Warfare Materials in the Baltic Sea – Model Chapter Germany

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HELCOM Thematic Assessment on Hazardous Submerged Objects in the Baltic Sea (Submerged Assessment), Volume 1

Warfare Materials in the Baltic Sea
HELCOM Submerged

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Executive Summary
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1. Introduction
1.1 The Warfare Materials Threat in the Baltic Sea

Contemporary society’s perception of the horrors 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 ever-present all throughout European land and waters, including the Baltic Sea.

When an aerial bomb explodes after lying dormant underground for decades, injuring and killing people or when white phosphorus from an incendiary bomb is washed ashore, burning the skin of vacationers searching the beach for amber, the wars of the past claim additional victims more than 70 years past their conclusion. The tragedy of such events is unspeakable and ultimately originates in the battles of the previous century and irresponsible disposal methods that were applied once the guns fell silent. The environmental damage caused by these munitions are less obvious than the direct impact on humans, but they are nonetheless concerning. Still, our knowledge of the scale of munitions-related contamination and ecosystem consequences remains incomplete.

Marine waters of every single abutter to the Baltic Sea contain warfare materials. Threats resulting from warfare materials may be direct and short-term. Among others, fishermen, divers, offshore wind farm constructors and beachgoers are affected and face the munitions hazard, merely while performing their daily work or while collecting objects in the surf. Every year people are severely injured after unintentionally getting in contact with warfare materials. Other threats are indirect and long-term such as the enrichment of carcinogenic toxic substances and their derivatives in the food web. The latter must be especially emphasized, due to the unknown scope of the effects and its potential effects on the whole ecosystem.

If these are not enough reasons to act, it should be understood, that detecting these munitions becomes increasingly difficult with time passing. Corrosion continuously dissolves the warfare materials’ metal casing and consequently eliminates the chance to find and remediate these sources of risk and contamination.

Initially driven by scientific institutes and organizations (both governmental and non-governmental) in the most affected countries, relevant measures were undertaken in each HELCOM member state to support expanding the knowledge base concerning munitions and their effects on humans and the marine environment. As a result of regional, national and international scientific research relevant knowledge increases and consequently numerous recommendations, on how the munitions challenge can be addressed, are published. However, international coordination is necessary or inadvertent duplication of efforts, thereby wasting time and money, or failure to identify obvious synergies, will be unavoidable. An integral part of coordinating those efforts is a centralized ammunition cadastre including results of previously conducted and ongoing research, management and analysis options for historic data from archives as well as risk determination and monitoring tools. Coordinated efforts by all affected countries are going to provide decision makers with the ability to deal with all aspects of warfare materials in the offshore environment, covering the identification of munitions, monitoring of dump sites and ultimately the elimination of the threats in a systematic manner.

The global ocean economy is predicted to double in size by 2030, as compared to 2010, thereby reaching an annual gross value added of USD 3 trillion and providing more than 40
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million full time equivalents to the global labour market (OECD 2016). The ocean economy’s potential to outperform the expected growth of the overall global economy is reflected in the Blue Growth Strategy laid out by the European Commission. In this strategy the economic potential for the extended economic use of the oceans was recognized and focus was placed on five blue growth sectors. Two of these sectors (ocean energy and seabed resources) require the capacity to safely access large areas of the sea floor (European Commission 2017). For sea floor utilization of this magnitude, UXO constitute a hazard and an obstacle (Bundesministerium für Wirtschaft und Energie 2017). Due to the variety of modes of entry of UXO into the sea over a timeframe of more than 140 years, ensuring a site is UXO free is not possible in many areas, without conducting an appropriate investigation in prior. In order to utilize the economic potential of the ocean energy and seabed resources sectors, an increase in UXO detection and removal action in affected areas will become necessary. Accordingly, the market for these services can be expected to grow and attract new actors.

1.2 Introduction to HELCOM SUBMERGED
The HELCOM Expert Group on Environmental Risks of Hazardous Submerged Objects (SUBMERGED) works to compile and assess information about all kinds of hazardous objects and assess the associated risks.

➔ Relation to 2013 report (here one recommendation is that conventional munition should be investigated)

1.3 Objective of the Report

1.4 Scope of the Report

1.4.1 Limitations

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2. Warfare Materials – State of Knowledge

2.1 Historic Overview

The military occupation and reconstruction of Germany after WWII were negotiated in Potsdam in 1945 by Joseph Stalin, Leader of the Soviet Union, Harry Truman, President of the United States of America and Clement Attlee, Prime Minister of the United Kingdom. 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 any chemical weapons (CW), chemical warfare agents (CWA) and production facilities within their respective areas 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.

The Baltic Sea is an inland sea with a long coastline proportionally to its area. Due to this fact the Baltic Sea is of immense strategic importance to its neighbouring countries, especially regarding trade and military campaigns.

Numerous wars have been fought over territories adjacent to the Baltic Sea. Those conflicts normally had a naval warfare component. Because of the rare use of gunpowder-based ordnance, the wars of medieval and early modern times are of limited interest to the scope of this report.

The First World War (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. While Germany and Russia were at war the active warfare was limited to operations on a smaller scale 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. But the use of sea 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. This action arguably helped Germany because it guarded their flank against an intervention of the Royal Navy in the Baltic Sea. Germany was still able to transfer ships of their main battle fleet between the seas using the Kiel Canal and thus keep the battlefleet element of the Russian Baltic Fleet in check. (Jentzsch, 2018)

As a result of the First World War some territories of the warring parties became autonomous nations. Neighbouring countries of the Baltic Sea now were Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, Sweden and the Free City of Danzig.
Following the rise of the Nazi Party in Germany since 1933, the Second World War (WWII) began with the German invasion of Poland on 1. September 1939. Having signed the Molotov-Ribbentrop Pact the relations between Germany and the Soviet Union remained neutral. After the defeat of Poland Germany had, for the moment, no enemies adjacent to the Baltic Sea. 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 was 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 on 22. June 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 that time Allied warfare in the Baltic Sea was mostly limited to aerial operations, e.g. air-deployed mine laying which was conducted by the RAF since 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 WWII were negotiated in Potsdam in 1945 by Joseph Stalin, Leader of the Soviet Union, Harry Truman, President of the United States of America and Clement Attlee, Prime Minister of the United Kingdom. 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" (United States, 1950) 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." (United States, 1950)

With Germany divided into four occupation zones (American, British, French and Soviet), the parties were individually responsible for handling the leftover ordnance including chemical weapons (CW), chemical warfare agents (CWA) and production facilities within their respective areas, either by adding them to their own arsenals or by rendering them unusable. This was primarily done by dumping the ordnance in oceans and seas, resulting in an estimated amount of 300,000 tons of dumped explosive ordnance, including approx. 5,000 tons of CW and CWA, rusting in the German EEZ of the Baltic Sea (Böttcher et al., 2011). Overall more than 40,000 tons of CW and CWA are believed to be dumped in the Baltic Sea (HELCOM, 2013).

The Second World War was the last war fought in the Baltic Sea. The two main power blocks, the North Atlantic Treaty Organization (NATO) and the Treaty of Friendship, Cooperation and Mutual Assistance (Warsaw Pact), participated in the Cold War which saw no shots fired in anger at least officially. With the collapse of the Soviet Union in 1991 the Warsaw Pact ceased to exist. The NATO as military organization and the European Union (EU) as political organization expanded eastwards peacefully. Nowadays, most of the former members of the
Warsaw Pact neighbouring the Baltic Sea are members of the NATO and the EU. A certain amount of tension comes up between the NATO and the Russian Federation from time to time, so far not exceeding some moderate show of force.

### 2.2 Modes of Entry

During the world wars the Baltic Sea was an area of intense battles. Due to the strategic importance of the Baltic innumerable combat actions of great variety took place, all of which caused entry of munitions into the marine environment. These range from naval battle between war ships, submarine torpedo attacks, air raids, to complex mine laying operations. In addition, test sites for marine weapons and exercise shooting ranges were established.

Immediately before and after the conclusion of WWII, the dumping of ammunition constituted an additional mode of entry of warfare materials into the Baltic. Dumping of munitions was carried out for a multitude of reasons. With the end of the war drawing closer, munitions were dumped by the German Armed Forces to remove hazardous munitions from areas subjected to imminent attacks, to prevent munitions 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 from German territory. The dumping activities that took place during the final stage of war and during the post-war period were conducted while being pressed for time, either by the attacking Allied forces or by agreed deadlines. In later years, dumping activities were considered an inexpensive and safe alternative to land-based disassembly and decontamination procedures.

In addition to the conventional ammunition, chemical ammunition and CWA were dumped as well. At that time, it was believed that the vast amounts of water would neutralize the CWA. In contrast to the dumping operations in Skagerrak and Little Belt, where complete ships were sunk, the great majority of chemical munitions were dumped into the Baltic Sea in containers.

For the purpose of this report the modes of explosive ordnance entry into the Baltic Sea can be roughly categorized in naval warfare, military training (including various ordnance test sites) and munitions 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 munitions explosive ordnance into the marine environment. These range from naval engagement include:

- **Naval battles between surface war ships 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 normally deploying moored and ground mines by surface vessel, submarine or aircraft.**
- **A rare type of naval engagement in the Baltic Sea was and coastal bombardment by surface warships using artillery (including counter fire from coastal artillery batteries)**
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To complex mine laying operations. All of those, except for coastal bombardment, were geographically widely spread and even some coastal artillery batteries had a range of more than 40 km depending on their calibre.

Military Training

In peacetime military live-fire training was and is conducted in training areas normally. Those training areas are bound to contain unexploded ordnance (UXO). Training with non-explosive training ordnance can lead to misidentification in geophysical UXO surveys. Furthermore, training ordnance can contain propellant or residues thereof, depending on the ordnance type, which can present an environmental hazard. The training areas used today are bound to be known in their geographical borders to ensure the safety of civilian shipping, but the most of the ordnance used in the training areas is subject to military secrecy. The number of projectiles shot at sea in two German training areas has been specified for years 2009 to 2012 as 52 000 projectiles with a total weight of 28 metric tonnes. The percentage of unexploded ordnance of those is given as 1 to 3 % with a total weight of up to 790 kg (German Bundestag 2012).

In wartimes military training usually was not restricted to dedicated training areas but was conducted wherever possible, except for civilian shipping lanes of their own warring party. During the Second World War the German Navy used large parts of the Baltic Sea, which was a relatively secure from allied attacks most of the time, as a training area. In principle all of the modes of entry mentioned in the naval warfare subchapter are also applicable to military training in times of war.

In addition, test sites and firing ranges for weapon prototypes were established, e.g. at Peenemunde. Tests included air dropped weapons therefore the ordnance is not limited to coastal waters. Weapon prototypes in later stages of development often contained an explosive charge. In rocket type weapon prototypes the propellant or their residues can be hazardous to the environment.

Munitions Explosive Ordnance Dumping

Immediately before and after the conclusion of WWII, the dumping of ammunition ordnance constituted an additional mode of entry of warfare materials into the Baltic Sea. Dumping of munitions was carried out for a multitude of reasons. With the end of the war drawing closer, munitions were dumped by the German Wehrmacht (armed forces) to remove hazardous munitions from areas subjected to imminent attacks, to prevent munitions 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 from German territory. The dumping activities that took place during the final stage of war and during the post-war period were conducted while being pressed for time, either by the attacking Allied forces or by agreed deadlines. In later years, dumping activities were considered an inexpensive and safe alternative to land-based disassembly and decontamination procedures. It is well known today that civilian contractors hired for the dumping often dumped explosive ordnance early on the way to the assigned dumping area to save time (Böttcher et al., 2011).

In addition to the conventional ammunition, chemical ammunition and CWA were dumped as well. At the time it was believed that the vast amounts of water would neutralize the CWA. In contrast to the dumping operations in the Skagerrak and the Little Belt, where complete ships

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transporting CWA were sunk deliberately, the great majority of chemical munitions were dumped into the Baltic Sea in containers.

2.3 Geographic Distribution

The Baltic Sea is in overall a shallow body of water, but it includes some sea basins, such as the Bornholm Deep, the Gotland Deep and the Sea of Åland. The maximum depth can be found at Landsort deep in the Gotland Basin with 459 m, but the average depth of the Baltic Sea is 55 m. In the western Baltic Sea water depths between 20 m and 35 m are common but the depth increases further eastwards. The Baltic Sea is an inland sea with only three minor connections to the North Sea, the Öresund and the two Belts. In the western part the water has a salinity of 1.5 – 1.7 %, while in the eastern part the value drops to 0.4 %. Salinity, temperature, oxygen levels have a major impact on present warfare materials.

