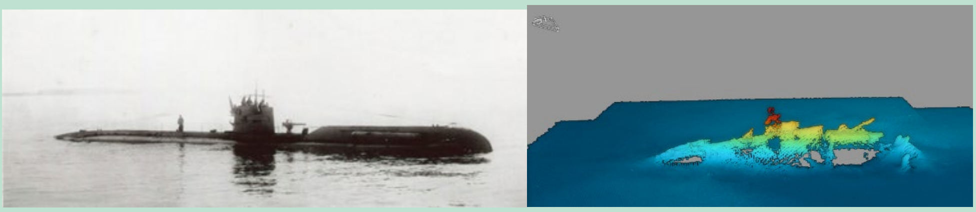


FIGURE 8. Left – photo of the German submarine SM UC 30 that sunk in 1917 (© Deutsches U-Boot-Museum, Cuxhaven-Altenbruch). Right – the SM UC30 have been further investigated in the NORTH SEA WRECKS project and the figure shows a multibeam echosounder scanning (© Aarhus University) of the wreck. The wreck was found in ‘Slugen’ near Horns Reef in 2016 by the Sea War Museum Jutland.

A similar search for the ten wrecks from the 1940-1945 (WWII) period (Fig. 7C, Table 4) revealed that, two are likely war-related wrecks (due to their listing as cultural heritage objects being remediated with blasting operations), six are smaller fishing vessels, and two have been listed as unspecified origin. Most of the wrecks are furthermore assessed as being either torn to pieces and/or drifted away (two wrecks), buried within the sand (two wrecks), or simply 'disappeared' (two wrecks), meaning that likely only four of the ten wrecks are currently visible at the seafloor.

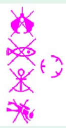
TABLE 4. Overview of wrecks from 1940-1945 in the study area. Information from the *Fund og fortidsminder* database.

Object nr	Absolute dating	Name of place	Additional information
177618	1940-1945	Fanø Vestkyst	Wrecked in 1945. Removal of cultural heritage object by blasting operation in 1950. Buried in sand
178046	1940-1945	Nordsøen SØ	Wrecked in 1942. German trawler. Removal of cultural heritage object in 1951 by blasting operation. Wreck remains buried in sand
178048	1940-1945	Fanø Vestkyst	Wrecked in 1945. Danish fishing boat.
178050	1940-1945	Fanø Vestkyst	Wrecked in 1944. Fishing boat. Wreck listed as disappeared in 1946
178058	1940-1945	Nordsøen SØ	Wrecked in 1944. Wreck likely torn apart and drifted away
178073	1940-1945	Skallingen	Wrecked in 1944. Fishing boat. Wreck listed as being torn apart in 1948
178083	1940-1945	Slugen	Wrecked in 1944. Fishing boat
182736	1940-1945	Nordsøen SØ	Wrecked in 1944. Named fishing boat (Ingrid R 162)
185560	1940-1945	Nordsøen SØ	Wrecked in 1940. Listed as disappeared in 1946
186518	1940-1945	Nordsøen SØ	Wrecked in 1944. Fishing boat

For comparison, a similar search in the selected study area has been performed using naval charts (version from November 2020) and the *vragguiden.dk* database. The naval charts provide information on the wreck location, the least depth of the wreck, or if the least depth is unknown, an indication of whether the wreck is potentially dangerous to some surface vessels. There is typically no other metadata available from the naval charts.

Of the 77 wrecks listed in the *Fund og fortidsminder* database, 19 also appeared on the naval charts (e.g., Fig. 9, Table 5) with one of these 19 wrecks (5.3 %) marked as a restricted access area (this is the SM UC30 submarine). Some of this relatively large discrepancy between the number of wrecks from the two sources, may relate to the fact that some wrecks listed in the *Fund og fortidsminder* database have disintegrated or are fully buried today, – and therefore do not represent an obstacle that must be mentioning in the naval charts. Although several other types of obstacles are indicated on the naval charts, there were no other (additional) wrecks as compared to the *Fund og fortidsminder* database.

TABLE 5. Overview of wrecks from the naval charts in the study area.

Type of wreck	Wreck with known least depth	Wreck with unknown least depth and considered potentially dangerous to some surface vessels.	Foul ground, e.g., remains of wreck, no longer dangerous to surface navigation but to be avoided by vessels anchoring, trawling etc	Wrecks with restricted access zone
Symbol				
Number of wrecks	12	5	1	1

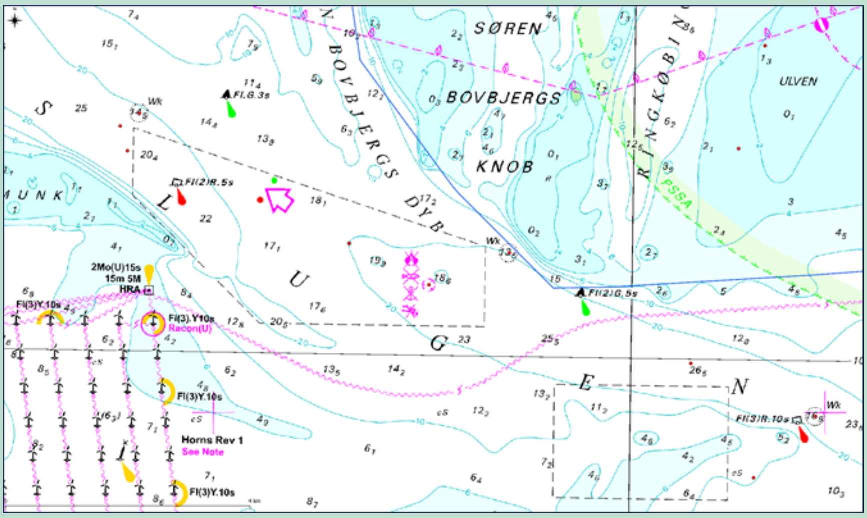


FIGURE 9. Overlap between wrecks from the *Fund og fortidsminder* database (red dots) and wrecks indicated on the naval chart. The figure is an excerpt from the naval chart at SLUGEN where the SM UC30 submarine wreck is located and marked as a restricted access area (100 m radius zone from the wreck).

The search in the *vragguiden.dk* returned 12 wrecks within the study area, with two of these being positioned at other locations than the wrecks from the *Fund og Fortidsminder* database (“Aircraft debris” and “Sinai”), indicating that these could be additional wrecks not included in the *Fund og Fortidsminder* database (Fig. 10).

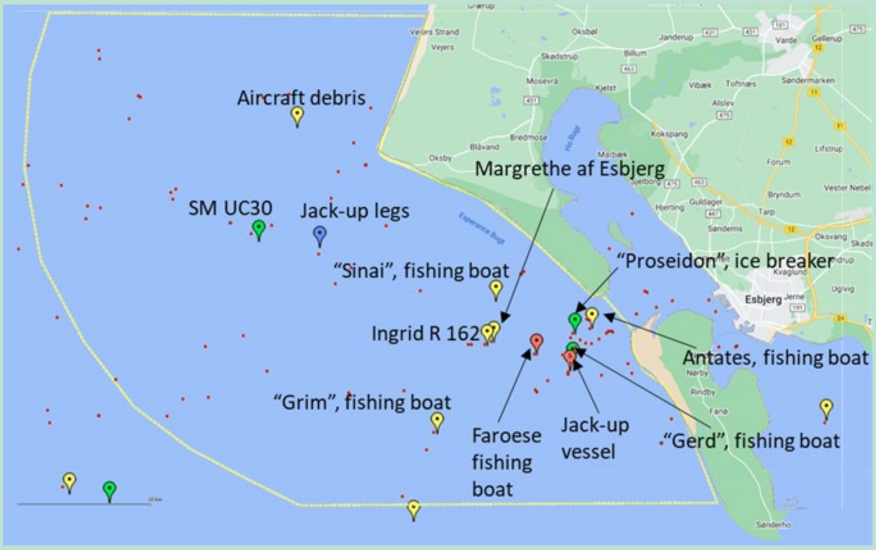


FIGURE 10. Overlap between wrecks from the *Fund og fortidsminder* database [red dots] and wrecks indicated on the *vragguiden.dk* database [yellow, green, blue, and red location 'drop-lets'].

Of the 12 wrecks, seven are listed as fishing boats, two are other types of ships (jack-up vessel, icebreaker vessel), one is aircraft debris, one is the German submarine SM UC30, and one is jack-up legs (see Table 6). Interestingly, one of the fishing boats is identified as ‘Margrethe of Esbjerg’ and hence given more specific information that was available in the *Fund og Fortid-sminder* database (wreck number 185560 in Fig. 7C and Table 4).

Four of the 12 wrecks (33 %) from vragguiden.dk can be ascribed as war-related origin; - two Danish fishing boats wrecked in 1940 ("Margrethe of Esbjerg") and 1944 ("Ingrid R 162"), the German submarine SM UC30 wrecked in 1917 and the aircraft debris that is listed as being found in connection with explosives (see Table 6).

TABLE 6. Overview of the 12 wrecks in the study area from *vragguiden.dk*, with indications of overlap to the wrecks also listed in the *Fund og fortidsminder* database.

Name/type of object	Additional information	Overlap with wreck from *Fund og fortidsminder* database
Aircraft debris	Only presumed location, also indications of explosives	No overlap
UC30	German submarine from WWI (wrecked in 1917). Restricted access	227837
Jack-up legs	Legs from dredging vessel	186693
Grim	Probably a fishing boat	178970
Ingrid R162	Danish fishing boat, wrecked in 1944	182736
Havsøki KG699	Faeroese fishing boat, wrecked in 1999	179440
Jack-up vessel	Wrecked in 1999	179424
Gerd	Probably a fishing boat, possibly wrecked in 1969?	177614
Antates	Fishing boat	177631
Proseidon	Icebreaker vessel made of concrete. Wrecked in 1922	178061
Sinai	Fishing boat	No overlap
Margrethe af Esbjerg	Danish fishing boat, wrecked in 1940 after encountering mine and exploding, three persons died	185560

To sum up, the simple wreck screening for the selected study area using three different information sources (*Fund og Fortidsminder* database, naval charts and *vragguiden.dk*) showed interesting results. First, the *Fund og Fortidsminder* database appears to be the most complete database, both in terms of the number of wrecks and the additional information, that can be extracted. Second, all three databases provided some information regarding the wrecks' relation to war. The *Fund og Fortidsminder* database showed four (5.2 %) likely war-related wrecks (two from WWI and two from WWII), the naval charts one (5.3 %) and the *vragguiden.dk* four (33.3 %) war-related wrecks (see Table 7). Furthermore, by combining the *vragguiden.dk* and the *Fund og Fortidsminder* database it is possible to get information for more specific wrecks and hence lower the number of unspecified wrecks.

TABLE 7. Overview of war-related wrecks from the three information sources.

Information source	Total number of wrecks	Number and percentage of war-related wrecks	Number and percentage of WWI-related wrecks	Number and percentage of WWII-related wrecks
Fund og fortidsminder database	77	4 (5.2 %)	2 (2.6 %)	2 (2.6 %)
Naval charts	19	1 (5.3 %)	1 (5.3 %)	0
Vragguiden.dk	12	4 (33.3 %)	3 (8.3 %)	1 (25 %)

2.4 Approach for classification of wrecks regarding significance for impact on chemical condition

For all databases, the meta-data information available varies to a large degree. Hence, it is non-consistent which information can be deduced for discrete wrecks and this makes a parameter-based comparison more complicated. However, based on the simple wreck screening above, it is possible to list some valuable (and available) meta-data information that are usable for a first-hand classification with respect to importance for and impact on the chemical conditions. These include:

- Location of the wreck
- Occurrence of wreck in multiple databases

- Year of wreckage
- Specific wreck identification (e.g., name of vessel or flag state – this allows for adding additional information from e.g., historical archives)
- War-relation (based solely on year of wreckage)
- Cargo, including potentially dangerous goods and warfare agents (based on war-relation and country of origin)
- Current condition of the wreck (important for evaluating the degradation state which influence the risk of leakage)

Based on such parameters, a simple first-hand classification of wrecks can be carried out categorizing wrecks into three types according to significance in relation to risk:
1) Wreck without significance
2) Significant wreck without dumped munitions (e.g., wreck with known large volumes of bunker oil or wreck from one of the two world wars but with no other war association (e.g., fishing boats))
3) Significant wreck with dumped ammunition

Table 8 exemplifies how the classification could be performed using the parameters and a Yes/No-based matrix. The approach however has a very high inherent uncertainty because of the many unknowns and some of the assumptions made. Specifically, the presence of munitions or other potentially polluting cargo (such as bunker oil) is very uncertain. Presence of munitions is hence assumed based only on the given relation to either of the two world wars and the flag state for the wreck. Fishing boats are generally viewed as 'harmless' but such were also to a large degree used for military purposes during the world wars and therefore pose a potential large source of error. Several additional investigations and parameters must be assessed to make a more realistic evaluation of whether munitions are in fact present on a wreck or not and how much there potentially is. Such further information should be part of a thorough risk assessment, and this is discussed in Chapter 4.

