Baltic Marine Environment Protection Commission

Response Working Group
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Background

RESPONSE 28-2020 invited interested parties to draft an excerpt based on the draft Submerged Assessment on “recent science on warfare materials”, to be submitted for approval to RESPONSE 29-2021. The focus of the excerpt should be on recent scientific results and background information found crucial to initiate a comprehensive interdisciplinary discussion on the national level among HELCOM Contracting Parties (c.f. paragraph 9.8 of the Outcome).

The attached excerpt has been prepared by interested parties, as requested by RESPONSE 28-2020.

Work has also continued on the full Submerged Assessment and it is expected to be finalized for submission for approval to RESPONSE 30-2022 in early 2022.

Action requested

The Meeting is invited to approve the attached excerpt – Warfare materials in the Baltic Sea, for publication on the HELCOM website.

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Warfare Materials in the Baltic Sea

EXCERPT

HELCOM Submerged

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Content

Executive Summary

Where are we at?

Warfare materials in the Baltic Sea are of quite special concern. This water body is under intensive human use for generations and multiple interests of different tribes, confessions and political powers, leading to peaceful and violent eras. Since the end of World War II the Baltic Sea connects a region of reference, exemplary for multilateralism and supranational cooperation.

The Baltic Marine Environment Protection Commission – also known as the Helsinki Commission (HELCOM) – was established in 1974 to protect the marine environment of the Baltic Sea from all sources of pollution. Thus, sea-dumped chemical munitions appeared on the agenda of HELCOM's governing bodies in the early 1990s already. Since then three working groups submitted two Baltic Sea Environmental Publications and the report at hand to explain how munitions matter, why HELCOM contracting parties and all Baltic Sea related societies are affected and what measures are recommended to successfully protect this unique environment to our best future.

What are the challenges?

For nearly a century, synthetic chemical compounds where produced, deployed, released and disposed of on land and in seas and oceans – all with hardly any concern. Since the 1960s we learn more and more about the consequences of hazardous chemical materials in the natural environment and how they affect life. State-of-the-art analytical equipment allows us to find traces of carcinogenic, mutagenic and toxic compounds in different matrices taken from the Baltic Sea and to understand the observed pathological phenomena increasingly well. Even if some relations between present chemical concentrations, disease patterns and changes in marine populations are not proven yet, we cannot decline our concern. There is insufficient research to understand all interactions of multiple stress factors in marine ecosystems, but there is little doubt that they interact and may be cumulative.

Over the last decade, some 30 million Euros of public funding have been allocated to research projects in the field of munition in the seas in Europe alone. Based on earlier results the majority of science focused on the Baltic Sea to understand the status of explosive objects resting on the seabed for decades. The distribution and biological effects of Chemical Warfare Agents (CWA) were scrutinized again and results of new experiments allow transferring toxicological assessment data to models for marine biotopes.

For the three areas of concern; the residual explosive hazard of the weapons, consequences of direct contact with munitions objects and indirect effects of dissolved munitions compounds, results are pointing in the same direction: Risk increases. On the other hand, corrosion reduces the mechanical manageability of munitions. Especially thinly cased naval mines, torpedo warheads, depth charges and airborne incendiary bombs appear increasingly fragile. Under given physicochemical conditions in saltwater the aging processes changes the properties of previously stable and safe to handle explosives. This development of properties towards increased sensitivity, limits options for remediation over time. In addition, the probability of detonations due to unintentional external kinetic impacts, e.g. by anchor dropping, trawling or ploughing for underwater cable laying, has already increased.

Scientists found traces of TNT, the most produced of all anthropogenic explosives on earth, in nearly all samples of seawater and sediments. Along with the two transformation products 2-ADNT and 4-ADNT it was also measured in marine biota. These compounds are proven to act mutagenic and to cause cancer in marine life. This leads to further research needs to understand if there is a significant risk for human seafood consumers.

What should be done next?

In contrast to land-borne contamination, that introduces nitrogen or micro-plastics to the Baltic Sea, the hazardous munitions objects are situated in the area of responsibility of shipping administration, marine spatial planning offices and national marine protection authorities. Based on data, that were collected in line with offshore project development, due to requirements of the Marine Strategy Framework Directive or for other reasons, a comprehensive risk assessment appears possible and affordable if executed in cooperation. A selection of validated methods to find, identify, assess and monitor relevant marine areas is publically available. The “Practical Guide for Environmental Monitoring of Conventional Munitions in the Seas” and products of DAIMON, among others the “Catalogue of Munitions’ types”, the “EcoTox Toolbox”, and “Fact Sheets of Standard Operation Procedures” are comprehensive examples. The task is further supported by providing a science-based Decision Support System (DSS).

Ten years ago, the “bubble curtain” was judged as sufficient technology to mitigate consequences of blast in place operations, especially for the protection of marine mammals and diving seabirds. Referring to concerning eco-toxicological findings, underwater “blast in place” operations of large munition objects must come to an end. As most of the technology to safely recover munitions from the seabed is available now, engineers are envisioning new opportunities for sustainable management of munitions in the sea. Responsible decision makers get new opportunities to protect future generations.

To achieve this, the technological and one political conditions are met. We need to rapidly increase the capacity for safe destruction of munitions and munitions compounds in an environmentally friendly way. Coincidentally the establishment of a transparent, supranational financial instrument in the spirit of the founders of cooperation for peace in the Baltic Sea Region is recommended.

1. Introduction

1.1 The Warfare Materials Issue in the Baltic Sea

Contemporary society's perception of past wars is almost exclusively driven by historic sources such as film recordings, photographs and written documents that are presented in mass media. However, the legacy of these wars is still present throughout European soil and waters, including the Baltic Sea. The marine waters of every Baltic Sea state contain warfare materials. Resulting threats may be direct and short-term. Among others, fishermen, divers, offshore wind farm constructors and beachgoers are affected, while performing their daily work or while collecting objects in the surf. Other effects are indirect and long-term such as the accumulation of carcinogenic toxic substances and their metabolites in the marine food web.

Since 1974 contracting parties of the Helsinki Convention are seeking to address the increasing, environmental challenges from human activities and that were having a severe impact on the marine environment. This includes the protection of the Baltic Sea from all sources of pollution and thus munitions in the Baltic Sea are engaging HELCOM since 1993. The convention commits the signatories to take measures on conserving habitats and biological diversity and for the sustainable use of marine resources. In addition, warfare materials constitute a hazard and an obstacle for the utilization of sea floor for economic purposes. The global ocean economy is predicted to double in size by 2030, as compared to 2010, (OECD 2016). In the Blue Growth Strategy laid out by the European Commission the economic potential for the extended economic usage of the oceans was recognized and focus was placed on five blue growth sectors. Two of these sectors (ocean energy and seabed mining) require the ability to safely access large areas of the sea floor (European Commission 2017). In order to exploit the economic potential of the ocean energy and seabed resources sectors, the detection and removal of warfare materials in affected areas will become increasingly important.

Recently, numerous HELCOM member states supported increasing the knowledge concerning warfare materials in the Baltic Sea and their effects on humans and the marine environment of the Baltic Sea. As a result of national, regional and international scientific research the understanding of the issue grows and consequentially numerous recommendations, on how the warfare materials challenge can be addressed, are published. However, international coordination is necessary to identify synergies and to avoid a duplication of efforts. Authors of this report are recommending HELCOM contracting parties to provide decision makers with the most recent insights on effects of munitions in the Baltic Sea and the increasing ability to deal with the challenges caused by warfare materials in the Baltic Sea.