Throughout history, the Baltic Sea has on a constantly been the scene of wars, combat and ammunition dumping activities. Almost the entire Baltic Sea served at some point in time as an area of conflict or as an exercise area for the different fleets. The Gulf of Finland was a mining area during both WWI and WWII, with a high density of mines. With an unknown amount of other warfare materials added in the same region, it needs to be considered a problematic area. A similar situation exists in the Irbestraat, the entrance to the Gulf of Riga. During both world wars, the western part of the Baltic Sea was subjected to heavy mining during the wars. After the conclusion of the wars, it was furthermore heavily used for the dumping of all kinds of warfare materials. In summary, former areas of conflict, dumping grounds and exercise areas are the current areas of concern.

2.3.1 Dumping Sites

Germany

After the conclusion of WWII, the allied forces captured an enormous amount of ammunitions and other warfare materials. Military organisations and scientist considered dumping the captured ammunition into the sea the best way for the disarmament of Germany immediately after the war. Nearly 1.6 million tons of ammunition of all kinds were dumped in the North Sea and the Baltic Sea in German waters. Some of these places are well known, others are only assumptions.

Two examples for sites, where a high amount of ammunition was dumped, are Kolberger Heide and Pelzerhaken. For Kolberger Heide some reports indicate the presence of some 25,000 t of dumped ammunition, consisting mainly of mines, torpedoes and depth charges. The amount might be lower but is nonetheless concerning. In Pelzerhaken 50,000 t of mostly different types of bombs and artillery ammunition were dumped. Furthermore, a hull filled with blast furnace slag is located at the site. Accordingly, a combination of explosive and toxic substances is located on a small area.

Chemical Warfare Agents in the entire Baltic Sea

For CWA the areas of concern in the Baltic Sea are primarily the official dumpsites east of Bornholm and southeast of Gotland. In addition, vast amounts of chemical munitions were located in the Little Belt area as well as on the transport routes starting in Wolgast. Finally, there are unofficial sites of concern in the Gdansk Deep and the Slupsk Furrow. Types and amounts of dumped chemical munitions in the Baltic Sea vary by location. The Bornholm Basin, containing the largest part, holds over 90% of the chemical munitions dumped in the Baltic Sea.
The three different official dumping sites contain different types of CWA: the area of Little Belt contains approximately 5,000 tonnes of munitions (an estimated 750 tonnes of warfare agent) consisting primarily of Tabun, a nerve gas, while the Bornholm Basin and Gotland Deep primarily consist of mustard gas.

Although the available data on the total amount of dumped chemical munitions contains some gaps, it still provides a much more extensive and detailed picture than currently possible for conventional munitions. According to reliable information the HELCOM Report Chemical Munitions dumped in the Baltic Sea states, that around 40,000 t of chemical munitions have been dumped in the Baltic Sea (Bornholm Basin, Gotland Basin, Little Belt, Flensburg Fjord; Bay of Gdańsk?). Of these around 5,000 t lie to the south of the Little Belt, between Germany and Denmark, in direct geographic proximity to the German Exclusive Economic Zone (EEZ).

Oceans and seas were believed to be a limitless and safe place to dispose the unused munitions until the London Convention in 1972. In 1945, right after the end of the World War II the worldwide stocks of chemical warfare agents (CWAs) reached about 500,000 metric tons. Problematic in safe storage and disposal (Pitten et al. 1999) the chemical warfare (CW) posed a high risk for human health on land. It is estimated that at that time up to 60 countries possessed chemical munitions, out of which 40 had chosen sea dumping as the quickest and efficient method of their disposal at that time (DEPA 2010). There are 127 documented chemical munitions dumpsites worldwide, however, it is estimated that their number exceeds 300 (James Martin Center for Non-proliferation Studies, 2019). Numerous reports including Knobloch et al. (2013), Beldowski et al. (2016a) and Greenberg et al. (2016) indicate that soon after the end of World War II, the Baltic Sea began to be used as a dumpsite for at least 40,000 tons of chemical warfare agents (CWA). Little Belt, Bornholm and Gotland Depress are recognized to be the most important, officially designated CWA dumpsite areas in the Baltic Sea. Post WW II sea-dumping operations of the German chemical arsenal were performed under the guidance of the Potsdam Conference, mainly by the Soviet army between 1945 and 1948. The three different official dumping sites contain different types of CWA: the area of Little Belt contains approximately 5,000 tonnes of munitions (an estimated 750 tonnes of warfare agent) consisting primarily of Tabun, a nerve gas, while the Bornholm Basin and Gotland Deep primarily consist of mustard gas. The CW dumping area commonly referred to as the ‘primary dumpsite’, is located in the Bornholm Deep centred on a point with surface coordinates 55°20'N, 15°37'E. Its northern part is currently marked on sea charts as ‘larger explosives dumping ground’. At least 3,761 tons of Lewisite, Adamsite and Arsine Oil were sunk mainly in the Bornholm Deep and in the Gotland Deep (Makles and Śliwakowski 1997). Less than a tone of Adamsite, had been additionally disposed in Bornholm Basin between 1952 and 1965 by East Germany (Knobloch et al. 2013). Sea-dumping operations in the Gotland Deep took place between May and September 1947, when approximately 2,000 tons of CW material consisting of 1,000 tons of CWA were dumped. On the other hand, studies performed in CHEMSEA project confirmed the existence of an unofficial dumpsite in the Gdańsk Deep (Beldowski et al. 2016a). The suspicion about CWA presence in Gdańsk Deep arose after two incidents, the first with a mustard gas bomb recovered by a fishing trawler and a second with similar bomb being washed ashore on the Hel Peninsula in 1954 (Szarejko and Namieśnik 2009). The CWA presence was finally verified by pore-water (Beldowski et al. 2016a). The total volume of dumped conventional munitions in Gdańsk Deep until 1954 was approx. 60 tonnes, however, the load of CWA is still unknown (Knobloch et al. 2013). Although the loads of sea-dumped CWA are believed to pose a possible threat to the Baltic Sea ecosystem, there...
Warfare Materials in the Baltic Sea – Model Chapter Germany

is already an existing environmental degradation linked with nutrient overload that caused reduction of dissolved oxygen (DO) concentrations in bottom waters and creation of a “benthic deserts” below the halocline (Diaz and Rosenberg 2008). Water stagnation has negative impacts on marine ecosystems, especially in accumulation basins, since states of hypoxia and anoxia not only negatively influence organisms (Vaquer-Sunyer and Duarte 2008), but also their habitats (Conley et al. 2009).

After the conclusion of WWII, the allied forces captured an enormous amount ammunitions and other warfare materials. Military organisations and scientist considered dumping the captured ammunition into the sea the best way for the disarmament of Germany immediately after the war. Nearly 1.6 million tons of ammunition of all kinds were dumped in the North Sea and the Baltic Sea in German waters. Some of these places are well known, others are only assumptions.

2.3.2 Confirmed Contaminated Areas

In WW II, a lot of marine areas were used as training areas. Nearly the complete coastline of Mecklenburg-Vorpommern was used either as training ground for antiaircraft defence by guns and coastal artillery, as Luftwaffe training area for surface bombing or as testing area for torpedo development. The other nations established such areas in a similar manner. The coastlines of Latvia, including the Bay of Riga, Estonia and areas in Finland and Sweden were used as training areas. In all these areas exercise ammunition and dumped ammunition from the war time are present.

Nearly the entire Gulf of Finland was a war zone and was and still is a training area. In WW I the Russian Forces established the Forward-, Central- and Kronstadt positions with artillery batteries and minefields, In WWII a close meshed net of minefields was laid in the same area. Named Seeigel, Nashorn, Corbeta, Apolda or Juminda minefield, nearly 100,000 mines were laid in both wars. Complemented by countless bombs, artillery shells and depth charges, the result was an extensive battlefield.

Some exercise areas from WW II are still used as training areas by the abutting nations of the Baltic Sea today. In Germany the exercise areas Schönagen and Putlos-Todendorf are used by German Navy, Air Force and Army.

2.3.3 Suspected Areas

Besides these known dumpsites and confirmed contaminated areas, it is also assumed that stray single items of munitions lie scattering along the former transport routes, e.g. from the German loading port of Wolgast to the designated dumpsites in the Bornholm Basin. During the dumping activities, warfare materials were scattered in the vicinity of the designated dumping areas and well away from them on the transport routes due to the practice of en-route dumping. The wide distribution has its origins in the item-by-item basis, in which the majority of dumping activities in the Baltic Sea have been carried out. Consequently, warfare materials have been scattered in high density within or near the designated dumping areas - and in low density also outside of them.

Vague information about additional dumping activities could not be verified to date.

The ongoing relocation of objects makes the assignment of suspected areas a very challenging task.
2.3.4 Relocation of Objects

Human and natural modes of relocation of warfare materials differ in magnitude and type of force. Natural modes of relocation are mostly driven by currents and extreme weather events, however, only trawled fishing nets, dredgers or other large machinery moving along the seabed (e.g. for laying pipes or power lines) are recognized as being able to relocate large objects along the Baltic seafloor.

2.3.4.1 Current-induced mobilisation

The force required to move containers or heavy munitions over noteworthy distances cannot be applied by natural processes. It is known that objects on the sea floor get partially buried by scour, while cylindrical objects also tend to orientate with its cylinder axis normal to the mean incident velocity direction due to the Munk-Moment (Menzel, Witte, & Leder, Windkanalexperimente zur Bestimmung der Strömungsstrukturen um einen quer zur Anströmung auf einer Bodenplatte lagernden Zylinderabschnitt, 2012). Both orientation, and scour structure around such an object mean it has to be lifted or tilted to leave its position. Numerous approaches have been performed to model such forces. The moment induced by the fluid flow can be computed by summation of the moments on the surface of the whole object. Adding the loads on the object leads to an equation to derive the critical velocity for current-induced mobilisation.

2.3.4.2 Wave-induced mobilization

Common wave theories used to describe oscillatory waves distinguish between shallow water, transitional water and deep-water waves. In deep water, the orbits of the water molecules are circular, whereas the radius decreases with increasing water depth and there is no interaction with the sea floor, meaning no significant influence of the waves on objects on the sea floor is expected. However, transitional waves (like e.g. tidal waves) will induce a force on the sea floor itself as well as on objects located on the sea floor. As the velocity close to the sea floor has to be solely parallel to the bottom, also the orbits above are elliptic. With increasing depths, the vertical velocity component of the elliptic orbits decreases faster than the horizontal velocity component. The horizontal velocity close to the sea floor is lower than the horizontal velocity at the surface. In contrast to this, the horizontal velocity component in shallow water waves is nearly constant and independent of the water depth. This way, the impact of the surface waves on objects on the sea floor or the sea floor itself achieves its maximum.

Besides the current-induced scour, burial and mobilisation, the wave-induced actions are much more common in offshore regions. Even if the water depths are more than $h = 40 \, \text{m}$, the sediment and the objects may be influenced by waves as the wavelengths can be much longer than $\lambda = 80 \, \text{m}$.

The results are shown in Fig. 1. It has to be noted that typical wavelengths in the North Sea will be much smaller than $\lambda = 100 \, \text{m}$ with period times of $T = 8 \, \text{s}$. The plot shows that the critical
wave height decreases with increasing wavelength. The results for the spherical buoyant mines show a special behaviour that easily can be explained by a resonance effect of the object. Due to its shape and weight, the maximum hydrodynamic lift and drag are of very similar value like the Froude-Krylov-Force and the added mass force and the resonance frequency of the object in the trough will be in the order of 10 seconds. Thus, the position of the object starts to oscillate within the scour trough with an increasing amplitude and then is damped again.

Fig. 1: Critical wave heights and lengths at 26 m water depth and $z_o=0.5D$.

It also is obvious in Fig. 1 that the cylindrical shaped objects (British 120lb and 250lb General Purpose Bomb) are less mobile in larger waves than the spherical objects (the buoyant mines). A comparison between the wave-induced mobility and the pure current-induced mobility is given in Fig. 2 for some exemplary objects.
Although both plots in Fig. 2 show different axes, the mobility of the different objects due to current and waves respectively can be seen. For the wave-induced mobilisation, curves at lower wave heights imply a higher mobility of the individual object. For the current-induced mobilisation, lower Reynolds numbers imply lower incident velocities and thus a higher mobility of an object. In contrast to the wave-induced mobilisation, the spherical objects (yellow and green) are less mobile than the cylindrical objects (red and blue) under the influence of pure currents. The reason for this behaviour can be found in the ratio between the cross-sectional area $A$ of the objects, projected to the currents, to the volume of the objects $V$. The Froude-Krylov-Force and the added mass force are related to the volume of the objects, whereas the hydrodynamic lift and drag are related to the cross-sectional area of the object. Since this ratio differs for both types of shapes, their behaviour changes significantly. It can be stated that the spherical objects with a low cross-sectional area to volume ratio $A/V$ are more sensitive to waves and the cylindrical objects with a higher cross-sectional area to volume ratio are more sensitive to constant currents.