TABLE 8. First-hand wreck classification based on the public available information. Exemplified by classification of four wrecks.

Specific wreck	227837	178046	182736	179440
Location known (Y/N)	Y	Y	Y	Y
Occurrence in multiple databases (Y/N)	Y	N	Y	Y
Wreck identified to name or flag state (Y/N)	Y, SM UC30, Germany	Y, Germany	Y, Ingrid R162, Danish fishing boat	Y, Havsøki KG699
Year of wreckage known (Y/N)	Y, 1917	Y, 1942	Y, 1944	Y, 1999
War-relation (based solely on year of wreckage) (Y/N)	Y, WWI	Y, WWII	Y, WWII	N
Munitions present (based on year of wreckage and flag state) (Y/N)	Y, war-relation, German submarine	Y, blasting operation, German trawler	N	N
State of wreck known (Y/N)	N	Y, buried in sand	N	N
Type classification (I/II/III)	III (war submarine with munitions present)	II (munitions likely to be remediated)	II (fishing boat)	I

3. Pollutants from historical wrecks with and without ammunition

3.1 Potential pollution from historical wrecks

This chapter provides a brief (non-exhaustive) overview of potential pollutants from historical wrecks with and without ammunition. The overview leans on existing lists of pollutants (EU prioritised and nationally specific substances) (including EHP) e.g. from the NOVANA monitoring program and from the available literature specifically dealing with dumped ammunition and wrecks (e.g. HELCOM, 2013; Boutrup et al., 2015; Beldowski et al., 2016; Maser et al., 2023).

According to Danish strategy for environmentally hazardous substances in the aquatic environments (Miljøministeriet, 2021) marine point polluting sources are currently viewed as being related mainly to sediment dumping sites [klappladser], harbours, offshore constructions, and offshore activities (such as fishery and shipping). Wrecks, and in particular war wrecks and dumped ammunition, are not mentioned specifically in the strategy, which focus mainly on surface water and groundwater. However, as shown by several studies, dumped munitions in the sea pose a pollution risk to the marine and coastal environments due to leakage of various pollutants (e.g., Beldowski et al., 2016) including chemical warfare agents (e.g., Sanderson & Fauser, 2015; 2017). For wrecks specifically, the literature is so far not very extensive, but a recent publication (Maser et al., 2023) documents that sunken warship wrecks are also point pollution sources in terms of contamination with nitroaromatic energetic compounds leaking from corroding munitions. Hence, it is relevant to consider wrecks as a potential source for EHP.

Boutrup et al. (2015) provided a comprehensive review of pollutants in the aquatic environments (from both point and diffusive pollution sources) that has been part of the NOVANA monitoring programme since 2004 to 2012/2013 (Table 9). They further provided a summarized list of pollutants (Boutrup et al., 2015, their table 2.1) which was based on the EU Water Framework Directive list of prioritized substances, the OSPAR and HELCOM list of substances of possible concern and the Stockholm Convention list.

TABLE 9. Main substance groups for pollution in the aquatic environment (after Boutrup et al., 2015).

Metals (mainly Lead, Cadmium, Nickel, Zinc)	Pesticides	Phenols	Chlorophenols
Aromatic hydrocarbons	Halogenated aromatic hydrocarbons	Halogenated aliphatic hydrocarbons	PAH (polyaromatic hydrocarbons)
Perfluorinated compounds (PFAS) (incl PFOS)	Softeners	PCB	Dioxins and furans
Brominated flame retardants	Organotin compounds	Ethers	Phosphotriesters (P-triesters)
Detergents	Chloroalkanes	Pharmaceuticals	Estrogens

Historical wrecks do not contribute to all the main substance groups defined by Boutrup et al. (2015). However, given that historical wrecks by nature represent the remains of multiple types of ships, aircrafts, and submarines from a very long period of time, there is a potential for wrecks contributing to pollutants within several substance groups. This also makes the evaluation of the possible pollutants from wrecks very complex. The pilot project has therefore focussed primarily on pollution related to wrecks with conventional (explosive) munitions.

In general, pollutants from historical wrecks can however be subdivided into three categories:
1) Pollutants from the wreck itself. These include various metals, plastics, paintings etc.
2) Pollutants from fuel and lubricants used as consumables on the vessels. These include various petroleum products (hydrocarbons) and other chemicals.
3) Pollutants from warfare related cargo and munitions. These include:
    a) Energetic chemicals used for explosives materials such as carcinogenetic trinitrotoluene TNT.
    b) Chemical warfare agents such as mustard gas and similar (e.g., Ganesan et al., 2010; Sanderson & Fauser, 2015, 2017)
    c) Metals used for casing, housing, driving bands, fuses, and initiators of explosives such as mercury and lead (Sanderson et al., 2017; Beck et al., 2018)

As mentioned, this pilot project focus on the potential pollutants from the cargo related to conventional (explosive) munitions (3a in the above list). The toxicological hazards from leakage of oil and similar substances (point 2 in list above) to the marine and coastal environments are relatively well-known, as are the risks from specific plastic and synthetic products (point 1 in list above) that may have been used on the wrecks. It is beyond the reach of this short pilot project to assess the amounts of oil, plastics, and synthetic products etc. currently present on historical wrecks in Denmark and these elements are therefore not evaluated further. Similarly, since metals used for building ships, aircrafts, submarines (point 1 in list above) (mostly iron and different steel compositions) are relatively harmless and furthermore hard to assess from the available material, such metals are also not considered further.

Beck et al. (2018) gave an extensive review of the chemical constituents from conventional munitions, which can typically be present in the marine environment. These include organic explosive compounds, metalloorganic explosives and metals used in casings and housings of munitions (such as mercury, lead, silver, iron, copper, aluminum, and zinc). They found that TNT (nitroaromatic trinitrotoluene) (and its derivatives), RDX (nitramines hexogen) and HMX (octogen) are the most important substances to focus on since these substances occur widely in the marine environment, as well as in the terrestrial environment. They furthermore concluded that although munitions do contain toxic metals (such as lead, mercury, cadmium, chrome) which can be problematic in other settings, the high background level in the marine environments (mostly human induced) hinders a conclusive identification of whether such toxic metals originate from munitions or not.

3.2 List of potential pollutants related to conventional munitions on wrecks

Table 10 summarizes the main compounds of concern related to historical wrecks with conventional munitions. To make a complete list of potential pollutants from wrecks, more input from experts within the field is required.

The table further provides a cross-link to substances listed in Enclosure 2 (Tables 2-5) of the EU Water Framework Directive and to the pollutant categorization presented above. As mentioned, Table 10 mainly comprise pollutants related to conventional munitions (Category 3).

The Appendix includes the full lists of pollutants from Enclosure 2 (Tables 13-16) of the EU Water Framework Directive with indications of cross-links to Table 10 and the pollutant category from the pilot project.

TABLE 10. Non-exhaustive overview of explosives compounds, metalorganic compounds (used as primary explosive (initiator)) and metals potentially found in relation to war-related wrecks with conventional munitions. References: a) Sanderson et al., 2017, b) Beck et al., 2018, c) Maser et al., 2023. The central columns (A-D) show the cross-link to substances listed in Tables 2-5 of Enclosure 2 in the EU Water Framework Directive. The last column shows pollutant category as presented in the top of page 26.

	Refer-ence	CAS-number	Included in list A) Priority substances within the EU's water policy, B) Nationally established environmental quality standards water, C) Nationally established environmental quality standards sediment and biota, D) EU established environmental quality standards. (Appendix A-D)				Pollutant category (page 26)
			A	B	C	D	
Explosive compounds (carcinogenic munition fillers)							
TNT (nitroaromatic 2,4,6,-tri-nitrotoluene)	a, b	118-96-7					3
RDX (nitramines hexahydro-1,3,5-trinitro-1,3,5-triazine)	a, b	121-82-4					3
HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetreazo-cine)	a, b	2691-41-0					3
HBX-1 (Hexahydro - 1, 3, 5-trinitro-8-Triazine)	a	118-96-7 & 121-82-4					3
Ethylene oxide	a	75-21-8					3
Gasoline	a	86290-81 & 8006-67-9					3
Explosive compounds (carcinogenic explosive filler by-products/metabolites)							
1,3-DNB (1,3-Dinitroben-zene)	c	99-65-0					3
2,4-DNT (2,4-dinitrotoluene)	a, c	121-14-2					3
4-ADNT (4-Amino-2,6-dinitro-toluene)	c	19406-51-0					3
2-ADNT (2-Amino-4,6-dinitro-toluene)	c	35572-78-2					3
2,6-dinitrotoluene	a	606-20-2					3
1,3-butadiene	a	106-99-0					3
1,4-dichlorobenzene	a	106-46-7					3
Benzene	a	71-43-2	Y			Y	3
Benzo(a)pyrene	a	50-32-8	Y (PAH)			Y	3
Carbon tetrachloride	a	56-23-5				Y (tetra-chlor-metan)	3
Naphthalene	a	91-20-3			Y	Y	3
Vinylchloride	a	75-04-1					3
Explosive compounds (other)							
Tetryl	b	479-45-8					3

Ammonium picrate	b	131-74-8					3
CL-20, HNIW (Hexanitrohex-aazaisowurtzitane)	b	135285-90-4					3
Metalorganic compounds							
Fulminates – particularly Mercury fulminate	b	28269-67-2					3
Azides – particularly Lead azide	b	13424-46-9 (lead)					3
Styphnates – particularly of Mercury, Lead, and Silver	b	63918-97-8 (lead)					3
(Heavy) metals							
Aluminum (powder (Chaff))	a, b	7429-90-6					3
Arsenic	a	7440-38-2	Y (naftalen 7440-38-2)	Y			3
Beryllium	a	7440-41-7					3
Cadmium	a, b	7440-43-9	Y		Y	Y	3
Chromium VI	a	18540-29-9		Y (Chrom 7440-47-3)			3
Cobalt	a	7440-48-4		Y			3
Copper	b	7440-50-8		Y			(1), 3
Iron	b	7439-89-6					1, 3
Lead	a, b	7439-92-1	Y		Y	Y	(1), 3
Mercury	a, b	7439-97-6	Y			Y	3
Nickel	a, b	7440-02-0	Y			Y	(1), 3
Selenium	a	7782-49-2		Y			3
Silver	b	7440-22-4		Y	Y		(1), 3
Strontium 90	a	10098-97-2		Y (Strontium 7440-24-6)	Y (Strontium 7440-24-6)		3
Titanium dioxide	a	13463-67-7					3
Vanadium pentoxide	a	1314-62-1		Y (Vanadium 7440-62-2)	Y (Vanadium 7440-62-2)		3
Uranium (depleted)	a	7440-61-1		Y			3
Zinc	b	7440-66-6		Y			(1), 3

4. Risk assessment of historical wrecks with and without ammunition

4.1 Risk assessment indicators

Risk assessment of wrecks is far from simple because of the many various factors that influence the wreck, and the typically high uncertainty regarding specific parameters. One of the main goals of the DAIMON research project that ran from 2016-2019, was to develop a risk assessment tool as a decision support system (DSS) for munitions in the Baltic Sea. In the DAIMON 1 and 2 projects the researchers therefore adapted the VRAKA risk assessment tool (Landquist et al., 2016; 2017), that was originally developed for shipwrecks to also include UXOs (unexploded ordnance) and CWA (chemical warfare agents). VRAKA is based on a Bayesian probabilistic modelling approach comprising three core elements: A – estimation of the **probability** of discharge of pollutants (e.g., opening of a wreck), B – assessment of **consequences** from a discharge, and C – evaluation of **risk** from wreck based on A and B (Landquist et al., 2016; 2017).