1.2 Introduction to HELCOM SUBMERGED

The Terms of Reference of the HELCOM Expert Group on Environmental Risks of Hazardous Submerged Objects (HELCOM SUBMERGED) were agreed upon by the HELCOM Heads of Delegation meeting HELCOM HOD 43/2013. HELCOM SUBMERGED worked under the supervision of HELCOM RESPONSE to compile and assess information about all kinds of hazardous objects and assess the associated risks. This compilation was used to produce the present thematic excerpt of the assessment on challenges related to warfare materials in the Baltic Sea.

HELCOM SUBMERGED was chaired by Jens Sternheim (MELUND – Germany), Jacek Bełdowski (Institute of Oceanology PAN – Poland) and Jorma Rytkönen (Finnish Environment

Institute (SYKE) – Finland). The group convened eight times. While the terms of reference of HELCOM SUBMERGED requested an assessment on various submerged hazardous objects, this report only covers the issue of warfare materials. This is because the number of experts on wrecks, lost dangerous goods, cargo and sea dumped waste joining the preparation of the excerpt of the assessment has unfortunately remained insufficient.

1.3 Objective and Scope of the Report

The present excerpt of the assessment has the following objectives:

1. Brief the reader on the latest scientific state of knowledge about warfare materials in the Baltic Sea and its effects.
2. Provide a short overview of past and present national and international efforts and their respective results.

The excerpt of the assessment focuses on warfare materials in the Baltic Sea. Due to its beneficial environmental conditions, research on warfare materials is often less cost and resource intensive than in the North Sea. The great majority of research results described in the subsequent chapters were generated here. Nonetheless, many of the results presented in this report can be transferred to other European waters, such as the North-, Mediterranean- and Black Seas.

Even though the warfare material issues in the Baltic Sea concerns both conventional and chemical weapons, this report leans towards reporting on conventional material. The reasons are twofold: Firstly, the vast majority of warfare materials are conventional. Secondly, the HELCOM report Chemical Munitions Dumped in the Baltic Sea (2013) already covers the issue of chemical warfare materials. For this reason, the report at hand addresses chemical warfare materials mainly in cases in which more recent knowledge was gained.

According to reviewed Terms of reverence, the Expert Network SUBMERGED will continue to prepare a comprehensive assessment report. The full assessment on Warfare Materials in the Baltic Sea, will be structured as follows: The first section will provide basic and background knowledge on various types of warfare materials that are present in the Baltic Sea and how they got there. Subsequently, the report will describe the effects and risks related to these dangerous artefacts to humans, marine infrastructure and the marine environment in detail. The following section will introduce state of the art methods for the management of the warfare materials issue. Next, the authors provide an overview of the national and international efforts and projects of the past and at present. The final section will introduce conclusions and personal recommendations on how the risks posed by warfare materials in the Baltic Sea should be managed in the near future.

2. Warfare Materials – State of Knowledge

2.1 Warfare Materials

Warfare materials is a term including many different objects all intended for military purpose. There are several ways to group and distinguish warfare materials, such as by the intended purpose, by certain properties of construction, by ways of their deployment or by characters of typical payloads.

To be able to understand direct hazards, related risks or general challenges that need to be taken into consideration, some very basic knowledge on warfare materials and especially different types of munitions is introduced in this chapter. Regarding "warfare materials in the sea", a very general distinction is commonly made, by dividing warfare materials into the following two groups:

1. conventional weapons, e.g. explosive, incendiary or ballistic munitions
   and
2. weapons of mass destruction (WMD), e.g. chemical, biological, radioactive or nuclear payloads (CBRN weapons).

Because BSEP 142 (HELCOM, 2013) refers in detail to chemical munitions in the Baltic Sea, the report at hand focuses mainly on conventional munitions. Some extraordinarily relevant and new findings on chemical munitions or crucial relations between both groups are also mentioned in this report. At this point, there is no evidence indicating that biological, nuclear or radioactive warfare materials have been introduced to the Baltic Sea.

To distinguish between conventional and chemical warfare materials, the composition of the payload is the critical indicator. Other munitions compounds and parts are usually equal in both groups. Thus, to explain the effects of warfare materials in the marine environment it is necessary to assess the composition of modern warfare materials, developed, produced and deployed in the Baltic Sea region after 1840.

The payload volume of practice ammunition is usually filled with environmentally harmless mineral materials (concrete, dry clay) and the fuze is a dummy. Thus, practice ammunition could remain in the sea floor but it should not to avoid further mistakes and false alarms.

2.1 Historic Overview

The Baltic Sea is an inland sea with a long coastline proportionally to its area. Due to this fact the Baltic Sea was and still is of strategic importance to its neighbouring countries. Numerous wars have been fought over territories adjacent to the Baltic Sea. Those conflicts often had a naval warfare component. Because of the rare use of gunpowder-based ordnance, the wars of medieval and early modern history are of no interest to the scope of this report. Since the vast majority of warfare materials were entered during and in the aftermath of World War I and II this report focuses on warfare materials from that era.

In the 19th century, weapons, ammunition and equipment for army and navy were significantly advanced. Guns for army and navy increasingly used grenades instead of cannon balls. In 1848, the introduction of mines in the Baltic Sea took place. A minefield was placed in the Bay of Kiel to prevent the entering of Danish warships. Werner von Siemens had constructed a waterproofed container that was filled with gunpowder and a simple firing system, which was activated by two land-based controllers. The knowledge about the minefield discouraged the

Danish ships from entering the bay. Later, during the Crimean War (1853-1856), Russia laid mines in the Black Sea but also in the Baltic Sea off the coast of Kronstadt and St. Petersburg. In 1864, during the Second Schleswig War between Germany and Denmark, the first modern naval gunfire exchange was reported.

The first war in the Baltic Sea utilizing modern explosives (TNT) was World War I (1914 – 1918). At the dawn of this war four countries were adjacent to the Baltic Sea, namely Denmark, Germany, Russia and Sweden. Of those Denmark and Sweden remained neutral during the conflict. Even though Germany and Russia were at war, the active warfare was limited to smaller scale operations without the commitment of the main battle fleets. Because of its shallow bathymetry the Baltic Sea was an ideal area for military operations using light vessels, submarines and minefields. Both opponents laid numerous minefields in order to close certain sea areas, sea lanes or ports to their adversary or to defend their own ports. However, the use of naval mines was not limited to the parties at war. Neutral Denmark laid extensive minefields in the Belts and the Sound in order to deny their use to all warring parties. (Jentzsch, 2018)

Following the rise of the Nazi Party in Germany in 1933, World War II began with the German invasion of Poland on September 1, 1939. The southern exits of the Great Belt and the Sound had been mined by Germany in early September 1939 (Zentrum für Militärgeschichte und Sozialwissenschaften der Bundeswehr, 1988). On 30. November 1939 the Soviet invasion of Finland marked the start of the Finnish Winter War which lasted about three and a half months and comprised almost no naval warfare. In 1940 Germany invaded neutral Denmark and Norway during Operation Weserübung. With Denmark and Norway occupied all maritime approaches to the Baltic Sea were controlled by Germany. The same year brought the annexation of the Baltic states Estonia, Latvia and Lithuania by the Soviet Union thus increasing the strategic flexibility of the Soviet Baltic Fleet. With Operation Barbarossa Germany invaded the Soviet Union, beginning on June 22, 1941. After the quick fall of the Baltic states and extensive mine laying operations by the German Navy in the Gulf of Finland, the Soviet Baltic Fleet was trapped in Leningrad until summer 1944. For the time between summer 1941 and 1944 Allied warfare in the Baltic Sea was mostly limited to aerial operations, such as air-deployed mine laying which was conducted by the RAF starting May 1940 (Middlebrook & Everitt, 2000). The German Navy used the Baltic Sea primarily as a training area. When the German Army was pushed back from the eastern occupied territories by the Red Army in summer 1944, Soviet naval and aerial activity in the Baltic Sea increased.