### 2.3.4.3 Human modes of relocation

Warfare materials may get caught in fishing nets and may be transported over long distances before being released. The highest potential for the relocation of warfare materials originates from bottom trawling, due to its direct high energy physical contact with large areas of the sea floor. Dredging is reported to be a way of accidentally relocating warfare materials, even moving them ashore to beaches (Mollitor, XX). Due to its spatial limitation dredging plays a less significant role. The relocation of warfare materials by dredging and trawling occur unintentionally, most likely involving objects resting outside the dumpsites marked on navigational charts and without the crew even being aware of it. Furthermore, some purposeful relocation of warfare materials happens in order to keep waterways free or to enable the construction of offshore infrastructure.
2.3.1 Burial of Objects

The subsequent steps of burial of a cylindrical object on the sea floor due to a constant incident flow are shown in Fig. 3, as published in (Menzel & Leder, Tankexperimente und numerische Simulati
ten zum wellen- und strömungsinduzierten Sedimenttransport im Umfeld minenähnlicher Objekte, 2013) and (Menzel & Leder, Versandung eines Zylinderabschnitts unter Einfluss von Oberflächenwellen im Laborversuch, 2015). The current induced scour and burial of cylindrical Objects on the sea floor has been investigated for model scale and was published in (Menzel, Rückborn, & Leder, Flow and scour around cylindrical objects in laboratory experiments, 2013), (Menzel, et al., 2014), (Menzel & Leder, Tankexperimente und numerische Simulationen zum wellen- und strömungsinduzierten Sedimenttransport im Umfeld minenähnlicher Objekte, Teil 2, 2014) and (Menzel & Leder, Versandung eines Zylinderabschnitts unter Einfluss von Oberflächenwellen im Laborversuch, 2015). Fig. 4 shows the scour structure close to the cylindrical model. It shows the typical scour trough in front of the cylinder, scour around and under the ends and a small accumulation area in wake of the object. Due to the low incident velocity in the shown large scale experiment, the amount of suspended sediment is small, compared to the experiments, published in (Menzel & Leder, Tankexperimente und numerische Simulationen zum wellen- und strömungsinduzierten Sedimenttransport im Umfeld minenähnlicher Objekte, Teil 2, 2014). Thus, the accumulation is a bit smaller because it just can be filled by sediment that enters the recirculation area by overflowing the object and therewith depends on the amount of suspended material.
To confirm that the scour and burial of realistic objects are quite similar to those of a simple cylinder as shown in Fig. 3, experiments in the water-channel have been operated for UXO models in small scale and in real scale. Regarding the results for the original scale model of a 250lb General Purpose Bomb in Fig. 5, it is shown that this model can be transferred into original scale.

The burial process of mine-shaped objects by waves was published by (Inman & Jenkins, 1996). In shallow water the scour in front and in the wake of a cylindrical object becomes nearly symmetric without an accumulation area.
2.4 Properties of Warfare Materials

2.4.1 Types of Warfare Materials

Warfare material in the Baltic Sea can be divided into two major categories – (1) conventional munition and (2) chemical munitions and warfare agents. Conventional munitions can be further distinguished into explosive, non-explosive and incendiary. In addition, munition components that were either dumped or separated due to deterioration may be found. Finally, ship and plane wrecks are located on the Baltic seafloor. The following chapters describe these categories of warfare materials. They are subdivided into the multitude of types and nations they were deployed by.

2.4.1.1 Conventional Explosive

2.4.1.1.1 Bombs

Bombs are weapons, that are transported by an aircraft, then dropped from the aircraft on a target and finally detonate when they reach this target. In 1849, the first trials with bombs from balloons were started by the Austrian Army. In 1911, an Italian pilot dropped bombs by hand from an aircraft to the enemy ground structures. Bombs are streamlined metal cylinders that are filled with an explosive charge and an ignition system. Different systems allow for the detonation of the bomb in a distance to the surface, on the surface or after impact. Professional construction and production started during WWI and the development of bombs is still ongoing.

Germany

The entirety of German airdropped bombs comprises of a cacophony of different types and sizes. The smallest bomb was the SD 0.5 with an explosive charge 0.031 kg. The biggest was the SA 4000 with a charge of 2700 kg explosive. Most deployed were the 50, 250, 500 and 1000 kg bombs. The number corresponds to the total weight of the respective bomb, 40% to 50% of which comprises the weight of the charge. Special constructions, such as armour piercing bombs PC-class have a total weight that is comparable to other bombs but contain a smaller charge of 10% to 20%.

All of these bombs were used in the Gulf of Finland, the coasts of Estonia, Latvia and Lithuania, in Gdansk Bay and in areas along the German coastline.
The development of Russian Bombs progressed in similar fashion as in Germany or other nations. The types of bombs are similar in weight of up to 5000 kg. However, most produced was the 100 kg class. The form of the casing displays some minor differences to the constructions of other nations during wartime, but the effectiveness was nearly the same.

In addition to Soviet developments, the Allies supported the Soviet Union with warfare materials, including aircrafts, mines and other weapons. Accordingly, Soviet replications of this material can be found in the marine environment as well.

All kinds of the Russian Bombs were deployed throughout the majority of the Baltic Sea from the Gulf of Finland all the way along the coastline to Swinoujscie and Bornholm.

**UK and USA**

Bombs from UK and USA are comparable to German or Russian types in terms of construction and firing systems. Weights were given in pound (lbs) and not in kilogram. From 8 lbs to 12000 lbs were the produced standard sizes, but mostly used were bombs from 100 lbs to 1000 lbs. The distribution area of UK or USA bombs is the western Baltic, the southern coastline of the central Baltic and the Gdansk bay. Allied bombers approached Germany via the border to Denmark and then changed the course to Kiel, Rostock, Stettin or other targets. The air defence attacked the bombers with artillery or fighter planes and in case of emergency bombers dropped the explosive cargo in the sea. The areas off the coast from Kiel, Lübeck,
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Rostock, Sassnitz, Usedom, Stettin, Gdansk and Kaliningrad are affected by a high density of submerged bombs.

2.4.1.1.2 Mines

The first trials with mines go back to the 18th century. Serious development started later and the first ever minefields were laid by Russian units in approach of Port Arthur in the Russo-Japanese War (1904-1905). From the beginning of WWI onwards, mines were essential weapons in naval warfare. Minefields were laid as offensive minefields to stop the merchant and military ships-traffic for the enemy and as defensive minefields for secure the own coastlines, harbours and traffic lanes.

The estimated number of mines laid in the Baltic Sea varies between 100,000 and 150,000. Of these 35,000 to 50,000 mines were swept and have been removed. It is estimated that 35,000 mines remain in the Gulf of Finland. The most common mines deployed were contact mines. In general, two types of naval mines – moored and ground mines – exist and both types are can still be fully functioning. Drifting mines were not allowed, but a small number of different drifting mines were produced in WW II. Drifting mines in form of cut moored mines without or defect sinking system were a problem.

Moored mines were invented prior to ground mines. Their case has a spherical shape, some with an additional belt connecting two hemispheres. Inside the mine casing the charge is stored in a separate container. The explosive charge in a moored mine weighs between 20 kg and 350 kg. The mines contain ignition systems that are based on different modes of contact ignition. Chemical Horns and switch-horns protruding out of the sphere give moored mine their characteristic look. Chemical horns contain a small glass phial with an electrolyte liquid. Resulting from a contact of a ship’s hull with the horn, the glass breaks and the electrolyte closes an electrical circuit resulting in the ignition of the mine. Switch horn system contain a fully loaded battery in the mine case. As a consequence of outside physical contact to the horn the switch is operated and again a current circuit is closed, and the detonation initiated.

The mine case is filled with air, thereby acting as a floating body and providing buoyancy for the mine. It is moored to the sea floor by means of an anchor. A wire or a chain connecting the mine case to the anchor ensures, that the mine’s position is maintained. Mines were located at a water depth between one and five meters below the surface when targeting surface ships and 100 m when targeting submarines. When the mooring was damaged by natural influences or cut by minesweeping gear, mooring mines ascended to the water surface. A secure system would open a hole in the casing, resulting in the mine being filled with water and sinking to the sea floor. Minesweepers also damaged the casing of mines by firing at them.

A contemporary challenge with legacy mines is the lack of knowledge regarding the constitution of the mines’ ignition systems. For mines with a casing that is in good condition, it is possible to encounter fully functioning ignition systems.
Ground mines were first developed towards the end of WWI, which also saw a small number of ground mines being laid. In WWII ground mines were fully functional.

The explosive charge of ground mines varies strongly between 45 kg and 880 kg. The ignition systems are magnetic, acoustic or pressure influenced. Combinations of two or all three variants were also developed. The magnetic field of a steel ship, the noise emanated by the engine and the marine propeller or the pressure change resulting from the displacement of water activated the ignition system. However, in order to function, the ground mine requires a sufficiently charged battery. It is possible, that some batteries of ground mines show a small current, but the last real function of a ground mine from WWII was dated to 1972.

Minesweeping against ground mines is intricate, as minesweeping systems need to be able to simulate the magnetic or acoustic fields of a real ship. The pressure displacement cannot be simulated by minesweeping systems.
In 1877, the first functioning moored mine from Germany, was commissioned. With an explosive charge of 40 kg and a simple contact-detector, the mine served as a defensive mine to defend coastal waters. Later, in 1914, Germany deployed new, improved moored mines with chemical horns and a well-functioning depth setting system and charges of up to 220 kg. An additional development were UC mines, moored mines laid by submarines with a charge of 200 kg explosives. All mines were contact mines and the majority used chemical horns to trigger the ignition system. Between the wars, further effort towards the development of moored mines were made. The resulting EMC or EMF mines contained explosive charges of 300/350 kg and influence distance firing systems added to the contact systems.

The development from ground mines started only during the 1920s. The development followed two paths: ground mines laid by surface ships or submarines and ground mines laid by aircraft. The LM (Luftmine) an BM (Bombenmine) are typical examples for air deployed mines and that could also function as a bomb. The explosive charge weighs between 290 kg and 720 kg. Ground mines laid by surface ships and submarines worked solely as mines and contain explosive charges of up to 880 kg.
Russia and Soviet Union

The development of mines in tsarist Russia and later in the Soviet Union was more advanced than in other countries. Part of the mines has similar characteristics as other mines, specifically the spherical cases and chemical horns. The mine-anchor has a greater weight and therefore providing superior stabilisation on the sea floor. Furthermore, the Russian Navy developed contact mines without chemical horns. The bottle with the electrolyte liquid was located inside the mine casing and a mechanical gear fixed a hammer. After physical contact by a ship, the mine case tilted, and the hammer broke the bottle. The electrolyte activated the detonation. This pendulum system was installed in a few numbers of mines in both wars.

The development of ground mines proceeded in similar fashion to that in Germany. Ground mines from the UK were provided to the Soviet Union after it entered the war, resulting in a mix of Russian and UK mines located in the Gulf of Finland.

Finland

Finland produced naval mines during WWII for the Merivoimat (i.e. the Finnish Navy). Most of them were replications of German, Russian and Swedish mines and own development efforts were very low.

Netherlands and France

After the war against France, the German Wehrmacht and Kriegsmarine captured some 100 mines from both navies. The fully functioning mines were added to the German mines in the Nashorn minefield, located between Helsinki and Tallinn from 1942 till 1944.

Sweden

The Kingdom Sweden was a neutral state during WWI and WWII. Sweden developed and deployed different types of mines with the purpose of defending and the securing Swedish
harbours and national waters. The construction principle was the same as that of other countries.

UK

UK mines were used in WWII. In April 1940, the Royal Air Force started with so called “gardenings”. Areas that were mined first were the access to Kiel canal and the Bay of Kiel. Later the entrance to the harbours with dockyards and the exercise areas from the submarines were targeted. All mines were ground mines of the types MK I-IV, MK V, and MK VI-IX. In total 13543 mines were laid in the Baltic sea and the access route Kattegat.

A special variant were “lent and leasing” ground mines from 1941. The UK sent some hundreds of mines to the Soviet Union which then used them in the Eastern Baltic. The Soviet Navy rebuilt these mines completely and used the replicas in the Eastern Baltic Sea.

2.4.1.1.3 Rockets

Germany

After WWI, Germany was not permitted to own airplanes, submarines and other highly developed warfare material. Civil research and development of rockets was a small, but effective branch. Werner von Braun drove the civil research, contacted with the research division of the German army and was eventually employed by it. The testing ground was established in Peenemunde/Usedom, which was initially out of reach of allied aircrafts. It was this test site, where the Luftwaffe developed and tested their rocket systems.