Today, the VRAKA tool is integrated as part of the Decision Support System for Baltic Sea munitions as an online tool and database, hosted by the AmuCad organisation, that can be used by the relevant authorities and public institutions.

In the NORTH SEA WRECKS project, the risk assessment tool developed in the DAIMON projects was further advanced to encompass the regional and local site-specific conditions for the North Sea. The North Sea is a much harsher environment compared to the Baltic Sea with more influence of storms and tides, and different salinity and oceanographic parameters, which should be accounted for in the risk assessment. The risk assessment tool developed in the NORTH SEA WRECKS project is called the WRECKNS (Fig. 11) and will similarly be an online-based tool available from the AmuCad platform, usable for authorities and governmental institutions. The expected release of WRECKNS is medio 2023 with initial webinar trainings for end-users during spring 2023. WRECKNS will contain build-in options for how to show and share data to the public, so that sensitive data concerning wrecks can be kept confidential if needed.

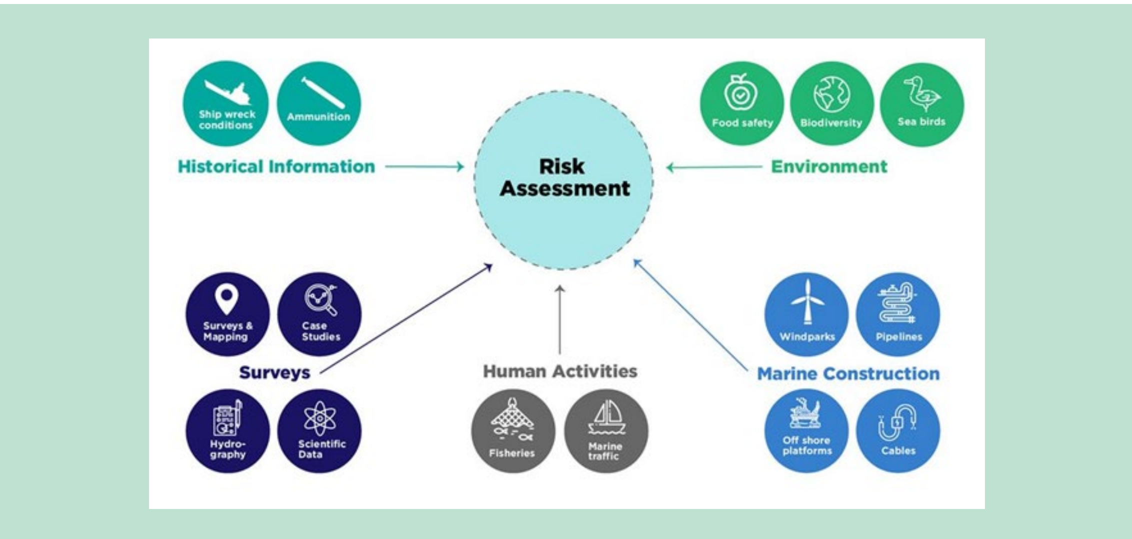


FIGURE 11. Generalized overview of data correlation in the WRECKNS software, © north.io GmbH

Common for the VRAKA and WRECKNS risk assessment tools, is that wrecks are generally described from several indicators, which are typically either site-specific or wreck-specific (e.g., Landquist et al., 2017) (Fig. 11).

The site-specific indicators include natural geologic and oceanographic factors, and anthropogenic factors related to human activities and maritime zones (Table 11), while the wreck-specific indicators include general information regarding the wreck, its cargo (at the time of wreckage) and its condition (Table 12).

TABLE 11. Overview of regional parameters and activities used in the WRECKNS risk assessment tool.

Regional oceanographic and geologic parameters	Human activities
Distance to shore and human activities	Shipping
Water depth	Fishery
Ocean currents (current speed)	Trawling
Tidal influence	Dredging
Wave impact	Diving
Oxygen concentration, salinity, pH values, bottom water temperature	Constructions (windfarms, pipelines, cables, oil and gas platforms)
Seabed character (geology)	Military activity
Deposition (burial) and erosion (scour)	Illegal salvaging
Maritime zones, laws, and regulations	**Natural activities**
Nature Protected Area	Deterioration
Military practice areas	Storm events
UNCLOS, OSPAR, HELCOM	Extreme weather
Global/EU/National laws and directives	Geohazards (earthquakes, tsunamis, submarine landslides, gas seepage/expulsion)

TABLE 12. Overview of wreck specific parameters used in the WRECKNS risk assessment tool.

Wreck information	**Wreck condition**
Name and type	Sinking date/wreckage year
Flag state	Cause of wreckage
Ship use (military/merchant)	Wreck position (standing upright, tilting on side, upside down, broken into pieces)
Dimensions	Integrity (incl. wreckage-induce damage)
Displacement	Present hull thickness/corrosion state
Material (iron, steel, aluminium)	Wreck site dimensions
Hull thickness	Salvaged (true/false)
Bunker volume	War grave (true/false)
Construction yard and commission date	Scour marks (true/false)
Commission date	Sedimentation/burial (true/false)
History up to wreckage	**Wreck cargo**
Wreck location	UXO (munition type, warfare agents, amount of TNT)
Precise position	Fuel (fuel types, oils, lubricants, estimated amounts)
Country and Maritime zone	**Wreck measurements**
Laws and regulations	Stations, samples, substance analysis

The risk in WRECKNS is, like VRAKA, evaluated based on the probability of certain activities generating an opening in the wreck (causing discharge or a potential of leakage), the degree to which the various indicators affect the probability of an opening, and the effects of a potential discharge. Simply said, the risk constitutes the product of probability of release and the amount of pollutants (Fig. 12).

In the case where measurements have been carried out at a particular wreck, the WRECKNS tool can provide a True/False return to whether a wreck is polluting (Fig. 13). When comparing more wrecks, the tool can also provide a ranking/prioritization of wrecks in terms of significance. This ranking depends on the pollution status for the wreck, the risk from the wreck and the probability of release from the wreck (e.g., with evolution through time) (Fig. 14).

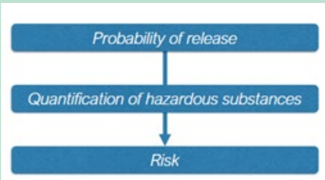


FIGURE 12. Schematic representation of risk assessment in the WRECKNS tool, © north.io GmbH.

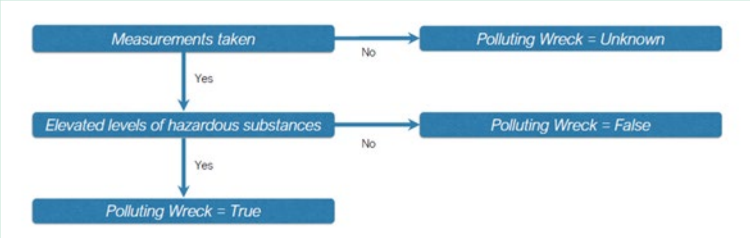


FIGURE 13. Schematic representation of pollution evaluation for wrecks with measurements in the WRECKNS tool, © north.io GmbH.

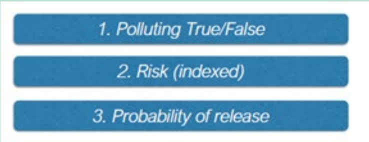


FIGURE 14. Schematic representation of wreck-ranking in the WRECKNS tool. © north.io GmbH.

The last component of WRECKNS is the ability of assigning appropriate actions to each wreck (Fig. 15). These actions will depend on what is already known about the wreck, what is not known, and which elements have already been assessed. Furthermore, for each wreck, the likeliness of certain (human) activities to cause an opening of the wreck can translate into the action of limiting such activities.

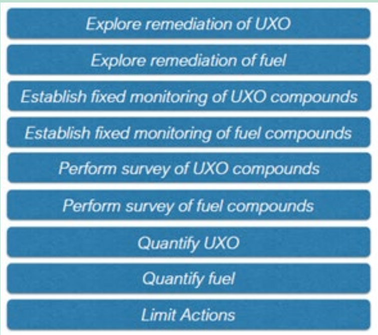


FIGURE 15. List of possible actions for wrecks in the WRECKNS tool, © north.io GmbH.

4.2 Cumulative effects

In addition to understanding the specific risk of discrete wrecks as point polluting sources, it is relevant to assess how wrecks may contribute to cumulative effects in terms of good chemical condition for the territorial waters. Doing such will also aid a more holistic understanding of wrecks as part of the marine ecosystem.

Cumulative effects are generally hard to assess and predict, because they by nature depend on various components that influence each other in various ways (Fig. 16) (e.g., Hansen & Høgslund, 2021). It is furthermore difficult to separate the effect of one component from the other, making it complicated to pinpoint the causes for changes in the ecosystems and predict ecosystem responses to decreased or increased effect of a particular component (Hansen & Høgslund, 2021). Still, cumulative impacts and effects in the Danish waters are assessed on a regular basis (e.g. Andersen et al., 2013, 2017b; HELCOM 2010, 2018) using input from the national monitoring program of the Danish waters NOVANA (e.g. Hansen & Høgslund, 2021; Jung-Madsen et al., 2021). Andersen et al. (2017a, b) describe how information regarding four components is needed in order to model and assess the cumulative (additive) effects: These four components include: 1) stressors [presfaktorer] (human activities such as fishery, dumped munitions, EHP), 2) ecosystem components [økosystemkomponenter] (such as a habitat or a species), 3) distance-of-effect [effektdistance] (to what distance do the stressors have any effect), and 4) sensitivity weights [sensitivitet] (the relative importance of a stressor towards a specific ecosystem component) (Andersen et al., 2017a, b).

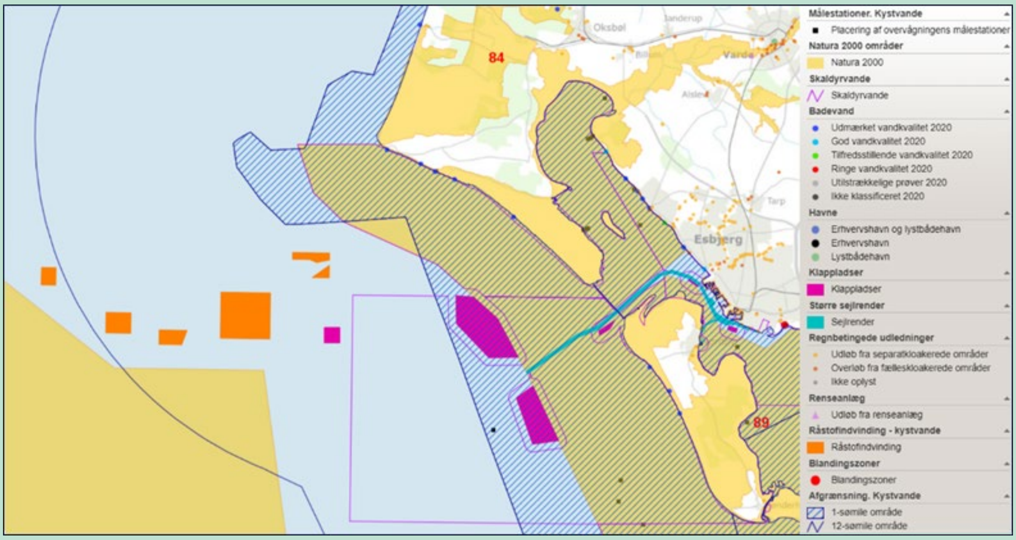


FIGURE 16. Overview of some stressors in the selected study area such as marine raw material extraction and dumping sites). The chemical condition in the selected study area is currently assessed as poor [ikke-god kemisk tilstand]. Information from MiljøGIS (2022).