Losing the war on all fronts Germany capitulated on 8. May 1945. The military occupation and reconstruction of Germany after World War II were negotiated in Potsdam in 1945 by Joseph Stalin, Premier of the Soviet Union, Harry S. Truman, President of the United States of America, and two Prime Ministers of the United Kingdom, Sir Winston Churchill and Clement Attlee. Even though there were numerous disagreements, the three leaders agreed on the disarmament and demilitarisation of Germany. In the resulting Potsdam agreement, the parties made terms that "The complete disarmament and demilitarization of Germany and the elimination or control of all German industry that could be used for military production" should be achieved and that "All arms, ammunition and implements of war and all specialized facilities for their production shall be held at the disposal of the Allies or destroyed. The maintenance and production of all aircraft and all arms, ammunition and implements of war shall be prevented."

With Germany divided into four zones (American, British, French and Soviet), the parties were individually responsible for tending to existing warfare materials within their respective area of oversight, either by adding them to their own arsenals or by destroying them by any means they found to be suitable. This was primarily done by submerging them in oceans and seas.

2.2 Modes of Entry

The modes of entry of warfare materials into the Baltic Sea can be roughly categorized into three categories naval warfare, military practice (including various test sites) and dumping.

Naval Warfare

During both world wars, the Baltic Sea was an area of conflict. Due to the strategic importance of the Baltic Sea, innumerable combat actions of great variety took place, all of them causing the entry of warfare materials into the marine environment. The following list provides an overview over these actions, all of which (with the exception of the final point) were geographically widely spread.

- Naval battles between surface warships using artillery and torpedoes
- Submarine torpedo attacks against military and civilian vessels using torpedoes and sometimes light artillery
- Anti-submarine warfare using depth charges deployed by naval vessel or aircraft, as well as artillery and bombs in a lesser degree,
- Air raids against military and civilian vessels as well as coastal installations using cannon armament, bombs, air-to-surface missiles and torpedoes
- Mine laying operations usually deploying moored and ground mines by surface vessel, submarine or aircraft
- A rare type of naval engagement in the Baltic Sea was coastal bombardment by surface warships using artillery (including counter fire from coastal artillery batteries)

Military Practice

In peacetime military live-fire training was and is conducted in dedicated training areas. Those training areas are bound to contain warfare materials. Training with non-explosive training ordnance can lead to misidentification in geophysical UXO surveys. Training ordnance may have been non-explosive but it may also contain propellant or residues thereof.

The training areas used today are bound to their geographical borders to ensure the safety of civilian shipping. During wartime however, military practice was usually not restricted to dedicated training areas. It was instead conducted wherever possible, with the exception of the warring parties civilian shipping lanes. During World War II the German Navy used large areas in the Baltic Sea for military practice, as it was relatively secure from allied attacks for the majority of the time. In principle all of the modes of entry mentioned in the previous section on naval warfare are transferrable to these military practice.

In addition, test sites and firing ranges for weapon prototypes were established, e.g. in Peenemunde and along the Baltic Sea coast of Mecklenburg-Western Pomerania. Tests included air dropped weapons, which means that the entry was not limited to coastal waters. Weapon prototypes in later stages of development often contained an explosive charge. Rocket type prototypes may contain propellants or their residues.

Dumping

Immediately before and after the armistice of World War II in the European theatre (May 1945), the dumping of warfare materials constituted an additional mode of entry into the Baltic. Dumping of warfare materials was carried out for a multitude of reasons. With the end of the war drawing closer, they were dumped by the German Armed Forces to remove them from areas subjected to imminent occupation by the Allies. The aim was to prevent warfare materials from being seized by the advancing Allied troops and to demilitarize before the impending surrender. In the immediate post-war period, the Allies chose dumping at sea as modus operandi to conduct swift demilitarization and removal of warfare materials. Sea-dumping was considered to be an inexpensive and safe alternative to land-based disassembly and a responsible disposal procedure. Even though traces of explosives are now being detected in seawater, the contamination of soil, fresh-water and air as a consequence land-based destruction using methods of 1945 was critical as well.

Both, conventional and chemical warfare materials were dumped at sea. While conventional munitions may have entered the sea as a direct result of military actions, the chemical warfare materials in the Baltic Sea originate exclusively from intentional dumping. At that time, it was believed that the vast amounts of water would neutralize the CWA. During dumping operations in Skagerrak (NOR), off Måseskär (SWE) and southern Little Belt (DNK) complete ships and semi-finished hulls were filled with munition objects and scuttled. On the other hand dumping grounds in German waters contain individual warfare materials and crates filled with smaller calibre objects. The vast majority of dumped chemical warfare materials were transported to the central Baltic Sea.

3. Warfare Materials – Effects and Risks

3.1 Known and Potential Effects

3.1.1 Detonation

Understanding of the physical theory of detonation and its impacts is important for the successful management of risks to human live, assets and the marine environment. Detonation is defined as a reaction of an energetic material after a stimulus. Such a chemical reaction consists of a conversion of a material into gaseous reaction products and leads to an instantaneous expansion in volume.

The detonation velocity and thus the detonation pressure are important indicators for the overall energy and force of the detonation in general and for the shattering effect of an explosive in particular. The velocity of a detonation depends on the type of explosive contained in the warfare material (Table 1).

Table 1 Detonation velocities of various explosives

Explosive name	**Detonation velocity [ms^{-1}]**
Ammonium nitrate	2,500
Lead azide	4,630
Trinitrotoluene (TNT)	6,900
Hexanitrodiphenylamine	7,200
Picric acid	7,350
Tetryl	7,850
RDX (hexogen)	8,750

When initiated, a shock wave develops inside the explosive material that drives the reaction further by compressing and heating the material. Next, the shock wave propagates into the surrounding medium (i.e. water). A typical pressure signature of an underwater detonation is characterized by a tremendously steep wave front of very high pressure (overpressure). This primary pulse decays exponentially. The first shock wave is followed by a series of so-called bubble pulses. These are caused by oscillations of a gas globe, which is a result of the explosion. It remains in the water after the detonation is completed and rises to the surface. Driven by the detonation force the gas globe expands up to the point at which the hydrostatic pressure in the water column exceeds the pressure inside the bubble. This leads to the collapse of the bubble, while it rises to the surface. Due to lower hydrostatic pressure in lower depth, the bubble expands anew, only to collapse again. This produces a series of secondary pressure pulses with each collapse. Each successive bubble pulse is weaker than the previous one.