The V1 (or Fieseler Fi 103) was developed by the German Luftwaffe (i.e. the German air force) and built by Fieseler Werke, an aircraft construction company. The V1 was the first ever cruise missile, shaped similarly to a small aircraft, with a special jet propulsion and a warhead containing a 700 kg explosive charge. The V1 was in service by the Luftwaffe and used in WWII since June 1944 against Great Britain. In March 1945, the production was halted and the V1 that were ready for combat were collected in Schleswig Holstein. The last 200 V1 were dumped in the outer part of Flensburg Fjord on May 3, 1945 by German forces. Parts of them and nearly complete V1 can be found in dumping area.

Figure 6: V1
The V2 (or Aggregat 4 – A4) was a rocket, that was produced and deployed, after a long time in development. With a firing range of around 330 km, the V2 was the first ballistic missile and nearly 3200 missiles were launched during WWII. It contained an explosive charge of 738 kg amatol.

Some additional types of rockets were produced and tested in smaller numbers. The types Taifun, Wasserfall and Rheintochter were antiaircraft missiles, Rheinbote was developed for the surface to surface application.

Several rockets were developed for the Wehrmacht unit Nebelwerfertruppe and put in service. The rockets were unguided and contained a large explosive charge. They were utilized to support the firepower of artillery. After the war, rockets captured from the Nebelwerfertruppe were dumped in the known dumping areas.
The Luftwaffe used some unguided rockets for air-to-surface attacks, as anti-tank weapons and in air-to-air combat. The diameter of these rockets was 5.5 cm to 21.0 cm and they were in service till 1944. The smaller units from the Kriegsmarine (War Navy) used a similar anti-aircraft rocket with the diameter of 8.6 cm.

**Allied forces**

Similar to the German forces, the allies used rockets in wartime. The unguided Russian missile Katyusha is a well-known example. The coastline area all the way from Mecklenburg-Vorpommern to Estonia it is highly probable to encounter rockets, that were misfired in wartime or dumped afterwards.

### 2.4.1.1.4 Torpedoes

The torpedo is a self-propelled weapon, consisting of an explosive charge, a control system and a power source for the engine.

#### Germany

Already during WWI German torpedoes in different sizes existed. Their diameter ranged from 45 cm to 53.3 cm and in rare cases up to 60 cm on few battleships. The explosive charge had a weight of up to 300 kg and the installed ignition system was initiated by a contact fuse. The propulsion was achieved by releasing on air pressure resulting in the typical bubble trail that can be observed at the rear of a propelled torpedo. The firing range for these WWI torpedoes reached from 600 m to a few kilometres.

In WWII, two standard torpedoes were used by the Kriegsmarine. The torpedo G7a, that was again propelled by pressurized air, contained a charge of 280 kg to 300 kg. Its firing range reached from 6 km at a speed of 44 kn all the way up to 12 km at a speed of 30 kn. The other type was the G7e propelled by an electric engine and batteries. The torpedo contained the same charge as the G7a, but the G7e reached a firing range of 5 km to 7.5 km at a speed of 30 kn.

A great number of airdropped torpedoes were used by the Luftwaffe. The F5b torpedo had a diameter of 45 cm, propulsion by pressurized air and contained a warhead with a 200 kg charge. In the Baltic, two areas are affected by a concentration of F5b torpedoes. One is located close to Gdynia at former testing area “Hexengrund”, where lost testing F5b are submerged. The second area is located in the Gulf of Riga where a school was operated by the Luftwaffe in 1944 and numerous torpedoes were lost.

Commented [S40]: do these have an explosive charge?
Warfare Materials in the Baltic Sea – Model Chapter Germany

Russia and Soviet Union

The Russian torpedo development started with three torpedo calibres: 37.5 cm, 45 cm and 53.3 cm. All torpedoes were wet-heathers, meaning that they were propelled by injecting a liquid fuel into the pressure air chamber, further supported by the steam resulting from cooling the combustion chamber. They contained warheads ranging from 200 kg to 300 kg. In WWII the 45 cm version and a series of 53.3 cm torpedoes was used by the Soviet Union. The explosive warhead could by then carry an explosive charge of up to 400 kg.

2.4.1.5 Depth Charges

The depth charge is a weapon developed for the combat against submarines. After beginning the submarine war in WWI, escort units required an antisubmarine weapon. The depth charge was the result. Explosives were filled in a metal case, a clockwork or a membrane (i.e. a pressure sensor) initiated the detonation after a certain amount of time had passed or the desired depth was reached. The detonation in the depth would result in damage to or destruction of submarines.

Germany

The German depth charge carried an explosive charge between 60 kg and 130 kg. A special type was the depth charge with floating aid. The explosive charge weighed 60 kg and the floating aid reduced the speed of sinking.

Russia and Soviet Union

The Russian and Soviet depth charges are similar to the German ones in terms of explosives utilized, shape and firing system installed.

2.4.1.6 Antisubmarine Rockets

Germany

A special form of antisubmarine weapon is the antisubmarine rocket (ASR). The German Navy used this kind of weapon from 1956 till 1982 with the type “Hedgehog” The Hedgehog was a small explosive charge from 12 kg and a propellant charge for a range approx. 250 m. The Navy used the ASR in an exercise area in the West Baltic Sea and part of the ammunition is still there on the ocean floor.

Commented [S41]: Where exactly? Name of area?
Warfare Materials in the Baltic Sea – Model Chapter Germany

Russia and WP Navy

A similar form as the Hedgehog were used by the Russian and WP Navies in the Baltic Sea. The ASR have the same form as Hedgehog, a higher weight of the charge and a higher range.

Figure 10: Russian Antisubmarine Rockets

2.4.1.7 Artillery Shells

The history of artillery shells goes back to the middle ages. Originating from a hollow sphere filled with black powder and using a burning fuse, development over the centuries has resulted in the development of a high technology warfare material.

Armed forces used many kinds of artillery shells. The small calibres of 2 cm to 5.7 cm serve two purposes. The main application is as antiaircraft defence against aircrafts in low and medium altitude. As such the guns work in rapid fire. The second application is combat against surface targets over short and medium distances. These calibres were mostly deployed as main weapons of small vessels and light tanks.

The calibres from 7.5 cm to 15 cm were installed as the main gun of vessels, Artillery and heavy tanks for use against surface targets. Antiaircraft artillery with calibres from 7.5 cm to 12.8 cm could work in a double roll. Antiaircraft and artillery firing support against surface targets. The larger calibres from 15 cm up to 40.5 cm were used in regular artillery roll.

Usually naval artillery and antiaircraft shells consisted of a combined shell and propellant charge in a cartridge up to a calibre of 12.7 cm. For bigger calibres shell and propellant charge were separate components.
The artillery shells used by ground and aerial forces were similar to those used by naval forces for antiaircraft purposes. Others such as field artillery and tank artillery consisted of separate grenades and propellant charges. Some artillery shells had specific effects. The variety encompasses exploding, hollowed, antitank, illumination, smoke and chemical agent shells. These differ terms of type of payload and the weight of the explosive charge in the grenade. The weight of the explosive charge in an antitank grenade for example is very small with just about 30% of the weight of a normal HE shell.

2.4.1.2 Conventional Incendiary

Incendiary munitions like shells or bombs are used to inflict damage by starting fires in the stricken structure. The payload is an incendiary mixture, e.g. thermite and sometimes a small charge is included to open the case and scatter the incendiary mix. The mixture starts to burn after the ignitor, often white phosphorus, gets in contact with air. The fillings include thermite and burning fluids and are further described in chapter xxx.

Germany

Two types of incendiary bombs employed by the Luftwaffe existed. The smaller type, called Elektronbrandbombe, weighing 1 kg to 2.2 kg contained a small explosive charge of 0.008 kg to 0.015 kg and a thermite charge. The other type was filled with a mixture of oil and fuel and the ignitor is white phosphorus. The biggest of this type was the C 500 bomb containing a mixed liquid charge of 157 kg.

For bombs releasing smoke for the purposes of camouflaging or target marking cases, that similar to those of the incendiary bombs, were used.
UK and USA

Incendiary bombs were of high priority both tactically and strategically. Similar to Germany, the Allies utilized small bombs containing thermite charges and bigger ones containing both a combustible liquid and a phosphorus charge. Up to 30% of 30 lbs incendiary MK III bomb with 1 lbs white phosphorus failed to detonate or ignite respectively.

2.4.1.3 Chemical

While conventional munitions contain explosives or incendiary agents and their effect is characterized accordingly by detonation or burning, chemical munitions are distinguished by a payload of chemical warfare agent. Their purpose is not the physical destruction of infrastructure, but rather directly or indirectly, a temporary or permanent incapacitation of humans due to the respective toxic effects of the compounds used. In addition, a strong psychological component exists, that is associated with the type of external injuries and the delay before their appearance (e.g. blisters on the skin). In contrast to the substances contained in conventional munitions, the hazards posed by chemical warfare agents for people and the environment appear obvious. Hence, researching this kind of munitions has received special attention in the past.

An extensive description of chemical warfare agents and the corresponding ammunition types is already listed in the HELCOM BSEP 142 report (2013).

The majority of chemical warfare munitions dumped are aircraft bombs. More than half of the chemical munitions dumped (in tonnes) were aircraft bombs containing mustard gas. However, not all CWA were dumped as payload of munitions. A considerable amount was dumped in encasements and containers.

2.4.2 Munition Compounds

Towards the end of the 19th century the explosives development was a highly innovative sector with a variety of new materials being produced. All larger powers developed their own explosive materials. These were based on the same basic chemical compounds and nearly all of them contained Trinitrotoluene (TNT). Numerous other materials were mixed in, to create explosives with higher explosive force.

Over the course of WWII, the German Wehrmacht and Luftwaffe deployed more than 117 types of explosive materials. On top of that, the Kriegsmarine utilized nearly 40 substances that were specifically designed for the use in naval weapons, such as mines and torpedoes.

The amount of explosive material contained in different types of warfare materials varied considerably. Naval mines and torpedoes were filled with large amounts of explosives. A moored mine contained up to 250 kg and a ground mine even held up to 880 kg. Torpedoes were filled with charges of up to 300 kg and depth charges contained between 20 kg and 100 kg. (Haas, year)

Munitions can contain a large number of compounds though these are intended to fulfil a relatively small range of tasks. The aim is to provide energy for blast, shock, or propulsion. The last of these can be used to propel missiles, shell or other payloads to their targets.

The development of modern explosives began at the end of the nineteenth century when protection systems made existing systems inadequate. Prior to that most weapons relied on gunpowder and gunpowder derivatives. The development firstly of nitrocellulose and then nitroglycerine changed the options and while these altered the weapon systems, they were
hazardous to use. The need for more stable solid material with higher performance and the development of nitrification technology, specifically the addition of nitro groups to organic molecules produced the next major change. Picric acid was one of the first of these nitrated solids but was rapidly replaced in the early twentieth century by Trinitrotoluene (TNT) as picric acid was found to be toxic.

The use of TNT replaced some of the other attempts to produce higher performance with ammonium nitrate (AN) mixtures through blends such as Amatol (AN/TNT) were used in naval shell fillings. These were insufficient to defeat armour and the synthesis and development of, firstly RDX/Hexogen, and then HMX/Octogen in both Germany and the UK added the needed power. Many such compositions are still in use, often with metal in the form of powdered Aluminium and Ammonium perchlorate added for blast effects.

A separate category covers a range of pyrotechnics which provide smoke, light or initiation systems. These are much more complex as many chemical systems, generally including metals, have been used. These are characterised as primary or secondary explosives – as noted by Urbanski, below. Primary explosives are those that are easily initiated and there are therefore regarded as the most hazardous, while secondary are those with greater output but much less sensitive. The categories and tests used are defined in the UN Series Tests and are described in the UN Manual of Tests and Criteria (MoTC). These are managed by national authorities and are subject to review and update.

The range of materials are well summarised in Urbanski, Chemistry and Technology of Explosives, 1984 and other works such as Agrawal, High Energy Materials, 2010 and Organic Chemistry of Explosives, 2007 provide both details of the type of materials used and their properties.

NATO has an Ammunition Safety Group, AC/326, which focuses on the military aspects of safety and classification. There is increasing activity on defining environmental hazards in these bodies.

There are also several databases containing information – one of which is managed by the NATO Munitions Information Analysis Centre (MSIAC) through this is only fully available to MSIAC members.

These NATO groups maintain expertise through Subject Matter Experts with access to detailed databases of properties and both hazards and quantified risks. There exist to develop and support international technical knowledge and to develop and support assessments through agreed testing and research. Most munitions safety assessments are described in NATO Standardisation Agreements (STANAGs) which are declassified to aid in risk and hazard assessments.

Most of the materials used in quantities are organic, nitrogen containing species, with the nitrogen located in either nitro groups or nitrate ester groups. These release energy rapidly when stimulated. The nature of these species mean that they are often bioactive and thus present a risk when released. Some are more soluble than others but almost all have solubility in water.