The stressors are today embedded in the 11 descriptors of the Marine Strategy II. The chemical condition in the Danish waters relates to descriptor #8 Pollution substances. Wrecks may however also influence some of the other descriptors such as #6 The integrity of the seafloor, #9 Pollutants in marine food for human consumption, #10 Marine waste, and #11 Underwater noise. For some of the stressors, wrecks may even have a positive effect e.g., by forming marine habitats on an otherwise flat sandy seafloor.

In order to evaluate how wrecks contribute to the cumulative effects, the risks from wrecks (once known) should be incorporated into the modelling scheme for the relevant stressors. As stated in Andersen et al. (2017b) (with updates from HELCOM (2018)), dumped munitions are already part of the analysis and it should therefore be possible to also include wrecks.

Another interesting element is the distance-of-effect in relation to pollution from wrecks. In a review from 2018, Beck et al. discuss the state of knowledge regarding the occurrence, the spread, and the effect of munition-related chemical pollutants in the marine environment. Other studies carried out on dumped munitions show various measurements of explosive compounds at various distance from the munitions (e.g., Maser & Strehse, 2020; Strehse et al., 2021). Andersen et al. (2017b) also discuss distance-of-effect and proposes (based on input from an expert panel) that a 1 km distance-of-effect should be used for dumped ammunition.

However, for wrecks specifically, there is so far only little research done in relation to distance-of-effects. One is presented in a recent paper by Maser et al. (2023) where it is documented how explosive chemicals can be traced in sediment samples 17.5 m away and in water samples 7.5 m away from a WWII wreck in Belgian waters. Their results furthermore show a high spatial variance likely related to the dynamic oceanographic (bottom currents) and geological (seafloor deposition and erosion) conditions around the wreck (Maser et al., 2023).

More research is needed on this topic, but the initial studies indicate that the simple distance-of-effect from polluting wrecks is likely to be relatively small and hence contemplated as 'local'. The potential impact of pollution from wrecks and munitions towards marine food safety over time (e.g., Maser & Strehse, 2021) together with the risk for explosions are however two elements that argue for a much larger effect distance.

Sørensen et al. (2021) reviewed the possibilities of using numerical modelling to assess how EHP spread in the surface waters. They concluded that initial simple models considering the geographic and temporal distribution of emissions could be developed. Such simple models could then guide further sampling and analyses to obtain specific data for more complex models. Generally, more data and more specific relevant data is needed (Sørensen et al., 2021). It can however be imagined that similar modelling in marine waters could be carried out using knowledge of both point and diffusive pollution sources, oceanography, geology, and wreck- and site-specific parameters.

4.3 Approach for designating potential hotspot areas that requires special focus

Following the notion that there are over 10,000 wrecks in the Danish waters (Slots- og Kulturstyrelsen, 2022), there is a need for prioritizing and ranking the wrecks. Chapter 2.4 exemplified a simple approach for type categorization of wrecks in terms of importance for impacts on chemical condition, using publicly available information. This outlined simple approach will however, as mentioned, have a very high uncertainty. On the other hand, the method represents a possible approach for a first-hand classification, which can be done without the need for much further data.

A risk assessment method such as the WRECKNS outlined in chapter 4.1 appears to be more robust for classification and prioritizing wrecks, which is critical for the hotspot designation process. Furthermore, the recommendation of actions for each analysed wreck, will also serve as an important input for the hotspot definition. However, for hotspot areas it is also necessary to have the cumulative effects and the various stressors in mind since some areas may be more important to keep safe for certain human activities (e.g., related to supply security [forsyningssikkerhed]) than other areas. It is therefore recommended that risk assessment of discrete wrecks is placed into context with the known cumulative effects in an area. Doing such, should enable the identification of hotspots that require special focus (e.g., high-activity areas with abundant wrecks). Finally, the temporal evolution for a particular wreck given its site-specific and wreck-specific parameters (Tables 11 and 12) should also be incorporated in the hotspot definition (i.e., how emergent is the particular risk and is there time to focus on other areas first).

4.4 Recommendation for best available methods for risk assessment of wrecks

The recommendation for best available approach for risk assessment of wrecks is to use the already developed decision support systems (DSS) with the risk assessment tools VRAKA and WRECKNS that are or will be available on the AmuCad platform. A user manual to the DSS developed in the DAIMON project is already available, training the users in manoeuvring the map service and filter options, and in adding additional data themselves.

To perform an actual risk assessment of wrecks in the Danish coastal waters would require that all information from e.g., the *Fund og fortidsminder* platform is uploaded to the databases for the VRAKA or WRECKNS. Currently, the WRECKNS database only holds information for wrecks that have been investigated as part of the North Sea Wrecks project. This work only includes two wrecks in the Danish EEZ. The WRECKNS tool is therefore dependent on a dedicated work programme to include all known Danish wrecks into the database. Furthermore, the risk assessment will work better and have lower uncertainty, if more specific information for each wreck is entered. This likely requires more scientific work on specific selected wrecks involving both sampling and historical archive searches.

Figure 17 shows an example of the user interface of WRECKNS at the wreck of the submarine SM UC30 in the Danish EEZ (within the pre-study mapping area of chapter 2). This specific wreck comprises much information due to the scientific investigations carried out in the North Sea Wrecks project. Of particular importance are the estimates given for the amount of TNT on the wreck. These are based on a combined effort from diver investigations, historical archive searches, and geochemical analyses of samples from the wreck.

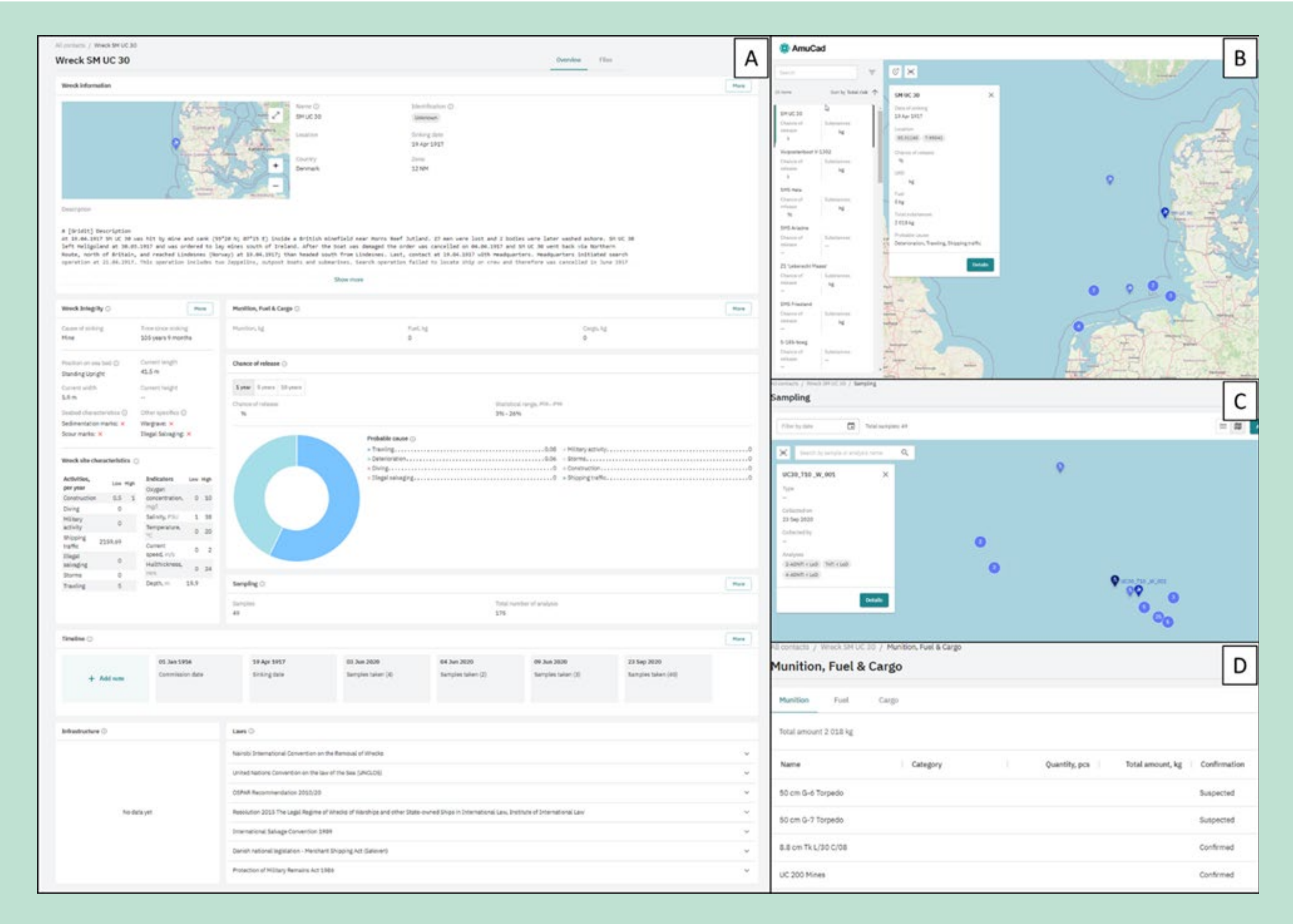


FIGURE 17. Example of user interface from WRECKNS tool at the SM UC30 wreck, showing A) Summary sheet including 'chance of release', B) Map overview with total amount of pollutants, C) Sample overview, D) Pollutant (munition, fuel, and cargo) overview. © north.io GmbH.

With the known Danish wrecks in the database, risk assessment and in turn decision support regarding how to handle wrecks in the Danish territorial waters could be accomplished. Another benefit of using the VRAKA or WRECKNS tools is that these systems are available across Europe and hence already geared towards the transnational collaborative efforts needed to solve the problem with wrecks and munitions in the sea.

5. Discussion and Perspectives

This final chapter discusses some general issues related to wrecks and further presents perspectives as to how the work related to risk assessment of wrecks in the Danish waters could continue.

5.1 Scale and temporal evolution

Investigating the subject of wrecks and dumped munitions quickly reveals that this is a substantial problem. The Baltic Sea is estimated to contain ca. 50,000 tons of dumped CWAs and at least 200,000 tons of conventional munitions from WWI and WWII (http://www.daimonproject.com/), and though the numbers for the North Sea are more uncertain they are likely in the same range of order.

For wrecks, the numbers are still very uncertain but one report from the NORTH SEA WRECKS project states that “As a transnational project, North Sea Wrecks is a trailblazer in this regard. Based on a comparison of the different datasets, we calculate that there are at least 680 wrecks from World Wars One and Two on the North Sea bed that could potentially contain some quantity of munitions. Of these, more than 160 lie in the Norwegian Part of the North Sea, and more than 240 in Danish waters, at least 120 in German waters, min. 60 in Dutch waters and around 100 in Belgian waters”. Denmark is thus likely to have several hundreds of problematic wrecks, that contain munitions, and adding to this, wrecks without munitions may also pose a risk to the marine environment in the case of bunker oil leakage or similar.

The amount of pollutants (e.g. from munition) on discrete wrecks is the most critical parameter for the risk assessment. This is however very hard to assess because it relies on information about the vessel’s operations up to the wreckage - in terms of determining its remaining cargo and fuel, and on evaluations of the current state of the wreck, from either diving or remote sensing inspections. For the SM UC30 submarine in the Danish waters, the combined efforts of historical archive searches - where blueprints, cargo lists, and ship logs revealed the final operations of the submarine, together with geophysical and diver-base investigations and sampling, led to an estimate of the wreck currently containing over 2000 kg of TNT (Fig. 17D). Thus, this wreck is a high-risk wreck where leakage is currently ongoing and is likely to increase in the future.

Time generally escalates the risks from wrecks because the probability of discharge continues to grow as the wrecks degrade due to physical tear-down from natural processes (redistribution of seafloor sediments under the influence of current-, wave-, tidal- and storm-induced erosion) and human activities (particular dredging and trawling), and from corrosion (e.g., Scharsack et al., 2021). Eventually, the physical tear-down and corrosion will remove the protective casings and housings of the dangerous munitions increasing the risk of discharge from the wrecks and in turn, the amount of pollutants released to the marine environment (e.g. Scharsack et al., 2021). Climate change with warming and ocean acidification may further speed up the process of corrosion (Scharsack et al., 2021), as well as the natural erosion-related seafloor processes due to more extreme weather. Several other stressors may also be negatively influenced by climate changes and in turn, place additional cumulative pressure on the marine ecosystems (Andersen et al., 2017b).