3.1.2 Warfare Materials Housings Corrosion

The toxic chemicals in warfare material are isolated from the environment by metal housings, so corrosion of the metal is a critical initial process through which contaminants are released from underwater munitions (Wang et al., 2013). However, corrosion is exceptionally difficult to predict, in part because munition housing materials are highly diverse and may have changed over the course of war time due to availability of raw materials (Silva and Chock, 2016; Jurczak and Fabisiak, 2017). Furthermore, the quality and thickness of the metal varies among different munition types, and likely changed during the wartime period. Warfare material is often made of combinations of metals, which can lead to galvanic corrosion. Others have protective coatings such as paints, which can protect the metal from exposure to sea water, thereby delaying or slowing corrosion. Environmental factors also control corrosion rate. For example, corrosion varies with time period of exposure, depth of burial in the sediment, exposure to anoxic vs. oxic conditions, concentrations of chemicals such as sulphides and methane, salinity, temperature, and microbial activity (Rossland et al., 2010; MacLeod, 2016; Silva and Chock, 2016). Corrosion rates also increase with current speed and water mixing (MacLeod, 2016; Overfield and Symons, 2009), so munitions in high energy shallow coastal waters are especially likely to show deterioration and damage.

3.1.3 Dissolution and Release of Compounds

Once the protective metal housings are breached, dissolution of munitions chemicals from the solids inside controls release into the environment and eventual biological and exposure. The solubility of TNT is only approximately 130 mg/L, and even lower in seawater (Beck et al., 2018, and references therein). Some CWA compounds such as Clark, Tabun, and phosgene have higher solubilities, on the order of grams per litre (Szarejko and Namiesnik, 2009). The solubility of thioxane, a degradation product of sulphur mustard, is also substantially lower in seawater than in fresh water (Zhang et al., 2009). The most frequently found compounds of mustard degradation are water extractable salts of so-called mustard heel, the mustard polymerization products 1,4 Dithiane and 1,4-Oxathiane (Vanninen et al., 2020).

3.1.4 Contamination

3.1.4.1 Sea Water

It is certain that chemicals are leaking from breached underwater munitions, as shown for the chemical munitions dumped in the Bornholm and Gotland Basins (Barsiene et al., 2014, Vanninen et al. 2020). Chemical warfare agents, particularly arsenic-based compounds, have been detected throughout the Bornholm dumpsite, as well as the surrounding area (Missiaen et al., 2006; Missiaen et al., 2010, Bełdowski et al., 2016). Leakage of CWA at munitions dumpsites is also evident indirectly, as they have been linked to environmental genotoxicity in flounder, herring, and cod (Barsiene et al., 2014). In addition, explosive compounds released from conventional munitions have been detected in the water column and wild-collected organisms (Gledhill et al., 2019) at a munitions dumpsite on the German Baltic coast.

3.1.4.2 Sea Floor and Sediment

Munitions objects located on the seafloor and on beaches represent a sort of primary contamination. They are similar to other anthropogenic marine litter, such as plastics, scrap metal, abandoned fishing gear, and shipwrecks. However, warfare material has the potential to detonate and contains toxic chemicals, making it substantially more hazardous than other litter.

Chemical contaminants leaked from corroded warfare objects can also be found in seafloor sediments. Conventional explosive compounds (including TNT, TNB, DNB, and DNT) have been detected in sediments throughout the Baltic Sea, including the Bays of Kiel and Lübeck (Germany), Bornholm Basin (Denmark), and Gdansk Deep (Poland) (Dawidziuk et al., 2018). Observed concentrations were between 0.5 and 1.5 µg/g dry sediment.

3.2 Risks to Humans

From a human risk perspective, the problem of sea dumped munitions has been growing simultaneously with the maritime economy. Given the increase in marine traffic and the expansion of offshore activities the presence of scattered explosives and dangerous chemicals poses a threat for the overall safety at sea. Offshore operations may result in accidental detonation, relocation, retrieval, release of hazardous compounds and environmental contamination or potential resurfacing on beaches.

3.2.1 Fishermen

Fishermen are directly threatened by the hazard of UXO in the Baltic Sea. According to numerous reports, the Baltic Sea fishermen have been the main group coming unintendedly into contact with all types of munitions. Risk levels are site-specific and depend on the type of fishing gear that is used. Bottom trawling is connected to the highest likelihood of both explosives and CWA containers accidently getting caught in fishing nets. The risk is highest when trawling is performed inside or nearby dumpsites. In this context, the reported practice of en route dumping is of special interest since these scattered warfare materials pose a risk that is very difficult to assess due to the unknown locations outside the assigned dumpsites. While the likelihood of trawling one of these objects outside their designated dumpsite areas is low, any incident might have severe consequences.

3.2.2 Offshore Construction Workers and Nautical Personnel

With the growth in offshore activities an increase in incidents with warfare materials can be expected. Many permanent structures, such as offshore wind farms, subsea cables and pipelines and a wide variety many temporary facilities are deployed during various offshore operations every year. All operations that involve disturbance of the seafloor may lead to an encounter of warfare materials and to damaging them. Intense disturbances such as pile driving or cable ploughing are commonly considered higher risk activities for causing an accidental detonation than jack-up or anchoring.

3.2.3 Harbour Staff and Workers

Discoveries of warfare materials were reported in many Baltic Sea harbours. The need for relocation or detonation can severely affect any commercial activities. All harbours that were under attack and extensively used during wartime, also where dumping operations originated (such as in Flensburg or Wolgast) must be considered as potentially contaminated by warfare materials. Discovery of chemical and conventional warfare materials can be expected during any future harbour development projects.

3.2.4 Recreational Divers

Most chemical munitions that were dumped in the Baltic Sea are located well away from the coastline and at depths exceeding 80 m. They are therefore not easily accessible to recreational divers. Conventional munitions are however randomly scattered along all coastlines and may therefore be encountered accidentally. In soft Baltic Sea sediments, all submerged objects, including warfare materials and wrecks can serve as the constitute hard grounds that are populated by benthic flora and fauna, often causing a locally increased biodiversity (Bałazy et al. 2019). This attracts pelagic and demersal fish, which may in turn attract divers to such areas.

3.2.5 Beach Visitors

Most frequently reported cases of contact and exposure to warfare materials along the Baltic Sea coastlines involve white phosphorous, a pyrophoric used in incendiary weapons (see xxx). White phosphorus can be mistaken for amber and upon drying it can self-ignite and burn up to a 1300℃. In the Baltic Sea, cases of people being severely burned occur on a yearly basis, particularly on the German island of Usedom. The relative abundance of white phosphorus in this area is related to bombing campaigns against the German rocket testing facility at Peenemunde that took place in 1943 (see XXX). According to HELCOM there are approximately 1.2 to 2.5 tons of white phosphorus in the area. Simultaneously, each year the Danish authorities record cases, in which location-markers containing phosphorus in a small quantity are washed ashore. Another troubling area is Liepaja beach in Latvia, as the Soviet Union used a dumpsite roughly 70 km from Liepaja (HELCOM, 2013).

3.2.6 Seafood Consumers

The highest likelihood of getting into direct contact with chemical and conventional warfare materials in the Baltic Sea is through commercial fishing. Consequently, there is also a risk for any fish netted with the warfare materials to be contaminated with e.g. small lumps of potentially sticky sulphur mustard. When this occurs, the authorities must be alerted, the fishing gear decontaminated and the whole catch destroyed to minimalize the risks for sea-food consumers. Various kinds of fish, mussels and crustaceans are consumed worldwide, but little is known whether conventional explosives or CWA occur in seafood. Likewise, data on body burdens of those compounds occurring in marine biota in laboratory studies are rare. Nevertheless, measurable readings of explosive residues were detected in biota from the vicinity of dumped munitions like naval mines and others that may indicate their entry into the marine food chain. Since, there are no existing quality regulations for TNT and CWA-contaminated food, thus, safe rates of fish consumption by humans are not known yet.