The general approach to use requires a sequence of operations. Most of the materials which form the main charge are both highly energetic and relatively insensitive. The energy may not be as great as in other organic materials such as food stuffs, but it is realisable rapidly in
response to stimulus. That release takes the form of detonation – a supersonic reaction – or deflagration – a high speed combustion process. The first is used for end effect and the second for propulsion, though deflagration can be used for an end effect.

Since these materials are high output their handling present problems and generally those used are relatively insensitive for the sake of safety. This mean that operation requires a stimulus, and this is provided by the ‘ignition train’ which contains a sequence of materials to create and amplify the initial stimulus and thus produce operation of the weapon. Explosives are categorised by their sensitivity. Primary explosives are those that are easily initiated by a simple shock or friction. Their output may be low but is enough to produce an effect that can be used to initiate secondary explosives. These are harder to initiate but contain more energy and so form the charge.

There is therefore a sequence of operation where the most sensitive material or primary explosive is present in very small amounts – producing the initial output which can initiate or ignite the main charge or trigger the operation of a booster charge which triggers full operation. This is an explosives train.

Most nations have preferred materials used in their munitions. This is based on history and availability, but TNT, nitramines such as hexogen (RDX) and octogen (HMX) are common, as are nitrate esters such as nitroglycerine and PETN. Nitrocellulose is also common.

As mentioned above primary explosives have a broader range of components but lead, nickel, copper and iron are common, normally as organic compounds or salts. Their physical nature will have an impact on risk in the Baltic environment. That includes packaging and accessibility – a sealed warhead has less likelihood of degradation than gun propellants held loosely or missile propellants with a large burning surface.

I should be noted that most CWA system contain an explosive component. This is designed to initiate the system and spread the CW agent. The charge must therefore be small and designed to propel the agent successfully without damage. Awareness of this vital for proper assessment.

An understanding of these materials and their roles is an important part of risk management.

### 2.4.2.1 Explosives

Explosives are energetic materials, that undergo a strong exothermic chemical reaction when a mechanical, thermal or shock wave stimulus delivers a sufficient amount of activation energy. The following reaction is self-sustaining and releases significant amounts of gases and thermal energy during a very short time period, normally in the scale of microseconds. The energy is converted into kinetic energy and the gaseous products expand faster than the surrounding air or matter can respond, so that a pressure wave/shock wave spreads out with devastating effects, accompanied by loud noise and light phenomena. For the use of explosives, different performance aspects are of interest, such as the velocity of detonation, the working capacity, the detonation pressure or the heat of explosion.

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 1: Main characteristics of the two reaction types of explosives

<table>
<thead>
<tr>
<th>Deflagration</th>
<th>Detonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface phenomenon</td>
<td>Wave phenomenon (high-speed shock wave propagates detonation)</td>
</tr>
<tr>
<td>Rate of deflagration is lower than sonic velocity in surrounding medium</td>
<td>Rate of detonation is higher than sonic velocity in surrounding medium</td>
</tr>
<tr>
<td>Reaction products of deflagration travel in opposite direction of propagation direction</td>
<td>Reaction products of detonation travel into same direction as propagation direction</td>
</tr>
</tbody>
</table>

As regards the chemistry of explosives, their composition is the key to understanding their specific properties. In contrast to combustion where the fuel, for example petrol, can only be burned in the presence of oxygen as oxidizer, explosives contain both an oxidizing group and the fuel in one molecule or within the same compound. Oxidizing groups for example can be -ONO₂, -NO₂, -NF₂, while -NH₂, NH or alkyl groups are fuel contributors. These characteristic chemical groups allow the classification of explosives into the following groups:

- Nitrate esters
- Nitroaromatics
- Aliphatic nitro compounds
- Nitrarines
- Heterocyclic compounds or
- Energetic salts

For handling safety, the materials have to be stable under expected storage and service conditions and in the environments to which they will be exposed. Factors affecting the stability are different environmental conditions such as temperature, pressure and exposure to water. Possible degradation mechanisms can be the chemical decomposition, phase changes or autocatalytic degradation. This can lead to enhanced sensitivity or even spontaneous auto-ignition (Köhler et al. 2008).

Besides stability, the most important issue affecting the handling safety of explosives is their sensitivity to mechanical, thermal and electric stimuli. The measurement methods are described by various guidelines such as the „Recommendations on the Transport of Dangerous Goods: Model Regulations“ by the United Nations. Here, based on results of standardized test procedures, substances are divided into different hazard groups. These procedures are used to obtain the impact and friction sensitivity, but also the thermal and electrical sensitivity. The same values are also used to categorize high explosives into primary and secondary explosives. Primary explosives are very or extremely sensitive to friction and impact, while secondary explosives range from sensitive to insensitive (see table 2).
A general differentiation of energetic materials can be made according to the safety related parameters described above and according to their intended application. The main categories are high explosives, propellants and pyrotechnics. This is shown in figure X.

Figure 10: Explosive materials classification (Zukas und Walters 1998)

2.4.2.1.1 Primary explosives

Substances belonging to the category of primary explosives are much more sensitive towards heat, impact or friction than secondary explosives and the transition between deflagration and detonation is faster even for very small quantities (Sučeska 1995). They are mostly used as initiating explosives in fuse trains, e.g. in detonators or booster charges (Klapötke 2009). Accordingly, warfare material in the Baltic Sea will only contain primary explosives if they were fused. That means that the warfare material was either dumped in a fused state or that it was deployed during combat, mining or training.

To qualify as primary explosives, substances need to be easy to initiate and display an adequate detonation performance. These properties enable them to transfer the detonation to less sensitive energetic materials such as secondary explosives.
Warfare Materials in the Baltic Sea – Model Chapter Germany

Figure 11: Schematic diagram of electric initiator type Smith-Gardiner (left) and booster charge (right) (Cooper 1996, Sučeska 1995)

The most common primary explosives and their characteristic values can be seen in Table 3. Usually their performance indicators like detonation velocity and pressure are lower than those of secondary explosives.

Table 3: Common Primary explosives according to (Köhler et al. 2008)

<table>
<thead>
<tr>
<th></th>
<th>Impact sensitivity [Nm]</th>
<th>Friction sensitivity [N]</th>
<th>Detonation velocity [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead azide</td>
<td>2.5 - 4</td>
<td>0.1 - 1</td>
<td>4630</td>
</tr>
<tr>
<td>Lead styphnate</td>
<td>2.5 - 5</td>
<td>&lt; 1</td>
<td>5200</td>
</tr>
<tr>
<td>Mercury fulminate</td>
<td>1 - 2</td>
<td>&lt; 1</td>
<td>5000</td>
</tr>
<tr>
<td>Tetrazene</td>
<td>1</td>
<td>8</td>
<td>4000</td>
</tr>
</tbody>
</table>

2.4.2.1.2 Payload explosives

The size of the payload depends on the type of ammunition. On one side of the spectrum, artillery shells contain the smallest payload, on the other hand, bombs and depth charges contain the largest. Artillery shells are encased with a heavy steel hull, that needs to withstand the large compressive force, which occurs during the firing of a shell. The shell must only explode when it hits or after it penetrates the target. The destructive force of the shell originates from the combined effects of the kinetic energy and the explosive energy. Hence, a small explosive charge is sufficient. Bombs and mines on the other hand rely heavily on the force of the detonation, resulting in them carrying larger amounts of explosive material. German payload explosives were usually Schießwolle 16, 36, 39 etc. Other countries filled mines with mixtures of TNT, Amatol, Minol (GB), HBX, Torpex (US) and Picratol (Russia).

Sea mines, moored mines and ground mines have a weight/charge ratio of 60 %. The same is true for unguided rockets. For general purpose air dropped bombs the share of the weight of explosives of the overall weight is 50%, while for piercing bombs it is 85% and, in some cases, even up to 95%. These weight/charge ratios are very similar in the ammunition across different countries.
Secondary explosives, when initiated, are more powerful and thus have a much higher detonation velocity and working capacity than primary explosives. The higher performance is combined with a lower sensitivity. Therefore, they are used as main charges in warheads of military ammunition like naval mines, torpedoes or bombs. As a result, every single piece of warfare material that is present in the Baltic Sea can be expected to contain secondary explosives.

In the past, especially during the world wars, one of the most frequently used explosives was TNT. It was part of various ammunitions and was also the main component in explosive mixtures employed in underwater ordnances along with ammonium nitrate (AN). AN was often used as a substitute for secondary explosives, due to its high availability, low price and non-ideal detonation behaviour which enables higher bubble energies (see XXX) (Strahle 1988). Depending on the manufacturing country, different formulations for explosive mixtures existed. British naval weapons consisted of Amatol or Minol, while the German mixtures were built up from block fitted Hexanite. An overview of these compositions is shown in the following table.

Aluminium powder was added to formulations to increase the shock wave and the bubble heave energy through reaction with the surrounding water, which resulted in a higher impulse that effected the surroundings (Komissarov 2015). This post-detonation process generally also increases the heat of the explosion and with it the temperature of the reaction products.

Table 4: Explosives and components included in different formulations (Köhler, Meyer, & Homburg, 2008)

<table>
<thead>
<tr>
<th>Structural formula</th>
<th>Minol</th>
<th>Amatol</th>
<th>Hexanite</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,4,6-Trinitrotoluene</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2,4,6,2',4',6'-Hexanitrodiphenylamine</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Aluminium powder</td>
<td>Al</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Another military explosive that was widely used is 1,3,5-Trinitro-1,3,5-triazinane, also known as RDX (Royal Demolition Explosive). It is still in use, for example in C-4 in combination with plasticizers. In the table below the most relevant explosives of the past decades are listed along with their date of invention.
2.4.2.2 Propellants

In addition to explosive materials, some warfare materials contained propellants. For anti-aircraft artillery with a calibre of up to 12.8 cm and navy artillery with a calibre of up to 15 cm, the cartridge containing the propellant was integrated with the shell. The burning velocity of the propellant is comparable to that of the payload explosive. Accordingly, the total amount of explosive material is complemented by an additional 120 g to 6 kg.

Propellants come in two major varieties – rocket and gun. While there are similarities, there are also differences both in physical nature and compositions. A third class, gas generators operates in a similar way to rocket systems. A fourth class are those based on liquid systems.

In all cases the performance is produced by the reaction of an oxidant with a fuel. Propellants are designed to provide thrust, either for a missile or for a projectile. Gas generators can do both but tend to be lower in output.

The general use of these in systems means that they are therefore likely to be found where munitions have dumped either actively or as a result of action. The difference in nature means that the response to the environment will also be different. The nature of activity in the Baltic means that all types are likely to be found. Both single base and double base (based on Nitrocellulose and Nitroglycerine) were common for all participants and early versions of composite propellants were in use during WWII. Germany experimented with liquid propellants in their missile programmes. However, since the end of WW2, all nations then bordering the Baltic and engaged in the Cold War would use and probably dump the whole range of materials.
The book Solid Rocket Propulsion (Davenas 1992) is still a sound review of the technology, and a more recent volume Chemical Rocket Propulsion (de Luca et al 2017) includes discussion of the environmental effects.

The nature of the technology means that most of the materials dumped underwater will be based on technology from the 20th century and thus contain ingredients whose nature is discussed in Agrawal, Organic Chemistry of Explosives, 2007.

Traditional solid gun and rocket propellants have similar ingredients, and there are two main classes – double base or composite. In the first which has broad applicability, the main ingredients are nitrocellulose and nitroglycerine with sometime an addition of nitroguanidine for triple base gun propellants. For some systems black powder is employed – basically a form of gunpowder based on carbon (charcoal) sulphur and potassium nitrate.

Composite propellants are much more common for high performance missile systems. Here the more common oxidant is ammonium perchlorate with a polymer binder, often hydroxy-terminated polybutadiene as the fuel. Where additional thrust is needed aluminium can be added.

The major difference between gun and solid rocket propellants is their physical form. Rocket systems are generally monolithic blocks of propellant which gun propellants are either sticks or grains, generally a few mm in diameter and with perforations. The size and perforations are designed to assist in controlled burning to obtain the desired output.

Both are normally contained within a vessel – either a missile body or a cartridge case. In many cases gun propellants may be kept and used in canvas bags or more recently nitrocellulose-formed combustible cases.

Both are designed for high speed combustion and not detonation, though mass detonation can occur. There is a slightly reduced hazard when compared to equivalent masses of explosives. They can of course contribute to any such explosive event.

The nature of the propellants, both chemical and physical has an impact on their behaviour underwater. As will be noted many of the components are water soluble as they are likely to be eroded with time. The rate of erosion will depend on the environmental conditions – temperature current flow etc as the dissolution will depend on the partition coefficient under those conditions and the rate of removal. Where soluble materials are locked into a polymeric matrix the dissolution will be slower and depend on the accessibility to water.