Expansion of human activities into the marine areas is also likely to increase in the future, with some activities driven by the ambitious green transition plans that involves huge growths in the number of offshore windmills and construction of energy islands (RePowerEU). It is thus required that the North Sea and the Baltic Sea become safe areas for Blue Growth operations.

For several purposes including a clean and safe marine environment, the risk from wrecks is therefore important to understand, monitor, and mitigate.

5.2 How to deal with hazardous wrecks?

Awareness and knowledge exchange

Both the DAIMON, NORTH SEA WRECKS and several other research projects have resulted in new knowledge and further gathered data from specific wrecks and dumped munitions within the Danish waters. Hence, a best practice approach for sample collection and laboratory analyses that can help to observe and understand the potential pollution from wrecks has been developed. Both projects also offer solutions for risk assessment and decision support when it comes to wrecks. Knowledge and awareness of risks from wrecks is thus rising, as a natural derivative from the increased focus and concern on marine environments (e.g., UNs Decades of Oceans program).

Risk assessment tools

One clear recommendation from this pilot study is to initiate the risk assessment from wrecks within the Danish waters using already developed risk assessment tools. All relevant information from known wrecks in the Danish waters should therefore be uploaded to the WRECKNS database, that currently only holds information about two wrecks in the Danish EEZ. The upload of information will be a relatively huge task given the number of wrecks in the Danish waters, but big data analytics could likely be implemented to support the process. Based on the uploaded information, risk assessment for the discrete known wrecks can be carried out using the tool. If linked with cumulative effect analyses, hotspot definitions guided by the decision support system in the tool, will clarify how urgent the problem is for the various parts of the Danish waters, and further provide input to which actions could be implemented.

Remediation efforts

Remediation of munitions in the sea is a debated subject. The most commonly used method is the blasting in place (BiP) operation with a so-called high order detonation, where the UXO is charged to explode. This method has the benefits of removing most of the problematic explosive material, but it severely damages the seafloor (by creating huge craters) and further has a very high impact in terms of underwater noise (e.g., Robinson et al. 2022). Some studies have also shown that the high order BiP operation can lead to increased pollution if the explosion does not combust all of the explosive material (e.g., Maser & Strehse, 2020).

The alternative deflagration (low order method) works by burning the explosive material using a much smaller charge that does not lead to detonation (e.g., Mietkiewicz, 2022). The low order method has shown good effects in terms of minor seafloor damage and significantly lower underwater noise levels (e.g., Robinson et al., 2020). The effects regarding pollution for the low order method however remain uncertain. But for the same reasons as the high order BiP operation, the low order method may potentially lead to more pollution. Due to the lower temperatures in the low order method, the chance of not disposing all the explosive material might be higher for the low order deflagration compared to the high order detonation. More research is however needed on this subject.

Wrecks are, due to their size more difficult to handle, and complete salvage is likely not a relevant remediation approach for most cases. Removal of specific munition on a wreck by divers or by using underwater robotics could likely help mitigate some of the most hazardous wrecks. The procedure is however tedious and of risk to the divers. The final success of such an approach also depends on whether the removed munitions can in fact be transported safely to another area (e.g., on land) where a safe and clean disposal can be performed. Alternatively, the marking of wrecks as restricted access areas may be relevant for a certain amount of time if a wreck only shows little and/or local pollution.

5.3 National and transnational collaboration

Denmark currently lacks knowledge of the amount, location, and risks from wrecks in the Danish waters. As the knowledge and the awareness of wrecks is steadily increasing, due to the increased focus on the use of the marine areas for recreation, energy production, and wildlife protection, there is furthermore a need for a strategy of how to handle potential risks from wrecks in terms of remediation and mitigation. To accommodate both the lack of knowledge and lack of strategy requires a stronger collaboration across the Danish authorities in the relevant governmental institutions. For instance, most of the information about wrecks is currently scattered across several institutions such as the Geodata Agency, the Agency for Culture and Palaces, the Environmental Protection Agency, and the Royal Danish Navy Mine Clearance Unit. Wrecks influence maritime activities (shipping, fishery), the marine ecosystem, and can also represent cultural heritage objects, so it is natural that assessment of wrecks requires national collaboration. A big step forward would be to harmonize and combine information from the various national governmental institutions and making the information findable and accessible from one single platform (the WRECKNS database). The use of a common database would homogenize the information and enable a comparison of wrecks, allowing for prioritizing which wrecks needs attention. Additionally, there are more private actors, such as the Sea War Museum Jutland, that currently has valuable and relevant information about wrecks in the Danish waters. It is essential that this information is activated, so that it can contribute to constraining a common knowledge of wrecks in Denmark. Hence, the task also calls upon more collaboration between the private and governmental actors.

Since wrecks and munitions in the sea is a global and transnational problem, that is legislated and regulated at both national and EU levels, it is important that the solutions and monitoring programs are also developed transnationally, so that difficulties related to across-borders collaborations can be overcome. The EU funded Interreg research projects (e.g., DAIMON and NORTH SEA WRECKS) show how results from transnational projects have a better chance of being implemented in more countries and in turn stimulate more future transnational collaboration. One example is the development of the Baltic Sea Action Plan that include dumped ammunition and wrecks.

5.4 Further work

Recent research has established that WWI and WWII wrecks do pose a potential point pollution source in the marine and coastal environments, with leakage of pollutants from war-related cargo and munitions (Maser et al., 2023). However, there are still open questions that requires more research. These include:

- What is the effect distance of pollution from wrecks and how will for instance carcinogenic compounds leaking from wrecks behave when entering the marine environment? What is the spreading distance and how long will the pollutants remain in the environment?
- Are there differences as to where the pollutants accumulate? For instance, with respect to the grainsize of the seafloor sediments (a muddy versus a sandy seafloor) or between the various medias (sediment, water and biota)? And how do the geological and biological processes around the wreck influence the spatial and temporal risk for contamination of the environment?
- Do pollutants from WWI and WWII wrecks enter the seafood, and is there a human health risk? Studies on this subject have only recently been initiated, but the topic requires more focus since this is one of the potential long-term effects of the pollution that is little understood.
- How is the temporal evolution of risk and effects from polluting wrecks and dumped munitions, particularly in the light of climate change and warming oceans?
- What is the best practice for remediation and disposal of hazardous cargo from the wrecks?

6. Conclusions

The purpose of this pilot project was to build knowledge for the location and number of historical wrecks in the Danish waters, identify possible pollutants from wrecks, discuss the cumulative effects from wrecks, and recommend a best method for risk assessment of wrecks.

Based on the analyses in the pilot study, the following conclusions can be reached:

- Wrecks are a potential point pollution source in the marine and coastal environments and should therefore be included in future cumulative effect analyses.
- The distance-of-effect from many wrecks is likely to be only local. There are however only few studies dealing with this subject, and the effect distance from wrecks should therefore be investigated in more detail.
- The main agent of concern for pollution is carcinogenic compounds leaking from explosives material in munitions that were part of the cargo on WWI and WWII wrecks (e.g., mines, torpedoes, grenades).
- Mapping and first-hand classification of wrecks in the Danish waters with regard to importance concerning impact on chemical condition is possible to carry out using public available information from various databases.
- The first-hand classification will however have a high inherent uncertainty due to the unharmonized information that exists for discrete wrecks.
- It is recommended to combine the existing information from known wrecks in the Danish waters into one database – such as the already developed risk assessment and decision support tool WRECKNS.
- According to results from the NORTH SEA WRECKS project, the North Sea bed in the Danish EEZ hosts the highest number of wrecks containing munitions, compared to the Norwegian, German, Dutch and Belgian North Sea bed. There is however currently only a fragmented effort towards the subject of wrecks and underwater munitions at national level.
- Therefore, there is a need for a national strategy on how to monitor, remediate and mitigate the risk from wrecks in the Danish waters. This requires much more collaboration across the Danish governmental institutions as well as towards relevant private actors.
- It is furthermore critical that the solutions are developed transnationally in association with our neighbouring countries around the Baltic Sea and the North Sea, to secure sustainable and widely usable solutions.

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Appendix

This is an appendix to the report: "Pilot study for source pollution detection and risk assessment practices for historical wrecks with and without ammunition". The appendix consists of four parts (A-D)

A: List of priority substances within EU's water policy

Copy of Table 2 from: https://www.retsinformation.dk/eli/lta/2017/1625#id393d7f02-4ddb-4cc6-918a-9c7866c469b8 with addition of two extra columns – one indicating whether the substance occurs on shipwrecks (comparison with Table 10 in report) and another indicating type of pollutant with respect to subdivision on page 26 in the report:

1. Pollutants from the wreck itself. These include various metals, plastics, paintings etc.
2. Pollutants from fuel and lubricants used as consumables on the vessels. These include various petroleum products (hydrocarbons) and other chemicals.
3. Pollutants from warfare related cargo and munitions. These include:
   a. Energetic chemicals used for explosives materials such as carcinogenetic trinitrotoluene TNT.
   b. Chemical warfare agents such as mustard gas and similar.
   c. Metals used for casing, housing, driving bands, fuses, and initiators of explosives such as mercury and lead.

TABLE 13.

1) CAS: Chemical Abstracts Service.
2) EU-nummer: Den Europæiske Fortegnelse over Markedsførte Kemiske Stoffer (Einecs) eller Den Europæiske Liste over Anmeldte Kemiske Stoffer (Elincs).
3) Hvor der er udvalgt en gruppe af stoffer, er typiske enkeltstoffer udpeget til fastsættelse af miljøkvalitetskrav, medmindre andet udtrykkelig er angivet.
4) Kun tetra-, penta-, hexa- og heptabrombiphenylether (CAS henholdsvis 40088-47-9, 32534-81-9, 36483-60-0, 68928-80-3).
5) Nonylphenol (CAS 25154-52-3, EU 246-672-0), herunder isomererne 4-nonylphenol (CAS 104-40-5, EU 203-199-4) og 4-nonylphenol (forgrenet) (CAS 84852-15-3, EU 284-325-5).
6) Octylphenol (CAS 1806-26-4, EU 217-302-5), herunder isomeren 4-(1,1,3,3-tetramethylbutyl)-phenol (CAS 140-66-9, EU 205-426-2).
7) Herunder benz(a)pyren (CAS 50-32-8, EU 200-028-5), benz(b)fluoranthen (CAS 205-99-2, EU 205-911-9), benz(g,h,i)perylen (CAS 191-24-2, EU 205-883-8), benz(k)fluoranthen (CAS 207-08-9, EU 205-916-6) og indeno(1,2,3-cd)pyren (CAS 193-39-5, EU 205-893-2), men ikke anthracen, fluoranthen og naftalen, som er opført særskilt.
8) Herunder tributyltin-kation (CAS 36643-28-4).
9) Dette gælder for følgende forbindelser:
– 7 polychlorerede dibenzo-p-dioxiner (PCDD): 2,3,7,8-T4CDD (CAS 1746-01-6), 1,2,3,7,8-P5CDD (CAS 40321-76-4), 1,2,3,4,7,8-H6CDD (CAS 39227-28-6), 1,2,3,6,7,8-H6CDD (CAS 57653-85-7), 1,2,3,7,8,9-H6CDD (CAS 19408-74-3), 1,2,3,4,6,7,8-H7CDD (CAS 35822-46-9) og 1,2,3,4,6,7,8,9-O8CDD (CAS 3268-87-9)
– 10 polychlorerede dibenzofuraner (PCDF): 2,3,7,8-T4CDF (CAS 51207-31-9), 1,2,3,7,8-P5CDF (CAS 57117-41-6), 2,3,4,7,8-P5CDF (CAS 57117-31-4), 1,2,3,4,7,8-H6CDF (CAS 70648-26-9), 1,2,3,6,7,8-H6CDF (CAS 57117-44-9), 1,2,3,7,8,9-H6CDF (CAS 72918-21-9), 2,3,4,6,7,8-H6CDF (CAS 60851-34-5), 1,2,3,4,6,7,8-H7CDF (CAS 67562-39-4), 1,2,3,4,7,8,9-H7CDF (CAS 55673-89-7), 1,2,3,4,6,7,8,9-O8CDF (CAS 39001-02-0)