3.3 Risks to Marine Life

Dumped munitions contain cytotoxic, genotoxic, and carcinogenic chemicals associated with conventional explosives, CWAs, and munition components (Tornero and Hanke, 2016; Sanderson et al., 2017). Release of explosive and chemical compounds to the environment was documented for many sites throughout the world, resulting in the contamination of surface and ground waters, soils, and sediments (Talmage et al., 1999; Bełdowski et al., 2016; Edwards et al., 2016; Silva and Chock, 2016; Jurczak and Fabisiak, 2017, Missiaen et al. 2010, Vanninen et al., 2020). Due to the narrow connection to the North Sea through the Danish Straits and the subsequently limited water exchange, the Baltic Sea acts as a sink for chemicals of all kind, including CWAs and explosives.

The toxic effects of TNT were first noticed after the First World War (Lima et al., 2011; Lotufo, 2012). In humans it is mainly absorbed through the skin and reduced in the liver (Johnson et al., 1994; Lima et al., 2011). Depending on the dose, human exposure of TNT can cause serious irritation of the skin and mucous membranes, impaired liver function, red blood cell disorders, aplastic anaemia, skin and hair peeling (Lima et al. 2011), hemotoxic symptoms

(Esteve-Nuñez et al. 2001) and it is causing carcinogenic and mutagenic effects (Ahlborg et al. 1988). The uptake of dissolved TNT by aquatic organisms is potentially possible either by swallowing contaminated water or food items or by diffusion processes from the surrounding water via gills or comparably to humans via the skin.

3.3.1 Marine Mammals

The most obvious threat to marine mammals derives from munitions clearance by detonation. Besides the rupture of tissues in the lungs and ear cavities mentioned above further types of blast injuries have been described for marine mammals. The compression of the thorax by the shock wave causes rapid increase in blood pressure resulting in the rupture of blood vessels and haemorrhages (e. g. in the brain or ears) (Ketten 1995). The rupture of lung alveoli leads to air embolism inhibiting oxygen supply (Landsberg 2000). Cavitation by the negative pressure occurring shortly after the shock wave may cause gas embolisms through nitrogen bubble formation in the blood and tissues of diving animals such as seals and cetaceans (Lewis 1996).

3.3.2 Water birds

Marine ducks such as common eider, common scoter, velvet scoter, greater scaup or long-tailed duck predominantly feed on mussels. It is not known how much TNT and its derivatives from contaminated blue mussels (chapter 3.4.4.) are taken up or further accumulated in water birds. In a feeding study with common pigeons, it was shown that the metabolic intermediates 2-ADNT and 4-ADNT were accumulated. Exposed pigeons showed a number of responses including weight loss, neuromuscular effects, and changes in haematological parameters, liver, kidney and ovary weight. It was concluded that subchronic exposure to TNT metabolites can adversely affect the central nervous system and haematological parameters in birds (Johnson et al. 2005). Since marine ducks are long-lived and slow reproducing species, this may be another pressure to be considered in the context of conservation of these birds.

3.3.3 Fish

Fishes are an ecologically and economically important component of marine ecosystems and some species represent the top of the marine food chain. Thus, they are particularly vulnerable to the uptake, accumulation and adverse biological effects of leachable toxic chemical constituents of warfare materials, either due to direct exposure or due to biomagnification throughout the food chain. Recently, fish were sampled close to a munition dumping site in the Bay of Kiel. The target fish species was the common dab (Limanda limanda), a flatfish species that is abundant in the western Baltic Sea, comparably territorial and has been regularly used as a bioindicator in environmental research and monitoring concerning biological effects of anthropogenic contaminants (Lang 2002). Fish collected in the periphery of the Kolberger Heide dumpsite (fishing in the munitions dumpsite is strictly prohibited) by gill net fishing were examined for various diseases. Findings revealed that they were afflicted by neoplastic liver lesions (benign and malignant liver tumours as well as the precursor stages) at a prevalence that exceeded the prevalence detected in fish from reference sites at a level of statistical significance (Straumer et al. 2020). In chemical analysis, TNT metabolites in the ng/ml range were detected in the same fish specimens sampled close to the dumpsite. In fish from reference sites, metabolites could only be detected at low concentration in few specimens (Koske et al., 2020). It was furthermore demonstrated that TNT as well as its two main metabolites 2-ADNT and 4-ADNT are genotoxic (Koske et al., 2019a). Therefore, a potential risk of TNT for fish health can be assumed. Even if TNT itself has been metabolized, the toxic metabolites are still present in the environment and in the fish. In addition to the main metabolites 2-ADNT and 4-ADNT, more metabolites can be assumed to occur in fish which have so far not been tested for toxicity. Thus, a link between exposure to explosives, uptake of the compounds and development of liver cancer is plausible.

3.3.4 Crustaceans (Blue Mussel)

During recent projects mussels were exposed, both in the field and the lab, to arsenic containing warfare agents, such as Clark and Adamsite. The results clearly show that blue mussels from the Baltic Sea take up CWAs in accordance with the provided treatment concentrations (Höher et al., 2019). The exposed mussels showed measurable genotoxic, cytotoxic and immunotoxic effects even at low exposure concentrations (Höher et al., 2019).

In addition, mussels were exposed to TNT and its derivatives 2- and 4-ADNT, both in the field and under lab conditions. All experiments showed that mussels are able to take up TNT and derivatives in accordance to the exposure concentrations (Schuster et al., 2020, Strehse et al. 2017). Mussel exposed to higher concentration of dissolved TNT in the lab immediately close their shells to protect themselves from the toxic environment. Overall, lab exposure experiments revealed that “no-effect” concentrations seem to be rather low, since lowest exposure concentrations used in the experiments resulted in negative biomarker responses (Schuster et al. 2020). Further, in field exposure studies, tissue concentrations in mussels reached high values, when mussels where placed in close vicinity of openly exposed TNT lumps, excluding them e.g. from human consumption (Strehse et al., 2017).

4. Warfare Materials – Methods for Management

4.1 Historic Reconstruction

All military decisions and circumstances were documented in different forms. Archives, especially military archives, store these documents. The research and check of relevant documents are of high importance and information generated during historic reconstruction are relevant for the determination of subsequent measures. Due to the large amount of preserved orders, reports, diaries, logs and other documents, the military archives are extremely valuable. The challenge however, is to be able to find and identify the documents, relevant for the research scope.

Sources

The military archives of Germany and the UK both contain a mighty stock of documents. German military documents were captured during the final weeks of World War II or after the war. They were brought to the UK and to the USA for evaluation. Most were later given back to Germany and they are now stored in the military department of the German Federal Archives at Freiburg. Around 51 km of files are currently stored, and the archive is a source of paramount importance for historic reconstruction. The database is however not complete: Some gaps, e.g. in the special operations section, indicate that some files were lost.

The UK National Archive in Kew holds a significantly larger volume of documents than the German archive. The quality of the files is similar to that in Germany and is complemented with files of the naval historical branch and the UK Royal Air Force (RAF). It is therefore possible, to generate an excellent historical reconstruction.