Since most rocket motors have a slotted grain design, again to assist with combustion there are access routes for water, provided that the weapon is not hermetically enclosed. The solubility properties of the ingredients is addressed in Agrawal’s texts (ibid and High Energy Materials 2010). Most of the solid oxidisers are readily water soluble and nitroglycerine has an appreciable solubility.

Other components, such as nitrocellulose degrade and decompose in contact with water, but that rate is strongly dependent on temperature and pH. (Blum, Natick 1976).

The result is that the explosive hazard can be reduced with time but that leaching of toxic ingredients will need to be considered and managed.

Finally, more novel materials have been introduced in the last twenty years but have many of the same characteristics and hence the same issues.
2.4.2.3 CWA

Chemical ammunition was developed both for use of the army and the air force. The development of chemical ammunition for use by army forces focused on artillery shells. Since the tactical purpose of artillery deployment is to cover a specific area with heavy fire, army forces required the production of large quantities of shells. During WW II, German artillery shells with calibres of 10.5 cm and 15 cm were filled with CWA. In addition, captured French 7.5 cm and Hungarian 15 cm artillery shells were stored in German ammunition storage. Other types of warfare materials containing CWA, developed for the army were 10 cm and 15 cm rockets and a small amount of 8 cm mortar shells. With the aim of blocking approaching infantry, Germany also developed landmines called Sprühbüchse 37 and Schwefelkerze (similar as smoke or fog), that were filled with CWA, most commonly S-Lost. At the beginning of WW II, the German army equipped three battalions with a spray system that used containers which could hold up to 970 kg CWA. While construction of these containers was finished, they were never filled. After WW II they were dumped in the Bornholm dumping area, containing numerous types of CWA. German chemical ammunition was entirely stored in different locations throughout Germany. It was not stored in any of the occupied countries. Air force mainly developed bombs for the application of CWA. The German Luftwaffe conducted a multitude of tests with a variety of different bombs, for the use of CWA. However, the only development that was successful, were KC 50, KC 250 and KC 500 type bombs. In total 1800 KC 500 bombs were produced. Another air force application were spray attacks executed from special containers that were attached under the wings of aircraft. Systems like this were tested by most air forces involved in WW II, but no attacks were ever executed. Nevertheless, the systems and containers were produced and filled with CWA. (Gellermann 1986)

2.4.2.4 Other Materials

A multitude of payload materials were used. Next to the high explosives and CWA described in the previous chapters, these include incendiary and signalling materials.

A special type of payload is the highly flammable material which is contained in incendiary munitions. Incendiary munitions were used in WW II in all fighting areas in the Baltic Sea. Among those, the most dangerous are the ones containing white phosphorus. This kind of warfare material (shells or bombs), contained only a small explosive charge. A container was filled with the main incendiary charge, which was usually a liquid flammable blend of gasoline, diesel and rubber. To trigger the ignition, white phosphorus was stored in a separate container, as it ignites when reacting with oxygen. At the moment of impact, the explosive charge would burst open both the container with the main incendiary charge and the container with white phosphorus, resulting in the spreading of the incendiary material over a large area. Only a few seconds release to oxygen the white phosphorus would ignite independently and the fire would therupon spread to the flammable liquid.

Many of the incendiary bombs were constructed with very thin shells. They broke when hitting the water surface and released their payload. However, the water prevented the contact of white phosphorus with oxygen. The phosphorus charge was often broken in multiple small pieces. Over the years that it was submerged, the phosphorus reacted with the sea water and took on a similar colour to amber (see chapter 3.2.10). In addition, white phosphorus has toxic effects on humans, animals and ecosystems.
Another class of incendiary ammunition was filled with a charge of thermite. The hazard of this kind of ammunition originates from the fuse which contains explosive material. The incendiary charge however is not toxic.

Yet other material is contained in pyrotechnic signal ammunition. Different mixtures were used in the past and are still in use today.
3. Warfare Materials – Effects and Risks

As a result of military conflicts in the 20th century, large quantities of warfare material ended up in global rivers, lakes, seas and oceans. Thousands of tons of various poisonous toxic chemicals were purposely and accidentally submerged in both coastal or deep-sea areas and the Baltic Sea is no exception. First of all, the extensive amounts of explosives got into marine ecosystems due to battlefield encounters. Many navy units and munition transports lost their cargo or got destroyed during battles and later sunk, while aerial raids dropped significant amounts of bombs and aerial mines to coastal areas. Mine warfare, intense in both World War I and World War II, introduced ca. 160 000 mines to the Baltic Sea, from which, up to date barely 20% were removed or destroyed in clearance operations. This resulted in UXO dispersal in many areas of the Baltic Sea. On top of that, the Baltic Sea started playing a role of a dumpsite for at least 40 000 tons of chemical munitions, which could be treated as discarded military material (DMM). Sea dumping operations took place soon after WW II leaving the official and unofficial underwater dumpsites unmonitored for several decades (Knobloch et al. 2013).

3.1 Known and Potential Effects

Nowadays, sea dumped chemical munitions pose a recognized environmental hazard for marine ecosystems. Recent studies performed in Baltic Sea dumpsites revealed, that 50% of all UXO and DMM have already corroded, and their constituents have leaked to the surrounding sediments. Many substances among ignites, explosives and CWAs used as munitions fillings have a recognized terrestrial toxicity, therefore, the sea dumped warfare pose a potential threat to aquatic organisms. The aquatic conditions are, on the other hand, dramatically different from terrestrial in a way that could possibly alter their effects on biota. Solubility, oxidation and hydrolyzation are among various factors that shape the fate and bioavailability of a chemical compound in aquatic ecosystems. The environmental pathway degradation, transportation and transformation of explosives and chemical warfare agents (CWA) is complex and generally depends on multiple factors. However, it can be concluded, that those substances are persistent, and their degradation products and metabolites may be as toxic or even more toxic as parent compounds.

3.1.1 Detonation

A detonation is defined as the reaction of an energetic material after a stimulus. This chemical reaction consists of a conversion of a solid material into gaseous reaction products and leads to an instantaneous multiplication 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 6).

<table>
<thead>
<tr>
<th>Explosive name</th>
<th>Detonation velocity [ms⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium nitrate</td>
<td>2,700</td>
</tr>
<tr>
<td>Lead azide</td>
<td>4,630</td>
</tr>
</tbody>
</table>
When a detonation is initiated, a shock wave develops inside the explosive material that drives the reaction further by compressing and heating the material. The shock wave propagates into the surrounding water. A typical pressure signature of an underwater detonation (Figure 12) 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 results from 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.

Figure 12 Pressure signal over time of a mine detonation (Quelle:source: dosits.org).

Underwater detonations are the loudest anthropogenic point sources of noise in the oceans and have the potential to cause serious injury in marine vertebrates and invertebrates (Richardson et al., 1995; Lewis, 1996). Both the steep wave front and the high peak pressure caused by underwater detonations control the severity of injuries to marine vertebrates (Landsberg, 2000) such as fish, water birds and marine mammals (chapter 3.4). A large
fraction of the total chemical energy in an explosive material is upon detonation radiated as acoustic energy (e.g., 40 % for a 1 lb charge (Urick, 1967)). Also, marine invertebrates are impacted by the shock wave. However, effects on invertebrates have been studied to a lesser extent and are not well understood.

Explosives are generally divided into two classes – ideal and non-ideal, a definition that is related to the gas laws. In theory, the chemical reaction zone should be infinitely thin, producing maximum shock velocity. Ideal explosives’ behaviour is closer to this theory. They are therefore more predictable in their behaviour. Non-ideal explosives on the other hand have a wider reaction zone resulting in a more complex reaction system.

The mechanism for underwater detonations resemble that of non-ideal explosives. In these, the desired effects focus on the production of gas in the form of a blast. Non-ideal explosives for underwater use have often been formulated to maximise the blast and generate a larger reaction zone. This can be induced by the addition of metals such as aluminium or oxidisers such as ammonium perchlorate. The effects of underwater detonations are in fact a combination of shock, produced by a very high detonation velocity and blast, appearing as a gas bubble. The nature of the environment causes that the two mechanisms operate over different timescales.

Effects of underwater explosions to surface ships are the bubble jet and the shredding effect. The extent of an explosion is not only determined by the detonation velocity of the explosive but also by the integrity of the UXO shell. By means of a defined weakening of the shell and a deliberately low energy input the much weaker deflagration (chapter xxx) can be triggered. As a consequence, only a small fraction of the explosive quantity is converted at subsonic velocity. However, objectives have to be defined carefully for each UXO treatment as with a deflagration, a shockwave and associated risks of injury and acoustic trauma can be avoided, but contamination of the sea with reaction products of incomplete combustion is increased at the same time (Koschinski, 2011).

Explosive materials possess a critical or failure diameter, which is the charge diameter below which a detonation cannot be sustained. Assessment of this critical diameter is important for the management of detonation risk, as there is limited risk of detonation below it. Furthermore, the presence of water may act as a diluent and quencher for reaction and it may increase the size of the critical mass.

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.

### 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.

Some estimates have predicted that corrosion in the Baltic Sea will lead to maximum chemical release rates from submerged munitions in the early twenty-first century (Granbom, 1994; Malyshev, 1996; Glasby, 1997). Other and more recent reports generally confirm these predictions of munition deterioration and show that chemical munitions dumped in the Baltic and Adriatic Seas exhibit severe to complete corrosion (Sanderson and Fauser, 2015; Amato et al., 2006; Lisichkin, 1996; Sunkov, 1996). Shipwrecks in the Skagerrak were investigated with ROVs and many chemical weapons were found with thin walls frequently breached by corrosion (Tornes et al., 2002). Virtually all of these reports describe the extent and frequency of corrosion only in a qualitative sense, and there are few data available that quantify the disintegration of underwater munitions housings. A rare example, the OSPAR Commission compiles reports of munitions encounters in the North Sea from beachgoers, divers, fisherpersons, and militaries (Nixon, 2009), and includes both munition type and corrosion state (when available). This database shows that most munitions throughout northwest European waters are “extensively” or “completely” corroded, and munitions in the Baltic Sea are likely to show a similar state of degradation. This is consistent with recent results from the DAIMON project showing that the average corrosion rate of barrels equals 0.0434 mm/year, bombs 0.0365 mm/year, and artillery shells 0.0313 mm/year (Beldowski, IOPAN, unpublished data). Experiments exposed original steel samples from museum collections in sediments for two years at different dumpsites in the Baltic Sea. The results suggest complete breach of barrels and bombs between 2020 and 2030, while the artillery shells will completely corrode in ca. 2100. As a result, many underwater munitions are likely breached, or will be within the next decade, and the chemicals within exposed to seawater.

3.1.3 Dissolution and Release of Munition Chemicals

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 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). Although the solubility of munitions chemicals tends to be low, they are nonetheless highly toxic and can have biological and ecological effects even when substantially diluted.

Dissolution rates of munitions compounds (MC) from solid explosives depend on formulation, where less-soluble components such as RDX reduce dissolution rates of more soluble components such as TNT (Lynch et al., 2001; Monteil-Rivera et al., 2010; Dontsova et al., 2006). This means that the rates of chemical release and spread in the environment depend...
in part on the type of explosive fill. There is little information available on the dissolution rates of CWA from underwater munitions.

Submerged warfare material is a greater source of MC to the water column where munitions are not buried and breached, for example, by corrosion. Release rates increase with exposed surface area of the solid explosive material and with increasing current speeds and water mixing (Wang et al., 2011). Like corrosion rates, dissolution is higher in high energy environments, so the shallow Baltic Sea may be particularly susceptible to both exposure and dissolution of explosive compounds. Furthermore, sedimentation rate in the Baltic Sea is comparatively low (1-2 mm/year, (Leipe et al., 2013), meaning that warfare material is more likely to be proud than e.g. in the North Sea.

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, Beldowski et al., 2016). A range of CWA compounds were also detected in fish and lobster samples and caged mussels at the Bornholm and Måseskår dumpsites (Vanninen et al., 2014; Niemikoski et al., 2017). 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.

Numerical simulation of chemical release from CWA dumpsites suggests that some chemicals (i.e. Tabun) will be hydrolysed to non-toxic products within 48 h of release, but wind- and density-driven mixing can lead to long-range transport of the remaining toxic compounds (i.e. Mustard degradation products and arsenic based agents) (Korotenko, 2003, Jakacki et al. 2020). Indeed, CWA release modelling in Bornholm Basin indicated potential bottom water contamination of tens of kilometres from the source site, with triphenylarsine, Adamsite, Clark I, and Yperite having the highest toxicity risk profiles (Sanderson et al., 2008; Jakacki et al., 2020).