– 12 dioxinlignende polychlorerede biphenyler (DL-PCB): 3,3,4,4-T4CB (PCB 77, CAS 32598-13-3), 3,3,4,5-T4CB (PCB 81, CAS 70362-50-4), 2,3,3,4,4-P5CB (PCB 105, CAS 32598-14-4), 2,3,4,4,5-P5CB (PCB 114, CAS 74472-37-0), 2,3,4,4,5-P5CB (PCB 118, CAS 31508-00-6), 2,3,4,4,5-P5CB (PCB 123, CAS 65510-44-3), 3,3,4,4,5-P5CB (PCB 126, CAS 57465-28-8), 2,3,3,4,4,5-H6CB (PCB 156, CAS 38380-08-4), 2,3,3,4,4,5-H6CB (PCB 157, CAS 69782-90-7), 2,3,4,4,5,5-H6CB (PCB 167, CAS 52663-72-6), 3,3,4,4,5,5-H6CB (PCB 169, CAS 32774-16-6) og 2,3,3,4,4,5,5-H7CB (PCB 189, CAS 39635-31-9).
10) CAS 52315-07-8 gælder for en isomerblanding af cypermethrin, alpha-cypermethrin (CAS 67375-30-8), beta-cypermethrin (CAS 65731-84-2), theta-cypermethrin (CAS 71697-59-1) og zeta-cypermethrin (52315-07-8).
11) Dette gælder for 1,3,5,7,9,11-hexabromcyclododecan (CAS 25637-99-4), 1,2,5,6,9,10-hexabromcyclododecan (CAS 3194-55-6), α-hexabromcyclododecan (CAS 134237-50-6), β-hexabromcyclododecan (CAS 134237-51-7) og γ-hexabromcyclododecan (CAS 134237-52-8).

Number	CAS-number [1)]	EU-number [2)]	Name of prioritized substance	Identified as prioritized dangerous substance	Could potentially be present on wrecks (compared with Table 10 in report)	Pollutant classification as defined on page 26 in report
1	15972-60-8	240-110-8	alachlor			
2	120-12-7	204-371-1	antracen	X		
3	1912-24-9	217-617-8	atrazin			
4	71-43-2	200-753-7	benzen		Y	3
5	anvendes ikke	anvendes ikke	bromerede diphenylethere	X[4)]		
6	7440-43-2	231-152-8	cadmium og cadmiumforbindelser	X	Y	3
7	85535-84-8	287-476-5	chloralkaner, C_{10-13}	X		
8	470-90-6	207-432-0	chlorfenvinphos			
9	2921-88-2	220-864-4	chlorpyrifos (chlorpyrifosethyl)			
10	107-06-2	203-458-1	1,2-dichlorethan			
11	75-09-2	200-838-9	dichlormethan			
12	117-81-7	204-211-0	di(2-ethylhexyl)ftalat (DEHP)	X		
13	330-54-1	206-354-4	diuron			
14	115-29-7	204-079-4	endosulfan	X		
15	206-44-0	205-912-4	fluoranthen			
16	118-74-1	204-273-9	hexachlorbenzen	X		
17	87-68-3	201-765-5	hexachlorbutadien	X		
18	608-73-1	210-168-9	hexachlorcyclohexan	X		
19	34123-59-6	251-835-4	isoproturon			
20	7439-92-1	231-100-4	bly og blyforbindelser		Y	(1), 3
21	7439-97-6	231-106-7	kviksølv og kviksølvforbindelser	X	Y	3
22	7440-38-2	202-049-5	naftalen		Y (Arsenic 7440-38-2)	3
23	7440-02-0	231-111-4	nikkel og nikkelforbindelser		Y	(1), 3
24	anvendes ikke	anvendes ikke	nonylphenoler	X[5)]		
25	anvendes ikke	anvendes ikke	octylphenoler[6)]			
26	608-93-5	210-172-0	pentachlorbenzen	X		

27	87-86-5	201-778-6	pentachlorphenol			
28	anvendes ikke	anvendes ikke	polyaromatiske kulbrinter (PAH)[7)]	X	Y (benzo (a) pyren 50-32-8)	3
29	122-34-9	204-535-2	simazin			
30	anvendes ikke	anvendes ikke	tributyltinforbindelser	X[8)]		
31	12002-48-1	234-413-4	trichlorbenzener			
32	67-66-3	200-663-8	trichlormethan (chloroform)			
33	1582-09-8	216-428-8	trifluralin	X		
34	115-32-2	204-082-0	dicofol	X		
35	1763-23-1	217-179-8	perfluoroctansulfonsyre og derivater heraf (PFOS)	X		
36	124495-18-7	anvendes ikke	quinoxyfen	X		
37	anvendes ikke	anvendes ikke	dioxiner og dioxinlignende forbindelser	X[9)]		
38	74070-46-5	277-704-1	aclonifen			
39	42576-02-3	255-894-7	bifenox			
40	28159-98-0	248-872-3	cybutryn			
41	52315-07-8	257-842-9	Cypermethrin[16)]			
42	62-73-7	200-547-7	dichlorvos			
43	anvendes ikke	anvendes ikke	hexabromcyclododecaner (HBCDD)	X[11)]		
44	76-44-8/1024-57-3	200-962-3/213-831-0	heptachlor og heptachlorepoxid	X		
45	886-50-0	212-950-5	terbutryn			

B: List of nationally established environmental quality standards for water

Copy of Table 3 from: https://www.retsinformation.dk/eli/lta/2017/1625#id393d7f02-4ddb-4cc6-918a-9c7866c469b8 with addition of two extra columns – one indicating whether the substance occurs on shipwrecks (comparison with Table 10 in report) and another indicating type of pollutant with respect to subdivision on page 26 in the report.

TABLE 14.

1) CAS: Chemical Abstracts Service.
2) Denne parameter er miljøkvalitetskravet udtrykt som årsgennemsnit (generelt kvalitetskrav). Medmindre andet er angivet, gælder det for den samlede koncentration af alle isomerer.
3) Denne parameter er miljøkvalitetskravet udtrykt som højeste tilladte koncentration (maksimumkoncentration).
4) Indlandsvand omfatter vandløb og søer og dertil knyttede kunstige eller stærkt modificerede vandområder.
5) Kvalitetskravet er denne koncentration af stoffet tilføjet den naturlige baggrundskoncentration, jf. dog note 6. Gælder ikke i kombination med note 7.
6) Kvalitetskravet angiver den øvre koncentration af stoffet uanset den naturlige baggrundskoncentration.
7) Kvalitetskravet gælder for den biotilgængelige koncentration af stoffet. Gælder ikke i kombination med note 5.
8) Kvalitetskravet gælder for blødt vand (H<24 mg $CaCO_3$/l).

CAS-number 1)	Substance name	General quality requirement µg/L 2)		Maximum concentration µg/L 3)		Could potentially be present on wrecks (compared with Table 10 in report)	Pollutant classification as defined on page 26 in report
		Inland water 4)	Other surface water	Inland water 4)	Other surface water		
75-05-8	acetonitril	2000	200	191000	19000		
83-32-9	acenaphten (PAH)	3,8	0,38	3,8	3,8		
208-96-8	acenaphthylen (PAH)	1,3	0,13	3,6	3,6		
107-02-8	acrolein (acrylaldehyd)	0,1	0,01	1	1		
393085-45-5	2-amino-4-(methylsulphonyl)benzosyre, AMBA	77	7,7	140	14		
41668-11-5	6-amino-5-chlornicotinsyre, clampyrsyre	95	9,5	949	95		
26787-78-0	amoxcillin	0,078	0,078	0,37	0,37		
118-92-3	anthranilsyre	19,4	1,94	194	194		
7440-36-0	antimon	113	11,3	177	177		
7440-38-2	arsen	4,3	0,6 5)	43	1,1 5)	Y	3
7440-39-3	barium	19 5)	5,8 5)	145	145		
25057-89-0	bentazon	45	45	450	450		
56-55-3	benz(a)anthracen (PAH)	0,012	0,0012	0,018	0,018		
94-09-7	benzocain	7,2	0,72	72	72		
65-85-0	benzoesyre	90	9	900	900		
100-51-6	benzylalkohol	360	36	3600	3600		
98-87-3	benzylidenchlorid (alfa, alfa-dichlortoluen)	0,21	0,021	2,1	2,1		
50-28-2	17-beta-østradiol	0,0001	0,0001	4,6	4,6		
80-05-7	bisphenol A	0,1	0,01	10	10		

	2,2-bis(4-hydroxyphenyl)propan						
7440-42-8	bor	94[5)] 20000[6)]	94[5)] 20000[6)]	2080[5)]	2080[5)]		
3844-45-9	Brilliant Blue	96	9,6	960	960		
7722-84-1	brintoverilte	10[5)]	10[5)]	100	100		
85-68-7	butylbenzylftalat (BBP)	7,5	0,75	15	15		
79456-26-1	chlampyr	0,08	0,08	160	160		
29091-09-6	chlonibenz (2,4-dichlor-3,5-dinitro-benzotrifluorid)	0,0006	0,00006	0,06	0,06		
97-00-7	1-chlor-2,4-dinitrobenzen (DNCB)	5	0,5	37	37		
90-13-1 91-58-7	1-chlornaftalen 2-chlornaftalen	∑ = 2,7	∑ = 0,54	∑ = 3,7	∑ = 3,7		
89-63-4	4-chlor-2-nitroanilin	1	0,1	10	10		
59-50-7	4-chlor-3-methylphenol (PCMC)	9	0,9	90	90		
95-74-9	3-chlor-p-toluidin	0,62	0,062	62	62		
130-16-5	5-chlor-8-quinolinol (CHO)	0,027	0,0027	0,27	0,027		
88349-88-6	5-chloro-8-quinolinol-oxy (CLOQ-syre)-(9CL)	30	3	300	30		
57-15-8 1320-66-7	chlorbutanol	135	14	1350	135		
79-11-8	chloreddikesyre (MCAA)	0,58	0,058	3,3	3,3		
126-99-8	chlorpren (2-chlorbuta-1,3-dien)	32	3,2	2000	2000		
615-65-6	2-chlor-p-toluidin	0,62	0,062	62	62		
89402-40-4	4-(5-chloro-3-fluoro-2-pyri-dinnyloxy)phenol	2,4	0,24	24	2,4		
114420-56-3	clodinafop	3,2	0,32	450	45		
105512-06-9	clodinafop-propargyl	10	1	21	2,1		
56-72-4	coumaphos	0,0007	0,00007	0,007	0,007		
7440-47-3	chrom	Cr VI Cr III	3,4 4,9	3,4 3,4	17 124	17 124	Y (Chromium VI 18540-29-9)	3
218-01-9	chrysen	0,014	0,0014	0,014	0,014		
7440-48-4	cobolt	0,28[5)]	0,28[5)]	18	34	Y	3
108-39-4 95-48-7 106-44-5	m-cresol o-cresol p-cresol	∑ = 100	∑ = 10	∑ = 1000	∑ = 1000		
504-02-9	1,3-cyclohexandion (1,3 CHD)	24	24	240	240		
913545-19-4 1156459-77-6	2-cyclohexen-1-on,3hydroxy-2-(6-(methylsulfonyl)-2,1-benzisoxazol-3-yl), M4	47,6	4,8	476	47,6		
103-23-1	di(2-ethylhexyl)adipat (DEHA)	0,7	0,07	6,6	0,66		
53-70-3	dibenz(a,h)anthracen (PAH)	0,0014	0,00014	0,018	0,018		
106-93-4	1,2-dibromethan	0,002	0,002	0,02	0,02		
84-74-2	dibutylftalat (DBP)	2,3	0,23	35	35		
69045-84-7	dichlopyr	0,53	0,53	30	30		
2008-58-4	2,6-dichlorbenzamid (BAM)	78	7,8	780	780		
91-94-1	dichlorbenzidiner (3,3'-dichlorbenzi-din), (DCB)	0,001	0,001	0,01	0,01		
75-34-3	1,1-dichlorethan	10	10				