To understand the situation in the entire Baltic Sea also archives in Finland, Russia, Estonia, Lithuania, Latvia and Poland should be carefully assessed.

Methodologies

The first step of historical reconstruction is scoping and the definition of research boundaries regarding a specific operation, a geographic area or a timeframe. Furthermore, the affected components are determined. The archival research is initiated with basic data and information. In the research process war logs of the involved units, diaries of members of staff and of higher commanders are investigated. All influencing factors, such as weather conditions, enemy threat, navigation and morale of the crew and commanding officers constitute important inputs. Collecting complementary information from the opposing warring faction leads from a one-sided representation to the development of a complete picture.

A very good example are the minelaying activities conducted by the RAF in February 1944. The account was completed by examining the war log of the air defence area Kiel, the war logs of the minesweepers in the Bay of Kiel, the mining maps produced by the RAF and the summery report of the Royal Navy.

4.2 Quality Management in Offshore EOD

If activities surrounding the detection and clearance of UXO are executed erroneously, managed poorly or even overall omitted, UXO threaten the lives of construction workers (see 3.2.2), the construction schedule, marine fauna (see 3.4.1) and the public image of the involved parties. However, preserving comprehensively high quality during UXO operations in the offshore environment has turned out to be a challenging endeavour for a number of reasons:

- Entry barriers into the attractive market are low, leading to cost pressure.
- Legal areas are manifold and oftentimes not rigorously regulated.
- No guideline for the validation for the appropriateness of applied technologies or for the qualification of appointed personnel exists.

4.3 Modes of Detection

In order to be able to perform mitigative actions, it is first necessary to detect warfare materials. For this task, numerous technologies are available. These comprise geophysical, hydroacoustic, optical and chemical analysis methods as well as the use of biomarkers and bioindicators. However, only geophysical and hydroacoustic technologies are considered best available technologies for commercial use (Winkelmann 2014; Frey et al. 2019).

4.3.1 Geophysical Methods

Geophysical surveying methods measure different properties of surface and subsurface materials and they are capable of detecting changes in these properties. Some geophysical methods are called passive methods, because they measure naturally occurring fields or properties of the earth and spatial variations in this field or property. Active methods, on the other hand, require the introduction of energy into the earth, thereby triggering a response that can be measured. The property measured by a passive method exists regardless of the conducted survey, while the property measured by an active method only exists because of the signal, that was introduced. A multitude of geophysical methods exist. They include seismics, radioactivity, gravity and many other methods. The two geophysical methods that have been proven to be suitable for the detection of warfare materials in the sea are magnetic and electromagnetic methods, both of which are introduced in the following chapters. (Butler et al. 1998)

4.3.1.1 Magnetic Methods

Magnetic methods are potential field methods. This means that they exploit the existence of a pre-existing field, which is in this case the earth’s magnetic field. They detect anomalies in the earth’s magnetic field, that are caused by the presence of magnetic objects and materials in the sensor’s vicinity. Anomalies actually consist of a dipole; a negative north pole and a positive south pole (Reynolds 2011). Since magnetic sensors measure anomalies in an existing magnetic field without inducing energy to produce a local magnetic field, they belong to the group of passive sensors. The magnetic anomalies caused by warfare material are solely attributed to its magnetic components and not to any other materials such as the explosives it contains. The total field amplitude of the magnetic anomaly depends on numerous variables such as the ferrous mass of an object, a parameter that is different for every type of warfare material. Other parameters influencing the amplitude are an object’s degree of corrosion, its orientation in relation to the earth’s magnetic field (Butler et al. 1998) and even the type of steel that was used for its construction.

4.3.1.2 Electromagnetic Methods

Electromagnetic (EM) methods induce an electromagnetic field which is produced by a coil. If this induced electromagnetic field meets an object that is made of a conductive material electric currents are in turn induced. These currents cause the development of a secondary field, which is measured by the electromagnetic sensor. Due to the induction of energy for the purpose of detecting objects, EM sensors belong to the group of active methods. (AK AH KMR 2018) The secondary field is a consequence of the presence of conductive material, usually metal, which is a common component of warfare materials. Accordingly, there is an overlap between the types of materials that magnetic and EM systems can detect. The strength of the secondary field depends on the amount of conductive material contained in the object. (AK AH KMR 2018)

4.3.2 Hydroacoustic Methods

Hydroacoustic methods are the most commonly used technology for the investigation of the seabed and objects on the seafloor. They are transmitting acoustic signals and measure the time and/or amplitude of the return of this signal. Properties of the reflecting surface, such as its material and structure or inclusion of air or any gas have an effect on the signal backscatter (Böttcher et al. 2011, IHO, 2005; Lurton et al., 2015)). Different types of hydroacoustic methods may be used during the detection of warfare material. These include side-scan sonars (SSS), synthetic aperture sonars (SAS), multibeam echosounders (MBES) and sub-bottom profilers (SBP), all of which are sonar technologies.

4.3.2.1 Side-Scan Sonar

For the detection of warfare material that is located on the seabed, the use of SSS has numerous advantages over magnetometers and EM-systems. One of them is their longer range (seafloor coverage), which is however limited by requirements for spatial resolution. The resolution should be at least half of the shortest dimension of the warfare material that is expected to be detected. SSS offers another advantage, in that their measurements are not impaired by the presence of geologic magnetic anomalies and their detection capabilities are independent from the warfare material’s ability to cause magnetic anomalies or to induce a secondary magnetic field. Therefore, both LMB mines and loose lumps of explosive material or other warfare agents are generally detectable. However, due to their indistinct shape, chunks of compounds remain difficult to spot. Furthermore, SSS allows for the detection of objects that are located in close vicinity or above buried infrastructure (Frey et al. 2019). SSS are typically used as towed systems in relatively close vicinity to the seabed, as this allows for the use of high frequencies which have low range but high resolution (Bjørnø 2013). This provides the ability to detect the majority of objects that differ in structure from the surrounding sediment material and that may be present at the seabed and that may pose a threat to offshore construction projects. As an auxiliary means to support the full area magnetic survey, SSS is therefore considered best available technology. Its data also allow for the discrimination of objects that are false positives in the magnetometer data (Winkelmann 2014), albeit this is only possible in areas, where no or very little burial of warfare materials takes place. AUV mounted SSS has been utilized for the identification of chemical warfare material hotspots in both the Bornholm and the Gotland Deep, by analysing its spatial distribution. The acquired data were deemed of high quality, highlighting their high resolution, enhancing the ability to classify objects as chemical warfare materials (Majcher et al. 2017).

4.3.2.2 Multibeam Echosounders

Advantages are similar to that of SSS as this method allows for detection of objects present on the seafloor surface, independent from the object’s and its surroundings’ magnetic and electromagnetic properties (Frey et al. 2019, Kampmeier et al., 2020). If mounted at the ship’s hull, MBES does not suffer from the positioning challenges of towed systems or other platforms and provides overall improved positing data of target locations. It may therefore be applied in monitoring programs of known dumping grounds (Kunde et al. 2018, Kampmeier et al., 2020). Its dependency on the distance between the ship's hull – and therefore the sensor – and the seabed, results in a limitation for the spatial resolution that is achievable. In waters deeper than 25 m, it is therefore regarded as a support system for general information. Suspicious areas can then be repeatedly mapped with higher resolution and additional sensors (Frey et al. 2019). In parallel to the bathymetry, MBES can record backscatter snippets and water column data. Backscatter snippets give additional SSS-like information about seafloor properties and water column data might enhance imaging munition on the seafloor. Multibeam data includes bathymetry, acoustic backscatter, and water column data.