3.1.4.1 Sea Water

The levels of dissolved munitions compounds tend to be very low in seawater, even very near munitions objects. These low concentrations make it difficult to detect CWA and MC in the water. One study in Bornholm Basin collected 61 near-bottom water samples, but did not detect any CWA compounds in the dissolved phase (Missiaen et al., 2010). Water samples near chemical munitions-laden shipwrecks in the Skagerrak did not show any CWA compounds, despite the fact that munitions showed corrosion breaching and high levels were detected in sediments (Tornes et al., 2002). Although CWA compounds have not been widely detected in the water column, they can be found at high concentrations in porewaters of contaminated sediments (Christensen et al., 2016). These studies highlight the need for more sensitive analytical methods in studies of dissolved munitions chemicals in marine waters.
munitions in Puerto Rico. These concentrations are generally considered “trace” for chemicals in seawater.

In the Baltic Sea, passive samplers have shown positive accumulation of TNT and its degradation products in the dissolved phase. One study in the Bay of Kiel detected TNT on five of ten passive samplers deployed during test detonations of munitions (Pfeiffer, 2009). A set of four passive samplers deployed in Gdansk Bay by a WWII-era ship containing munitions showed accumulation of TNT, RDX and degradation products of TNT (Warren et al., 2018). Although it is difficult to contextualize these results in terms of concentrations, they do confirm that MC are released from underwater munitions.

Gledhill and colleagues (2019) recently developed a highly sensitive method for detection of conventional explosives compounds in seawater. At one munitions dumpsite in the Bay of Kiel Bight, they detected dissolved munitions compounds in seawater at concentrations of 0.01 – 10 ng/L. For context, 1 ng/L is the equivalent of dissolving 2–3 mg of material in an Olympic-sized swimming pool. Subsequent samples collected by divers directly adjacent to exposed explosive material at the site showed concentrations up to nearly one million times higher (Beck et al., 2019). This latter study showed clearly that chemicals are released from the underwater munitions, but also demonstrated that they are rapidly mixed and diluted away from munition surfaces. The combination of slow dissolution and rapid dilution leads to the low concentrations in the water column, but it also means that MC have a high potential to spread away from the source. Mussels (Mytilus edulis) transplanted to the same munitions dumpsite showed accumulation of TNT and its degradation products (Strehse et al., 2017; Appel et al., 2018), confirming that although concentrations may be low, chemical release from conventional munitions is bioavailable and accumulates in biota.

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 relict munition 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 Bight (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.

One of the most extensive sediment CWA datasets was collected in Bornholm Basin and Gotland Deep (Missiaen et al., 2010; Vanninen et al., 2020). Intact parent compounds were detected in low amounts, usually not exceeding 1% of total CWA (this included sulphur mustard, tabun, Clark I, Clark II, Adamsite or α-chloroacetophenone), but degradation products of sulphur mustard, Clark, Adamsite, and components of arsine oil were found in sediments throughout both dumpsites. On a spatial scale of hundreds of meters, higher levels of CWA contamination were observed near shipwrecks and identified chemical munitions. Early studies showed that within tens of meters, sediment CWA content was poorly correlated with distance from the putative sources (Missiaen et al. 2010). In contrast, recent investigations demonstrated an exponential decrease in the concentration of mustard degradation products up to 250 m away from the source (r²=0.64; XXXX, unpubl. data).
Whereas intact CWA compounds are often below detectable levels, degradation products are frequently observed in sediments around chemical munitions dumpsites (Missiaen et al., 2010; Sanderson et al., 2010; Vanninen et al., 2020). Degradation products of cyclic sulphur mustard (1,4-Oxathiane, 1,3-Dithiolane, 1,4-Dithiane, 1,4,5-Oxadithiepane) were detected in sediments in the Bornholm Basin at concentrations between 15 and 308 µg/kg dry weight (Magnusson et al., 2016). These concentrations are higher than the 1 - 10 µg/kg levels observed in sediments from the Skagerrak using similar methodologies (Roen et al., 2010). Several CWA compounds, including mustard, Clark, and other arsenic-containing compounds were detected in sediments around shipwrecks containing chemical munitions in the Skagerrak (Torres et al., 2002). Most samples had CWA levels < 1 µg/kg, but many samples were 10- to 100-fold higher. Sediments collected in immediate vicinity of munitions in the Bornholm primary dumpsite contained mustard degradation products as high as 2900 µg/kg d.w., and degradation products of arsenic based agents up to 18700 µg/kg (Vanninen et al., 2020).

Modelling studies have shown that CWA migration in sediments is likely to be limited (< 1 m) due to the relative time scales of diffusion and CWA hydrolysis (Francken and Hafez, 2009). Nonetheless, persistence of degradation products, especially arsenic and its associated compounds, can lead to long-term toxic contamination of the sediments (Francken and Hafez, 2009). Moreover, the possibility of arsenic reemission from the uppermost sediments in Baltic Sea dumpsite areas has been suggested, due to reduction of As [V] to As [III] under anoxic conditions (Szujska, 2020). Conventional explosives may not pose such a long-term risk considering that they lack a toxic inorganic component and the organic material is, in principle, possible to completely remineralise.

3.1.4.3 Beaches

Although many munitions dumpsites were by design far from shore and usually in deep waters, there remains a concern that warfare material may be transported to locations where it poses a greater risk to e.g., beachgoers. Relocation by fishing activities is a major concern (HELCOM CHEMU, 1994; Glasby, 1997; Missiaen et al., 2010), and chemical munitions recovered during dredging have occasionally been unwittingly brought to port. There are a number of reports of fishermen who were exposed to chemical munitions at sea during fishing operations, and munitions have also been found on beaches (Fabisiak and Olejnik, 2012). Chemical munitions fragments have been reported on beaches in Poland (e.g., Fabisiak et al., 2018), and chemical munitions have washed ashore elsewhere as well (Missiaen and Henriet, 2002). Chemical mustard is one of the primary CWAs of concern because the surface polymerizes in seawater, creating elastic lumps which are protected from further decomposition or dilution (Granbom, 1994; Missiaen et al., 2010). These lumps can be transported farther by natural and anthropogenic mechanisms, or recovered in fishing nets, posing a risk when handled by humans.

Koch (2009) compiled more than 580 munitions-related incidents in the Baltic Sea during the period following WWII. These particularly involve fishing vessels and personnel, but there are many documented incidents on beaches. Munitions finds on beaches include conventional explosives and intact ammunition, lumps of CWA and chemical munitions, solid propellants, and white phosphorus. [There are no published data regarding the presence of chemical contaminants from munitions on beaches] although it may be as likely there as in any regional sediments.

In addition to relocation by fishing, natural water currents can move munitions on the seafloor. Munition mobility depends on physical parameters such as currents, waves, and tides, and...
high energy storm events may have a particularly strong effect. The current speeds required to mobilize munitions increases with the degree of burial (Menzel et al., 2017), so proud munitions are more easily transported and redistributed. Sediment scour around munitions during sub-critical current conditions can promote burial (Menzel et al., 2018), and small, tapered ammunition tends to bury more easily than other shapes (Rennie et al., 2017). The movement of underwater munitions depends on drag and lifting forces, and because of different designs, some munitions may have a higher likelihood of being mobilized than others (Menzel et al., 2017).

3.2 Risks to Humans

From the direct and non-direct marine end-user's perspective, the problem of sea dumped munitions has been growing simultaneously with a demand for maritime services. With an increasing marine traffic and expansion of offshore activities a presence of scattered explosives and dangerous chemicals pose a threat for workers and overall safety in the seas. Mishandled offshore operation can result in accidental destruction, relocation or retrieving of submerged munitions resulting in either explosion, release of their loads or potential resurfacing on beaches. Indeed, the hazardous chemicals like white phosphorus have been found on beaches, no cases of chemical warfare agents washed ashore have been reported since the HELCOM reporting system was established in 1994. By design, the CWAs are extremely toxic to humans. Agents like sulphur mustard, phosphorous-based and arsenic-based compounds were designed to trigger severe biological effects already at very small doses. The threats of chemical munitions can be triggered in many ways: the munitions might function as intended and release the toxic contents by detonation of the explosive charge after being improperly handled. However, in a more likely scenario effects can be a result of a direct or indirect contact with the released CWA, i.e. via vapours, or skin contact. In many cases, the degradation products also show some degree of toxicity, while some compounds have the potential to be bioaccumulated in the food-web. This, however, also addresses the newly discovered issues with underwater explosives. Not only, the energetic compounds instability can be induced due to the mishandling, but the release of such compounds into the environment is now recognized to have severe consequences. Reported bioaccumulation of explosives and CWAs into the marine food web can result in contaminated seafood products for human consumption and thus pose a risk to seafood consumers.

3.2.5 Fishermen

Fishermen are in a direct danger of UXO presence in Baltic Sea bottom, however, the risk levels depend on the type of fishing gear that is used. According to reported incidents, the Baltic Sea fishermen have been the main group coming into contact with all types of sea-dumped munitions. Reported incidents involving chemical munitions were most frequent through the 1980s and peaked in 1990, 1991, and 1992, when 19, 103, and 58 incidents were reported, respectively. With the exception of 2003 when 25 incidents were reported to HELCOM, there has been a notable decline in reported incidents since the early 1990s. The decrease is attributed to the decline of fishing activities in the areas off Bornholm (where the most incidents occurred), changes in the size of fish population, fewer fishing hours, better fishing technologies, and gaps in national reporting systems (HELCOM, 2013). Bottom trawling poses the biggest threat for explosives and CWA containers to get accidentally caught in fishing nets. When recovered and accidentally activated on board, the explosives can detonate, while the poisonous gases cause severe blisters or death of the crew. The risk of such encounter is the highest when trawling nets are used inside or nearby dumping areas. For this reason, as
trawling nets that dredge the seafloor can catch ordnance along with harvested fish, these sites are being marked on the official sea charts together with additional information on where fishing activities, anchoring and extracting seabed materials are not advisable. In this context, the reported practice of item-by-item en route dumping is of special interest since these chemical warfare materials pose a considerable risk - one that is very difficult to assess due to the unknown locations outside the assigned dumping areas and because they were disposed of and scattered item-by-item. While the likelihood of trawling one of these objects outside their designated dumpsite areas is low, any incident might have severe consequences, being an unexpected event and mishandling. For this reason, various federal institutions launched multiple informative campaigns or trainings to raise the awareness of fisherman working at the Baltic Sea region. There is a need to elaborate new, updated Guidelines for fishermen within the framework of the Helsinki Commission in consultation with the International Baltic Sea Fishery Commission (IBSFC), considering improved knowledge.

Direct and indirect exposure to chemical weapons is common enough in the Baltic Sea area, for all the fishing vessels to be required to carry advanced first aid kits to deal with contamination and all crew members are required to be trained in how to deal with an incident involving underwater munitions. HELCOM tracks the frequency of reported contact with chemical munitions and it has determined that sulphur mustard-type materials account for 88% of all reported incidents involving fishermen. The frequency of encounters is likely related to the sulphur mustards low solubility and the fact that its lumps form hard outer shell of intermediate breakdown products in cold sea water (M. I. Greenberg et al., 2016). Most instances involving the retrieval of chemical weapons were localized to the Bornholm Basin and some 200 fishermen have sustained injuries requiring medical attention between 1947 and 1992 (Sanderson et al., 2010).

In relation to the fact that some fishermen conceal the bycatching of chemical munitions and "solve the problem on their own" without notifying the relevant authorities, the problem should be solved systematically and not with the method of obligations and prohibitions. Since the fishermen claim that they incur financial losses in the case of reporting the fact of fishing out chemical munitions, the possibility of covering them by the local authorities in the form of compensation in the case that fishermen fish out CWAs in any form and report the fact to the relevant authorities should be considered.

3.2.6 Offshore Construction and Maintenance Workers

The rapid growth of the offshore industry is accompanied by changes in human behaviour and thus raises many new issues related to munitions dumped at sea. Therefore, the planning and preparation processes for sub-surface operations in suspected areas should include the implementation of standard operation procedures (SOP) for the unlikely event of an accidental contamination of workers or equipment. All personnel should be considered responsible for correctly carrying out such standard operation procedures. In the event of an encounter, the relevant national authorities must be informed and should thoroughly investigate and formally agree before the operation can be continued.

Whenever the piles are rammed-driven into the seabed, there is a possibility to encounter munitions buried deep in the sediment. Available technologies to detect objects in terrestrial soil are still not fully sufficient, as are most of the present solutions for underwater detection. Apart from permanent ones like offshore wind farms, sea cables and pipelines, many temporary facilities will be deployed on the seafloor in the near future e.g., Remotely Operated
underwater Vehicles (ROV) or maintenance stations. All operations on or in the sediment layer may damage the en-casements of the munitions that have not yet lost their integrity. Moreover, all of these installations are at direct risk coming from sea-dumped warfare material. Apart from the direct threats, the operating personnel are also indirectly at risk of contact with warfare agents that could have contaminated underwater robots, tools, diving suites and related gear.