540-59-0 75-35-4	1,2-dichlorethylen 1,1-dichlorethylen	6,8	0,68	68	68		
120-83-2	2,4-dichlorphenol	0,2	0,2	20	6		
87-65-0	2,6-dichlorphenol	3,4	0,34	34	34		
15165-67-0 120-36-5	dichlorprop-p (dichlorprop)	41	4,1	41	41		
342-25-6	difluorbenzophenon	0,082	0,0082	8,2	8,2		
887502-60-5	3,4-dihydro-6-(methylsulphonyl)-1H-xanthene-1,9(2H)-dion, Xanth	83	8,3	830	83		
68-12-2	dimethylforamid	22800	2280	22800	22800		
576-26-1 105-67-9 108-68-9 95-65-8 526-75-0 95-87-4 1300-71-6	dimethylphenol (6 isomerer af dimethylphenol)	∑ = 13,1	∑ = 1,31	∑ = 132	∑ = 132		
75-18-3	dimethylsulfid	15	15	230	230		
13472-45-2	dinatriumwolframat	33	3,3	330	33		
383412-05-3	eddikesyre, chloro-, 1-methylhexyl ester (ACM-ester)	0,036	0,0036	0,36	0,036		
99607-70-2	eddikesyre, ((5-chloro-8-quionolinyl)oxy)-, 1-methylhexyl ester (CLOQ)	0,02	0,002	5,3	0,53		
57-63-6	ethinyløstradiol	0,000075	0,000075	0,00075	0,00075		
110-76-9	2-ethoxyethylamin	152	15,2	1520	150		
100-41-4	ethylbenzen	20	2	180	180		
76639-94-6	florfenicol	7	2,1	21	3,4		
79622-59-6	fluazinam	0,29	0,029	0,36	0,36		
462-06-6	fluorbenzen	7,4	0,74	74	74		
445-29-4	2-fluorbenzosyre	900	90	9000	9000		
86-73-7	fluoren	2,3	0,23	21,2	21,2		
88374-05-04	fluorphenylepoxyethan (FOX)	0,048	0,0048	4,8	4,8		
76674-21-0	flutriafol	31	3,1	31	31		
54041-17-7	FOE-hydroxy	23	2,3	230	23		
201668-31-7	FOE-oxalat	4750	475	47500	4750		
201668-32-8	FOE-sulfonsyre	760	76	980	98		
50-00-0	formaldehyd	9,2 [5)]	9,2 [5)]	46	46		
16872-11-0	HBF_4	830	83	8300	830		
94050-90-5	HPPA	35	3,5	350	35		
514797-96-7	2-hydroxy-3-fluor-5-chlor-pyridin (FCHP)	100	10	1000	100		
611-70-1	isobutyophenon	13,2	1,32	132	13		
98-82-8	isopropylbenzen (cumene)	22	2,2	22	6		
7553-56-2	jod	10 [5)]	10 [5)]	10 [5)]	10 [5)]		
562-54-9	kaliummethylsulfat	1000	100	10000	10000		
7722-64-7	kaliumpermanganat	0,84	0,084	8,4	8,4		
127-65-1	kloramin-T	5,8	0,58	5,8	5,8		

7440-50-8	kobber	1 [5)7)] 4,9 [6)]	1 [5)] 4,9 [6)]	2 [5)] 4,9 [6)]	2 [5)] 4,9 [6)]	Y	(1),3
68411-30-3	LAS	54	54	160	160		
7439-96-5	mangan	150 [5)]	150 [5)]	150 [5)]	150 [5)]		
16484-77-8 93-65-2	mechlorprop-p (mechlorprop)	18	1,8	187	187		
104206-82-8	mesotrion	0,2	0,02	0,77	0,077		
90-12-0 91-57-6 28804-88-8 28652-77-9	methylnaftalener (PAH), herunder: 1-methylnaftalen 2-methylnaftalen mimethylnaftalener (bl. af isomerer) trimethylnaftalen	∑ = 0,12	∑ = 0,12	∑ = 2	∑ = 2		
121-44-8	triethylamin	110	10	800	80		
104-96-1	4-(methylmercapto)anilin	1,5	0,15	15	1,5		
1671-49-4	1-methyl-4(methylsufonyl)-2-nitroben-zen, NMST	1000	100	5900	590		
1671-48-3	2-methyl-5-(methylsulfonyl)anilin, AMST	65	6,5	650	65		
110964-79-9	4-(methylsulphonyl)-2-nitrobenzsyre, mesosyre	1000	100	1300	130		
1634-04-4	methyl-tert-butylether (MTBE)	10	10	90	90		
7439-98-6	molybdæn	67	6,7 [5)]	587	587		
110-71-4	monoglym	500	50	5000	5000		
81-15-2	moskusxylen	0,11	0,057	0,68	0,68		
917-61-3	natriumcyanat	1	0,1	47	4,7		
14698-29-4	oxylinsyre	15	15	18	18		
79-57-2	oxytetracyklin	10	10	21	21		
106700-29-2	pethoxamid	0,12	0,012	0,12	0,0396		
85-01-8	phenanthren (PAH)	1,3	1,3	4,1	4,1		
108-95-2	phenol	7,7	0,77	310	310		
129-00-0	pyren	0,0046	0,0017	0,023	0,023		
69-72-7	salicylsyre	171	17,1	390	39		
7782-49-2	selen	0,1 [5)]	0,08 [5)]	31 [5)]	31 [5)]	Y	3
124774-27-2	S-triazol	25	2,5	250	250		
7440-24-6	strontium	2100	2100 [5)]	5530 [5)]	5530 [5)]	Y (Strontium 90 10098-97-2)	3
68-35-9	sulfadiazin	4,6	4,6	14	14		
7440-22-4	sølv	0,017 [5)]	0,5 [5)]	0,36 [5)]	1,2 [5)]	Y	(1), 3
79-34-5	1,1,2,2-tetrachlorethan	70	7	93	93		
13674-84-5	tris(2-chlor-1-methylethyl)fosfat (TCPP)	640	64	640	640		
7440-28-2	thallium	0,48 [5)]	0,048 [5)]	1,2 [5)]	1,2 [5)]		
7440-31-5	tin	2	0,2	20	20		
108-88-3	toluen	74	7,4	380	380		
288-88-0	1,2,3-triazol	64	6,4	225	225		
71-55-6	1,1,1-trichlorethan	21	2,1	54	54		
88-06-2	2,4,6-trichlorphenol	1	1	160	40		

112-27-6	triethylenglycol	120000	12000	390000	390000		
126-73-8	tri-n-butylfosfat	82	8,2	170	170		
738-70-5	trimethoprim	100	10	160	160		
115-86-6	triphenylfosfat (TPP)	0,74	0,074	1,8	1,8		
7440-61-1	uran	0,015 5)	0,015 5)	2,3 5)	2,3 5)	Y	3
7440-62-2	vanadium	4,1 5)	4,1 5)	57,8	57,8	Y (Vanadium pentoxide 1314-62-1)	3
75-01-4	vinylchlorid	0,05	0,05	0,5	0,5		
1330-20-71	xylener (o-, p- og m-xylen)	∑ = 10	∑ = 1	∑ = 100	∑ = 100		
7440-66-6	zink	7,8 5)7) 3,1 5)8)	7,8 5)	8,4 5)	8,4 5)	Y	(1), 3

C: List of nationally established environmental quality standards for sediment and biota

Copy of Table 4 from: https://www.retsinformation.dk/eli/lta/2017/1625#id393d7f02-4ddb-4cc6-918a-9c7866c469b8 with addition of two extra columns – one indicating whether the substance occurs on shipwrecks (comparison with Table 10 in report) and another indicating type of pollutant with respect to subdivision on page 26 in the report.

TABLE 15.

1) CAS: Chemical Abstracts Service.
2) Gælder for tørvægt.
3) Gælder for vådvægt af bløddele.
4) Indlandsvand omfatter vandløb og søer og dertil knyttede kunstige eller stærkt modificerede vandområder.
5) Dette kvalitetskrav gælder for den biotilgængelige koncentration af stoffet. Gælder ikke i kombination med note 6.
6) Kvalitetskravet er denne koncentration af stoffet tilføjet den naturlige baggrundskoncentration. Gælder ikke i kombination med note 5.
7) Gælder for vådvægt af sediment.
8) f_{oc} er fraktion af organisk stof i sedimentet.

CAS-number [1)]	Substance name	Environmental quality requirement Sediment mg/kg [2)]		Environmental quality requirement Biota µg/kg [3)]		Could potentially be present on wrecks (compared with Table 10 in report)	Pollutant classification as defined on page 26 in report
		Inland water [4)]	Other surface water	Inland water [4)]	Other surface water		
120-12-7	anhtracen	0,024	0,0048	2400	2400		
7439-92-1	bly	163	163	110	110	Y	(1), 3
7440-42-8	bor			5480	5480		
7440-43-9	cadmium	3,8 [5)6)]	3,8 [5)6)]	160	160	Y	3
57-63-6	ethinyløstradiol	$6{,}63 \times 10^{-6}$ [7)] $17{,}3 \times 10^{-6}$ $3{,}428 \times 10^{-4} \times f_{oc}$ [8)]		0,00609	0,00609		
90-12-0 91-57-6 28804-88-8 28652-77-9	methylnaftalener (PAH), herunder: 1-methylnaftalen 2-methylnaftalen dimethylnaftalener (bl. af isomerer) trimethylnaftalen	$\sum = 0{,}478 \times f_{oc}$ [8)]	$\sum = 0{,}478 \times f_{oc}$ [8)]	$\sum = 2400$	$\sum = 2400$		
1634-04-4	methyl-tert-butylether (MTBE)	0,081	0,081	24	24		
91-20-3	naphthalen	0,138	0,138	2400	2400	Y	3
25154-52-3	nonylphenol	$25 \times f_{oc}$ [8)]	$2{,}5 \times f_{oc}$ [8)]				
1806-26-4	octylphenol	$39{,}3 \times f_{oc}$ [8)]	$3{,}93 \times f_{oc}$ [8)]				
7440-24-6	strontium	75 [6)]	-	63000	63000	Y (Strontium 90 10098-97-2)	3
7440-22-4	sølv	1,5	13			Y	(1), 3
288-88-0	1,2,4-triazol	$5{,}5 \times f_{oc}$ [8)]	$0{,}55 \times f_{oc}$ [8)]	166000	166000		

13674-84-5	tris(2-chlor-1-methylethyl)fosfat (TCPP)	111 × f_{oc} 8)	11,1 × f_{oc} 8)				
7440-62-2	vanadium	23,6 6)	23,6 6)	122	122	Y (Vanadium pentoxide 1314-62-1)	3

D: List of EU established environmental quality standards

Copy of Table 5 from: https://www.retsinformation.dk/eli/lta/2017/1625#id393d7f02-4ddb-4cc6-918a-9c7866c469b8 with addition of two extra columns – one indicating whether the substance occurs on shipwrecks (comparison with Table 10 in report) and another indicating type of pollutant with respect to subdivision on page 26 in the report.

TABLE 16.