4.3.2.3 Sub-bottom Profiler

The resolution of the parametric echosounder allows the detection of small objects on the sea bed, partially exposed, or buried within the sediments. It provides accurate information about the depth (top) of the object, but its exact size and orientation are difficult to deduce. Moreover, due to the narrow beam width any objects that lie outside the survey path will often remain undetected (Missiaen & Feller 2008). Recently, a novel approach was therefore developed using a multi-transducer parametric echosounder system (SES-2000 Quattro). This system consists of four individual transducers in a line array which allows 3D imaging of the sub-bottom with very high data density. The simple acquisition makes this system particularly fit for rapid, cost-efficient site surveys (Missiaen et al. 2017). The small transducer spacing (25 cm) provides ultra-high resolutions (bin size 20x20x1cm or smaller), but limits the maximum water depth to 12-15 m (due to beam overlap) and requires precise ship navigation. An additional advantage is the flexible configuration of the individual transducers, which also allows for a 2D single beam set-up (e.g. 4 transducers configured into a quadrangle and acting as a single transducer), resulting in higher energy and deeper penetration, or a pseudo-3D dual beam set-up (2 transducers combined as a single transducer), which will also increase the energy level and has an intermediate data density (max. water depth ~20 m).

4.3.3 Optical Methods

The key advantage of visual methods as compared to other methods is due to their simple and cheap application (using cameras). For humans, visual information plays a key role when we understand the world. Therefore, visual data is naturally understood well by humans and can not only be used by experts, but also to involve other stakeholders or to inform the general public. For systematic mapping campaigns visual data can also be used to infer the micro-navigation of the platform from the images which enables usage of extra sensors (e.g. magnetics). In any case, a systematic visual map will also help planning further operations, e.g. using divers or robots, and can be used for monitoring campaigns.

4.3.4 Chemical Analysis Methods

CWA compounds and degradation products

A comprehensive description of methods for CWA analysis is available from the Finnish Institute for Verification of the Chemical Weapons Convention (VEREFIN) (Vanninen, 2017). Sediment samples have been analysed for CWA by gas chromatography–mass spectrometry (GC–MS; for intact volatile chemicals or derivatized chemicals), and liquid chromatography–tandem mass spectrometry (LC–MS/MS; for intact water-soluble chemicals or oxidized derivatives) (Missiaen et al., 2010). Chemical warfare agents in fish tissues were extracted with acetonitrile and hydrogen peroxide, and measured by LC–MS/MS (Niemikoski et al., 2017).

Conventional explosives

A variety of analytical methods have been used to detect MCs in environmental samples (Barshick and Griest, 1998; Bromage et al., 2007; Badjagbo and Sauvé, 2012a; Xu et al., 2014; Rapp-Wright et al., 2017) but vary in their specificity, simplicity, and detection limits. A widely used method of dissolved MC analysis uses solvent extraction, separation by liquid chromatography and Ultraviolet–visible spectroscopy (UV-VIS) detection, with detection limits in the µg/L range (US EPA Method 8330) (EPA, U. S., 2007). It does however have numerous shortcomings. First of all, UV-VIS detection is not possible for MCs that absorb light poorly, such as nitro-glycerine or PETN. In addition, differences in sample solution composition can affect the chromatographic separation of different compounds, making the identification of specific compounds difficult. Moreover, abundant coloured organic matter in seawater can interfere with detection by UV-VIS spectrometry. More recently, mass spectrometric techniques (Badjagbo and Sauvé, 2012b; Rapp-Wright et al., 2017) provide enhanced sensitivities and specificity. Nanomaterial-based electrochemical detection of explosives (O'Mahony and Wang, 2013) has shown promise.

4.4 Modes of Clearance

For combustion waves two types can be distinguished, deflagration and detonation. If the propagation is associated with a velocity greater than the speed of sound and a strong shock, the term “detonation” is used. If the rate of combustion is subsonic (i.e. lower than the speed of sound) and associated with heat conduction to sustain the wave, it is called deflagration. A deflagration can turn into a detonation under special conditions (confinement, shock sensitivity, burning velocity) if the pressurization rate inside the unburnt material increases over a critical threshold (deflagration to detonation transition – DDT). The main characteristics of the two reaction types of explosives are shown below.

Table 2: Main characteristics of the two reaction types of explosives

Deflagration	Detonation
Surface phenomenon	Wave phenomenon (high-speed shock wave propagates detonation)
Rate of deflagration is lower than sonic velocity in surrounding medium	Rate of detonation is higher than sonic velocity in surrounding medium
Reaction products of deflagration travel in opposite direction of propagation direction	Reaction products of detonation travel into same direction as propagation direction

4.4.1 High Order Detonation

High order detonation occurs when detonation velocity reaches its maximum for an energetic material. The energetic output is therefore maximised which is the design function of all munitions. (Fickett and Davis - Detonation Theory and Experiment, 1979 and C L Mader, Numerical Modelling of Explosives and Propellants. CRC Press 2007) Clearance of warfare materials can require intentional execution of a high order detonation. It usually follows the placement of a donor charge or firing of a projectile. With high order detonation, the aim is the complete consumption of the explosive. Note that for propellants detonation is not a desired outcome. High order detonation is a common disposal practice for conventional munition items that cannot be transported and are therefore destroyed under water or on sandbanks that are dry during low tide. High-order detonation is characterized by high detonation velocity (5,000 to 10,000 m/s) resulting in an extremely short rise time of the pulse and consequent shock waves that can proliferate for many kilometres (Koschinski and Kock 2009).

4.4.2 Low Order Detonation

Low Order detonation occurs when the detonation reaction does not reach steady state and hence the maximum detonation velocity is not reached. It is still a detonation with a supersonic reaction rate, which is producing a shock wave and is therefore not a deflagration. It is however possible for a deflagration to burn to detonation, which is termed Deflagration to Detonation Transition. Such reactions can produce high order responses, that depend on the critical properties (mass, diameter and geometry) of the explosive and on its confinement. Low order detonation may occur when non-planned stimuli occur which may take place during disposal operations. Low Order is also a risk with high performance propellants.

4.4.3 Impact Mitigation

In the light of the increasing need to perform clearance of warfare materials in the Baltic and the negative consequences of detonation practices for the marine environment (see 0), this chapter describes ways to mitigate the impact of existing clearance techniques. If a detonation cannot be avoided, the presence of surrounding marine organisms should be considered and a combination of technical and organisational mitigation measures, that are appropriate to protect the environment, be implemented (**Error! Reference source not found.**).

In certain situations, such as imminent danger to humans, detonations cannot be completely avoided. In these cases, the application of mitigation measures can minimise adverse effects on the marine environment. In light of the critical situation of the harbour porpoise population of the Baltic Proper with less than 500 animals remaining (ASCOBANS, 2016a), the HELCOM Expert Group on Marine Mammals expressed deep concerns about potential effects of unmitigated detonations on individuals and underlined that for the critically endangered harbour porpoise population, all use of explosives having an effect on the individual level are very likely to have effects also on the population level (HELCOM, 2019b).