1) CAS: Chemical Abstracts Service.
2) Denne parameter er miljøkvalitetskravet udtrykt som årsgennemsnit (generelt kvalitetskrav). Medmindre andet er angivet, gælder det for den samlede koncentration af alle isomerer.
3) Denne parameter er miljøkvalitetskravet udtrykt som højeste tilladte koncentration (maksimumkoncentration). Hvis der under maksimumkoncentration er anført "anvendes ikke", betragtes det generelle kvalitetskrav som beskyttelse mod kortvarig høj forurening i kontinuerlige udledninger, da det er væsentligt lavere end de værdier, der er afledt af den akutte toksicitet.
4) Indlandsvand omfatter vandløb og søer og dertil knyttede kunstige eller stærkt modificerede vandområder.
5) For den gruppe prioriterede stoffer, som bromerede diphenylethere (nr. 5) omfatter, gælder kvalitetskravene for summen af koncentrationer af congenerne nummer 28, 47, 99, 100, 153 og 154.
6) For cadmium og cadmiumforbindelser (nr. 6) afhænger kvalitetskravene af vandets hårdhedsgrad, som opdeles i fem klasser (klasse 1: < 40 mg $CaCO_3$/l, klasse 2: 40 til < 50 mg $CaCO_3$/l, klasse 3: 50 til < 100 mg $CaCO_3$/l, klasse 4: 100 til < 200 mg $CaCO_3$/l og klasse 5: ≥ 200 mg $CaCO_3$/l).
7) Dette stof er ikke et prioriteret stof, men et af de andre forurenende stoffer, for hvilke miljøkvalitetskravene er identiske med de kvalitetskrav, der er fastsat i den lovgivning, der var gældende indtil den 13. januar 2009.
8) Der er ingen indikatorparameter for denne gruppe af stoffer. Indikatorparametrene skal defineres på grundlag af analysemetoden.
9) DDT i alt udgøres af summen af isomererne 1,1,1-trichlor-2,2-bis(p-chlorphenyl)ethan (CAS-nummer 50-29-3; EU-nummer 200-024-3); 1,1,1-trichlor-2-(o-chlorphenyl)-2-(p-chlorphenyl)ethan (CAS-nummer 789-02-6; EU-nummer 212-332-5); 1,1-dichlor-2,2-bis(p-chlorphenyl)ethylen (CAS-nummer 72-55-9; EU-nummer 200-784-6) og 1,1-dichlor-2,2-bis(p-chlorphenyl)ethan (CAS-nummer 72-54-8; EU-nummer 200-783-0).
10) Der foreligger ikke tilstrækkelige oplysninger til, at der kan fastsættes en maksimumkoncentration for disse stoffer.
11) For denne gruppe prioriterede stoffer, polyaromatiske kulbrinter (PAH) (nr. 28), gælder kvalitetskravene for biota og tilsvarende de generelle kvalitetskrav i vand for koncentrationen af benz(a)pyren, hvis toksicitet de er baseret på. Benz(a)pyren kan betragtes som markør for de øvrige PAH'er, og derfor behøver kun benz(a)pyren at blive overvåget med henblik på sammenligning med kvalitetskravet for biota eller de tilsvarende generelle kvalitetskrav i vand.
12) Kvalitetskrav for biota gælder for fisk, medmindre andet er anført. Et alternativt biotataxon eller en anden matrice kan overvåges i stedet, forudsat at de kvalitetskrav, der anvendes, giver et tilsvarende niveau af beskyttelse. For stof nr. 15 (fluoranthen) og 28 (PAH'er) gælder kvalitetskravene for biota for krebsdyr og bløddyr. Overvågning af fluoranthen og PAH'er i fisk er ikke hensigtsmæssig med henblik på vurdering af den kemiske tilstand. For stof nr. 37 (dioxiner og dioxinlignende forbindelser) gælder kvalitetskravene for biota for fisk, krebsdyr og bløddyr, i overensstemmelse med afsnit 5.3 i bilaget til forordning (EU) nr. 1259/2011 af 2. december 2011 om ændring af Kommissionens forordning (EF) nr. 1881/2006 for så vidt angår grænseværdier for dioxiner, dioxinlignende PCB'er og ikke-dioxinlignende PCB'er i fødevarer (EUT L 320 af 3.12.2011, s. 18).
13) Dette kvalitetskrav gælder for den biotilgængelige koncentration af stoffet.

14) PCDD: polychlorerede dibenzo-p-dioxiner; PCDF: polychlorerede dibenzofuraner; PCB-DL: dioxinlignende polychlorerede biphenyler; TEQ: toksicitetsækvivalenter ifølge Verdenssundhedsorganisationens toksicitetsækvivalensfaktorer fra 2005.
15) Gælder fra 22. december 2018.

Number	CAS-number [1)]	Substance name	General quality requirement µg/L [2)]		Maximum concentration µg/L [3)]		Environmental quality requirement Biota [12)] µg/kg wet weight	Could potentially be present on wrecks (compared with Table 10 in report)	Pollutant classification as defined on page 26 in report
			Inland water [4)]	Other surface water	Inland water [4)]	Other surface water			
1	15972-60-8	alachlor	0,3	0,3	0,7	0,7			
2	120-12-7	antracen	0,1	0,1	0,1	0,1			
3	1912-24-9	atrazin	0,6	0,6	2,0	2,0			
4	71-43-2	benzen	10	8	50	50		Y	3
5	32534-81-9	bromerede diphenylethere [5)]			0,14	0,014	0,0085		
6	7440-43-9	cadmium og cadmiumforbindelser (afhængigt af vandets hårdhedsgrad) [6)]	≤ 0,08 (klasse 1) 0,08 (klasse 2) 0,09 (klasse 3) 0,15 (klasse 4) 0,25 (klasse 5)	0,2	≤ 0,45 (klasse 1) 0,45 (klasse 2) 0,6 (klasse 3) 0,9 (klasse 4) 1,5 (klasse 5)	≤ 0,45 (klasse 1) 0,45 (klasse 2) 0,6 (klasse 3) 0,9 (klasse 4) 1,5 (klasse 5)		Y	3
6a	56-23-5	tetrachlormethan [7)]	12	12	anvendes ikke	anvendes ikke		Y (Carbon tetrachloride 56-23-5)	3
7	85535-84-8	C_{10-13}-chloralkaner [8)]	0,4	0,4	1,4	1,4			
8	470-90-6	chlorfenvinphos	0,1	0,1	0,3	0,3			
9	2921-88-2	chlorpyrifos (chlorpyrifosethyl)	0,03	0,03	0,1	0,1			
9a	309-00-2 60-57-1 72-20-8 465-73-6	cyclodien-pesticider: aldrin [7)] dieldrin [7)] endrin [7)] isoendrin [7)]	∑ = 0,01	∑ = 0,005	anvendes ikke	anvendes ikke			
9b	anvendes ikke	DDT i alt [7) 9)]	0,025	0,025	anvendes ikke	anvendes ikke			
	50-29-3	para-para-DDT 7)	0,01	0,01	anvendes ikke	anvendes ikke			
10	107-06-2	1,2-dichlorethan	10	10	anvendes ikke	anvendes ikke			
11	75-09-2	dichlormethan	20	20	anvendes ikke	anvendes ikke			
12	117-81-7	di(2-ethylhexyl)ftalat (DEHP)	1,3	1,3	anvendes ikke	anvendes ikke			

13	330-54-1	diuron	0,2	0,2	1,8	1,8			
14	115-29-7	endosulfan	0,005	0,0005	0,01	0,004			
15	206-44-0	fluoranthen	0,0063	0,0063	0,12	0,12	30		
16	118-74-1	hexachlorbenzen			0,05	0,05	10		
17	87-68-3	hexachlorbutadien			0,6	0,6	55		
18	608-73-1	hexachlorcyclohexan	0,02	0,002	0,04	0,02			
19	34123-59-6	isoproturon	0,3	0,3	1,0	1,0			
20	7439-92-1	bly og blyforbindelser	1,2 [13)]	1,3	14	14		Y	(1), 3
21	7439-97-6	kviksølv og kviksølvforbindelser			0,07	0,07	20	Y	3
22	91-20-3	naftalen	2	2	130	130		Y (Naphthalene)	3
23	7440-02-0	nikkel og nikkelforbindelser	4 [13)]	8,6	34	34		Y	(1), 3
24	84852-15-3	nonylphenoler (4-nonylphenol)	0,3	0,3	2,0	2,0			
25	140-66-9	octylphenoler (4-(1,1',3,3'-tetramethylbutyl)-phenol)	0,1	0,1	anvendes ikke	anvendes ikke			
26	608-93-5	pentachlorbenzen	0,007	0,0007	anvendes ikke	anvendes ikke			
27	87-86-5	pentachlorphenol	0,4	0,4	1	1			
28	anvendes ikke	polyaromatiske kulbrinter (PAH) 11)	anvendes ikke	anvendes ikke	anvendes ikke	anvendes ikke			
	50-32-8	benz(a)pyren	$1,7 \times 10^{-4}$	$1,7 \times 10^{-4}$	0,27	0,27	5	Y	3
	205-99-2	benz(b)fluoranthen	se fodnote 11	se fodnote 11	0,017	0,017	se fodnote 11		
	207-08-9	benz(k)fluoranthen	se fodnote 11	se fodnote 11	0,017	0,017	se fodnote 11		
	191-24-2	benz(g,h,i)perylen	se fodnote 11	se fodnote 11	$8,2 \times 10^{-3}$	$8,2 \times 10^{-4}$	se fodnote 11		
	193-39-5	indeno(1,2,3-cd)-pyren	se fodnote 11	se fodnote 11	anvendes ikke	anvendes ikke	se fodnote 11		
29	122-34-9	simazin	1	1	4	4			
29a	127-18-4	tetrachlorethylen [7)]	10	10	anvendes ikke	anvendes ikke			
29b	79-01-6	trichlorethylen [7)]	10	10	anvendes ikke	anvendes ikke			
30	36643-28-4	tributyltin-forbindelser (tributyltinkation)	0,0002	0,0002	0,0015	0,0015			
31	12002-48-1	trichlorbenzener	0,4	0,4	anvendes ikke	anvendes ikke			
32	67-66-3	trichlormethan	2,5	2,5	anvendes ikke	anvendes ikke			
33	1582-09-8	trifluralin	0,03	0,03	anvendes ikke	anvendes ikke			
34	115-32-2	dicofol	$1,3 \times 10^{-3}$ [15)]	$3,2 \times 10^{-5}$ [15)]	anvendes ikke [10)]	anvendes ikke [10)]	33 [15)]		

35	1763-23-1	perfluoroctansulfon-syre og derivater heraf (PFOS)	$6,5 \times 10^{-4}$ 15)	$1,3 \times 10^{-4}$ 15)	36 15)	7,2 15)	9,1 15)			
36	124495-18-7	quinoxyfen	0,15 15)	0,015 15)	2,7 15)	0,54 15)				
37	Se fodnote 9 til tabel 2	dioxiner og dioxinlignende forbindelser			anvendes ikke	anvendes ikke	Summen af PCDD + PCDF + PCB-DL 0,0065 µg kg-1 TEQ 14) 15)			
38	74070-46-5	aclonifen	0,12 15)	0,012 15)	0,12 15)	0,012 15)				
39	42576-02-3	bifenox	0,012 15)	0,0012 15)	0,04 15)	0,004 15)				
40	28159-98-0	cybutryn	0,0025 15)	0,0025 15)	0,016 15)	0,016 15)				
41	52315-07-8	cypermethrin	8×10^{-5} 15)	8×10^{-6} 15)	6×10^{-4} 15)	6×10^{-5} 15)				
42	62-73-7	dichlorvos	6×10^{-4} 15)	6×10^{-5} 15)	7×10^{-4} 15)	7×10^{-5} 15)				
43	Se fodnote 11 til tabel 2	hexabromcyclo-dodecan (HBCDD)	0,0016 15)	0,0008 15)	0,5 15)	0,05 15)	167 15)			
44	76-44-8/1024-57-3	heptachlor og heptachlorepoxid	2×10^{-7} 15)	1×10^{-8} 15)	3×10^{-4} 15)	3×10^{-5} 15)	$6,7 \times 10^{-3}$ 15)			
45	886-50-0	terbutryn	0,065 15)	0,0065 15)	0,34 15)	0,034 15)				

Pilot study for source pollution detection and risk assessment practices for historical wrecks with and without ammunition

Several thousand wrecks occur in the Danish waters. Some of these may pose a risk to the marine and coastal environments if leakage of bunker oil or pollutants from warfare cargo occur. In this pilot project, the purpose is to gather knowledge on how to map wrecks in the Danish waters, and dis-cuss the best approaches for risk assessment of wrecks relative to impact on cumulative effects. It is recommended to add current knowledge of wrecks in the Danish waters to already developed risk assessment tools such as the WRECKNS tool. In such tools, wreck-specific and site-specific information can be added to evaluate the probability of leakage and the effects of leakage, and to guide the integrated decision support system. Furthermore, there is a need for more research on pollution effect distance from wrecks as well as how the risk varies spatially and temporally in the light of climate changes. National collaboration between Danish govern-mental institutions (agencies, museums, military) and towards private actors should be strengthened as should the transnational collaboration. Hazard-ous wrecks are a growing global problem that should be remediated and mitigated collectively with widely usable solutions.

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