4.4.3.1 Detonation Risk Assessment and Mitigation Strategy

In the planning stage, a proper detonation impact assessment and a mitigation strategy should be developed in co-operation with competent nature conservation and fishing authorities with the aim of protecting the marine environment and commercial fish stocks from shock waves. This strategy may cover potential impact on:

- Protected and sensitive species
- Marine protected areas (MPAs)
- Sensitive habitats

4.4.3.2 Technical Mitigation Measures

One mitigation measure is the bubble curtain. It is generated by pressurised air forming a ring of bubbles freely rising from a weighted nozzle pipe on the sea floor to the surface at a distance of 70 to 200 m from the detonation site. Its design should ensure that the bubble curtain is fully closed around the detonation site to avoid noise leakage (**Error! Reference source not found.**). This can be achieved by a uniform pressure distribution within the bubble curtain

(Nehls et al., 2016). Bubble curtains are among the technical mitigation measures considered best available technique (BAT) (Bundestag, 2018).They have a very high potential to reduce impacts of sound and shock waves on marine wildlife by significantly reducing the affected danger area. This has been proven in various experiments and applications. It has been shown repeatedly that air bubbles in the water effectively reduce the sound pressure and the shock wave from detonations (Keevin and Hempen, 1997; Keevin et al., 1997; Keevin, 1998; Notarbartolo Di Sciara, 2002; Rude and Lee, 2007; Nützel, 2008; Schmidtke et al., 2009; Schmidtke, 2010; 2012; Grimsbø and Kvadsheim, 2018). The bubble curtain radius should be much larger than the gas bubble that is created by the explosion. Otherwise it can be affected by the water mass pushed away by the developing gas globe (Schmidtke et al., 2009). In reducing piling noise during offshore construction, it is state of the art to deploy a nozzle ring of up to 1.600 m in length. A bubble curtain with a radius of 22 m used in the detonation of a 300 kg mine containing “Schießwolle 39” has shown to be ineffective as it did not reduce the peak pressure at all (Schmidtke et al., 2009), whereas a bubble curtain with a radius of 70 m reduced the peak pressure of the shock wave by 16 dB to 19 dB re 1µPa (Schmidtke, 2010). Given the sound propagation properties in water, a bubble curtain this size would reduce the area of the impact zone for harbour porpoises, fish or birds by approximately 99%.

4.4.3.3 Scaring Devices

The use of acoustic deterrents serves the purpose of producing unpleasant noise with the aim of establishing an exclusion zone for noise sensitive species around a site before the detonation is executed. The application of such means requires careful consideration because of species specific behaviour and different properties of devices. For example, electronic acoustic scaring devices are not suitable for deterring birds (Melvin et al., 1999) or fish. The frequency spectrum of these do not cover the hearing spectrum of most fish species (Au and Hastings, 2008).

4.5 Other Tools

4.5.1 Monitoring

To evaluate the state of migration and displacement of munition shells, high resolution mapping with high positional precision is essential. The required data resolution is depending on object sizes and must ensure repeatable detection of single objects. Only object displacements greater than the achieved position precision can be reliably measured. Hydroacoustic and optical mapping methods are suitable for warfare materials laying on top of seafloor sediments. This includes multibeam sonar, synthetic aperture sonar, side scan sonar and AUV-/ROV-based optic surveys (Czub *et al.*, 2018; Kampmeier *et al.*, 2020; Kunde *et al.*, 2018). In addition to this, the presence of open explosives and corroding munition shells can be efficiently monitored via repeated optical surveys (ROV, AUV, towed cameras and inspection by divers). Buried munition detection requires ground penetrating methods, such as sub-bottom profiler and magnetometer (Missiaen and Feller, 2008; (Missiaen and Noppe, 2009). For the actual contamination detection, and confirmation of release of explosive and CWA-related compounds into the environment, multiple water, pore-water and sediment samples need to be collected in the vicinity to the munition using safe and standardized methods. Additionally, passive sampler can be installed within monitoring areas for defined time periods. This can be done via ultra-high-performance liquid chromatography-electrospray ionization mass spectrometry (uHPLC-ESI-MS) described in Beck *et al.*, 2018, 2019 and Gledhill *et al.*, 2019 and gas chromatography mass spectrometry (GC-MS) (Strehse *et al.*, 2017; Appel *et al.*, 2018). Due to the hazardous nature of CWA in potentially contaminated samples, chemical analyses should be performed by well-equipped and in CWA-detection case OPCW-accredited laboratories. To quantify the real uptake into the food web, the explosive compounds concentrations have to be measured inside flora and fauna using appropriate biomarkers. For all listed purposes the DAIMON2 project provides multiple Standard Operational Procedures (SOPs). Detailed methods and measuring intervals are published within the 'Practical Guide for environmental monitoring of conventional munitions in the sea' (Greinert, 2019). As metabolic effect can alter concentrations, biota of different food web levels should be examined. Biomonitoring makes it possible to analyse in-situ TNT accumulation within organisms (e.g. blue mussels) (Strehse *et al.*, 2017; Appel *et al.*, 2018). Detailed methods and measuring intervals are published within the 'Practical Guide for environmental monitoring of conventional munitions in the sea' (Greinert, *2019*).

4.5.2 Biomonitoring

Biomonitoring is differentiated in active and passive biomonitoring. For a passive biomonitoring, marine animals are collected in suspected burdened areas and analysed with regard to the presence of the compounds coming into question. For this approach, fish, bivalves and most of other vertebrates as well as invertebrates are suitable. For example, Niemikoski et al. (2017) have published the occurrence of CWA residues of Clark I and/or Clark II found in lobster (Nephrops norvegicus) and a flatfish species collected at a dumpsite for chemical warfare agents in the Baltic Sea. Gledhill et al. (2019) found several kinds of explosives in marine biota like algae, asteroidea and tunicata which had been collected at Kolberger Heide, a known dumping ground for different types of munitions in the Bay of Kiel in the Baltic Sea. They found body burdens of HMX, RDX, TNT and ten other explosives with measured concentrations up to the highest of nearly 25 mg/g in starfish.

For an active biomonitoring the species of interest are collected from an unburdened area prior to being selectively deployed in the suspected dumping ground to be tested. Advantages of the latter are: 1) the exactly known time periods of exposure which offers the opportunity of variation in exposure time to register long- and short-term trends of effects; 2) the ability to vary the distances to a suspected source of contaminants, such that chemical and physical gradients can be detected; 3) a sufficiently large number of test organisms can be exposed and a repetitive test design is possible, both ensuring the statistical power of the study; 4) a better estimation of the health impact on the species used is enabled by analysing biomarkers and comparing the results with species from a reference site.

5. Conclusions

Having read the written above, further questions arise. There is much more information available and also actions to prevent worsening of the described status are strongly recommended by authors of scientific papers. As emphasized by HELCOM the decision was taken to continue the initial task of HELCOM-SUBMERGED under the supervision of HELCOM-RESPONSE. Here, HELCOM adopted the status of the ad-hoc working group. The Expert Network SUBMERGED will maintain the already established relations and with the help of other entities broaden the knowledge on underwater munitions.

A crucial stakeholder to address is Baltic Sea Military. To achieve a comprehensive operational picture on abundant munitions in the Baltic Sea and to submit a HELCOM assessment report on conventional munitions HELCOM contracting parties are strongly invited to introduce relevant bodies of their respective departments of defence to the work of the newly established Expert Network HELCOM-SUBMERGED.