3.2.7 Nautical Personnel

Commercial, navy and emergency response sub-surface entrepreneurs and members of service crews related to underwater operations are seen to be exposed to an elevated probability of coming into contact with chemical and conventional munitions in the vicinity of dumpsites or scattered munitions, be it directly and indirectly, intentionally or unintentionally. Poor underwater visibility, the large variety in shapes of chemical warfare material containers and the degree of their corrosion and colonization by biota pose a challenge to even recognizing the potential danger. It should be stressed that some warfare agents will even penetrate the material of highly sophisticated gloves and diving suits and some substances (e.g., thickened sulphur mustard mixtures), may stick firmly to the surface of objects they come into contact with.

With the increase in activity on the seabed, emergency response personnel and commercial entrepreneurs may see an uptake in the number of times they come into direct or indirect contact with munitions. Poor underwater visibility, differing rates of corrosion, colonization by biota, and the fact that chemical weapons come in a variety of shapes and sizes, make visual identification harder and limit the ability to detect dangers. Accidental contamination from economic activity or in response to an emergency remains a constant possibility.

3.2.8 Harbour Staff and Workers

Investigations of German archives have revealed the numerous accidents at the majority of harbours used in the process of chemical warfare disposal. Thus, it should be assumed that some the harbour facilities and soil still might be contaminated, especially those used in the process of chemical warfare disposal. In 1945, two incidents took place on the 18th September and 1st October in the port of Flensburg directly in the post-war period. There is also reports of accidents in Denmark that happened during the unloading of rail cars filled with chemical munitions: Operations were performed on behalf of the British Military Administration in Germany and some workers were exposed to the sulphur mustard that was oozing from several malfunctioned artillery shells. Those contaminated objects received the highest priority resulting in emergency sea-dumping (cf. Chapter XXX).

Nowadays, all harbour workers are also at risk of being exposed to the CWA effects, when vessels bring their contaminated catchment and equipment back from the sea. Apart from objects that have been lying in harbours for decades, there is also risk of recently relocated materials being brought into the harbour by fishermen, possibly even without recognizing the hazards posed by some inconspicuous object in their nets. There is also an energetic threat putting harbour surroundings and people living nearby if the catchment contained explosives. Two incidents in Sweden highlight an extension to this exposure scenario because munitions can be transported from the sea, either intentionally or unintentionally, to densely populated areas. In April 2011, off the coast of Blekinge, fishermen unknowingly caught a sulfur mustard bomb and transported it back to the harbour at Nogersund where it was placed at one of the jetties for emergency personnel to handle. In December 2005, a trawler caught a sea mine and...
transferred it back to Gothenburg and caused closing down parts of the port and city. Such events highlight, not only the potential of increasing exposure risks, but it also demonstrates the potential costs to the offshore economy as fish catches required destruction and port facilities had to be temporarily shut down. Therefore, there is a need for standardized documents and guidelines on conduct in harbours when collecting containers and ammunition caught by fishermen, the methods of their decontamination by specialized institutions should be developed and the principles of reimbursement of the costs of such operations, as well as compensation for vessel owners should be defined.

3.2.9 Recreational Divers

Along with maritime activities in general, leisure and exploration-driven munition encounters can be expected to be increasing. Recreational diving becomes a more and more popular hobby among all European nations. Increasing availability of cheaper but sophisticated equipment makes this sport safer and more accessible for regular users. This type of sea-related recreation becomes a significant branch of “eco-tourism”. In several countries, including Poland, fishermen fishing vessels are transformed into diving platforms for organized groups of divers. Therefore, easily accessible public information of the dangers associated with sea-dumped warfare materials (both chemical and conventional) should also be targeted to raise the awareness of this special risk group.

Wrecks in general - also those from WWII - are of special interest to recreational divers. Most chemical munitions were dumped in the Baltic Sea at depths exceeding 80 m, mostly by item-by-item disposal and are located well away from the coastline and therefore are not easily accessible to recreational divers. However, in most dominant type of Baltic Sea sediments, the soft-bottom areas, all submerged objects, including stocks of munitions and wrecks can serve as the artificial platforms for benthic fauna, often causing a locally increased biodiversity (Balazy et al. 2019). This attracts pelagic and demersal fish to be more active in such areas. Being an interesting type of submerged objects themselves, when combined with higher appearance of marine fauna, Baltic Sea wrecks are regularly visited by numerous recreational divers and tour-operators. Due to multiple risks, the ship-wreck exploration is, however, considered to be one of the most extreme forms of recreational divers, in many cases requiring official permits. Depending on the type of the submerged vessel, there is a high possibility of accidents involving unexperienced divers. Shipwrecks are often covered with ghost nets and various marine litter. If the ship was sunk due to military operations during WWII, there is a high risk that it contains various types of artillery munitions. Some wrecks of the barges containing chemical munitions were also purposely sunk in the area south of the Little Belt, however most of them have been relocated and the materials recovered in the late 1950s (cf. Chapter 3.2.1). Of special concern, however, are the scattered single objects stemming from item-by-item disposal en-route from the loading harbours to the formerly designated dumping areas, since these objects are not associated with a landmark of interest like a wreck. It is unlikely that these scattered CWM will be found unintentionally in these shallower waters. In such depths, there is, however, a significantly higher possibility of conventional munitions encounters. There is a reported presence of sea-mines, ground mines, aerial bombs and rifle munitions in multiple sites at depths between 5 – 20 m. There is also a record of at least one munition self-combustion that has severely damaged the “Kanonierka” wreck near the coasts of Hel Peninsula, however, no casualties have been reported at that time, despite the object being a popular spot for recreational divers.
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3.2.10 Beach Visitors

Since most CWM dumped in the Baltic Sea were jettisoned into at least 80 m of water, they are relatively inaccessible to recreational divers or beachcombers. However, because item-by-item dumping was used frequently while open-route to designated dumping areas, unmarked debris trails followed the ship’s course. Moreover, some items were also liable to float and drift before sinking, (e.g., when disposed of in wooden boxes), which further dispersed munitions outside of designated dumping areas. This opens the possibility of encounters and exposures to munitions along shorelines, if the ships navigated closer to shorelines while dumping cargomunitions.

The most likely scenario of human exposure to chemical weapons during leisure or tourist activities involves munitions found along shorelines. Young children are the most at risk for accidental exposure, mainly because they are naive to the dangers and likely to pick up something curious or shiny at the beach. For instance, in July 1955 102 children were injured at a holiday camp in Poland when they played with a rusted barrel (full of liquid sulfur mustard) they found on a beach. At least four children suffered irreversible eye damage as a result (HELCOM, 2013).

The likelihood of people coming into the direct contact with CWM while visiting a beach except one particular compound is negligible. However, even though the number of reported encounters is very low, the consequences of such encounters are disproportionately high due to the severe consequences for the affected individual. The most frequently reported cases of contact and exposure to CWA along the Baltic Sea coasts involve nuggets of white phosphorus, a pyrophoric used in incendiary weapons. White phosphorus can be mistaken for amber and upon drying it can self-ignite and burn up to a 1300°C. In the Baltic, cases of people being severely burned happen every year, particularly on the German island of Usedom where two to four cases occur every year. The high concentration of white phosphorus lumps in this area is related to both post-war dumping operations and the bombing campaigns against the German rocket testing facility at Peenemünde that took place in 1943. According to HELCOM there is approximately 1.2 to 2.5 tons of white phosphorus in the area. Simultaneously, each year the Danish authorities record approximately 5 cases, where location-markers containing phosphorus in a small quantity have been washed ashore. Another troubling area is Liepaja beach in Latvia, as the Soviet Union used a dumpsite roughly 70 km from Liepaja (HELCOM, 2013). Incidents involving white phosphorus are not unique to the Baltic Region, as numerous cases along the Dutch and British coastlines have been reported over the years as well (Beddington and Kinloch, 2005).

Occurrence of white phosphorus at the beaches requires that responsible federal and local authorities take appropriate action to prevent similar incidents from occurring in the future. It should be i.e. clearly advised that before storage, amber should be collected in fire-proof metal containers and allowed to dry and heat up to 30°C when any white phosphorus mistakenly collected will ignite. Another way to raise the attention of beach visitors is the handout of “awareness brochures”. This has taken place for example at the beach area of Heidkate (Germany) in 2015 after several findings of explosives including children that had collected the explosive compounds (hexanite) and played with. If white phosphorus is found, the area has to be cordoned off while the authorities must be contacted. Further information for collectors who have been in immediate contact with white phosphorus should be included in the emergency operation procedures. Medical personnel in the wider area of concern also need
to be aware of the special toxic dangers posed by white phosphorus and not just the obvious, severe burn injuries.

There is also a growing risk of encountering conventional munitions or their parts on the Baltic Sea beaches. Beach maintenance employees and life-guards should receive training and public awareness should be increased through clear warning signs in the areas.

3.2.11 Seafood Consumers

The highest likelihood of getting into direct contact with chemical 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 minimize the risks for sea-food consumers. Various kinds of fish, mussels and crustaceans are consumed worldwide, but little is known whether on the occurrence of 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 sea 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, which puts the whole Baltic Sea area fisheries and aquaculture industries at a potential risk.

In example, besides playing a role of the CW dumpsite, the Bornholm Deep offers rich fishing grounds, as it is also the spawning area for migrating Eastern stock of Baltic Sea cod, a traditionally harvested fish population (Niiranen et al. 2008). On the other hand, large numbers of blue mussels, one of the most common seafood species worldwide, are found e.g. in a shallow-water dumping ground for explosives in the Bay of Kiel Bight. Because of their sessile behaviour, even small amounts of explosive materials near to their habitat could lead to measurable body burdens of those substances. Shell fishermen could harvest contaminated mussels, and both the increasing consumption of harvested wild mussels or aqua cultures established near munition dumping sites could affect the human seafood consumer worldwide. The situation is similar with fish. The possibility of sulphur mustard poisoning occurring via seafood consumption is supported by newspaper reports stemming from the late 1940s (June 1948, April 1949). It was reported that some Danish and German seafood consumers had become ill after eating fish caught in the area of the Bornholm dumpsite – cod roe later assessed by medical staff was found to contain Sulphur mustard (HELCOM 2011a). However, the exposure occurred due to mechanical mixture of warfare compounds with fish roe that was consumed. Bottom-dwelling fish chronically exposed to chemical warfare agents due to their on-habitat association in vivo in a dumpsite in the Mediterranean Sea off Bari, Italy, have been shown to carry obvious signs of biomarker responses; however, no chemical warfare agents were found in the fish flesh and thus any skin diseases, parasite infestation and general low health could be connected to overall environmental stress factors (Torre et al. 2013).

Due to the limited number of studies on seafood products contaminated with explosives or chemical warfare agents, the current state of knowledge reveals that effects and risks for human seafood consumers cannot be clearly denied or defined at the present time. It is proven that explosive chemicals like TNT and its derivatives are known for their mutagenicity and carcinogenicity. The role of TNT in the occurrences of cancer of the urinary tract in exposed humans has been confirmed by experimental evidence and supporting observations (Bolt et
al., 2006). However, most of the studies have been carried out with high affected persons from munitions factories or disposal units for military waste. The assessment of the impact onto seafood looks even worse with chemical warfare agents, because of the limited data.

Based on models results, Sanderson et al. (2009) assessed the maximum recommended monthly amount of fish servings stemming from the primary dumpsites/no-fishing zones in the Bornholm dumpsite to be zero to one. This assessment was based on extreme worst-case assumptions, considering the load of arsenic-containing chemical warfare agents dumped in the area, but not specifically addressing all potential transformation or break-down products. Their study concluded that there was a need for further empirical research, especially regarding the speciation of arsenicals in fish and their carcinogenesis as well as the effects of human exposure to CWAs via seafood.

Niemikoski et al. (2017) have published the first study that reports the occurrence of oxidation products of Clark I and/or Clark II found in lobster (Nephrops norvegicus) and a flatfish species collected at Måseskär dumpsite. However, only trace concentrations below the limit of quantification were detected. Furthermore, Höher et al. (2019) reports that exposed blue mussels (Mytilus trossulus) bioaccumulate the oxidized forms of chemical warfare agents Clark I and Adamsite. As for now, no parent chemical warfare agent-associated compounds have been detected in Baltic Sea species.

In two case studies carried out in Kolberger Heide, a known dumping ground for different types of munitions in the Bay of Kiel, blue mussels (Mytilus spp.) were deployed selectively at moored mines or loose hexanite lying on the seafloor. Blue mussels are one of the most common seafood species worldwide and because of their sessile behaviour, even small amounts of explosive materials near to their habitat could lead to measurable body burdens of those substances. After approximately three months, in the mussels deployed at the moored mines body burdens of 4-amino-2,6-dinitrotoluene (4-ADNT), a degradation product of TNT, was found up to 10 ng/g mussel-tissue (wet weight) (Appel et al., 2018). In mussels directly deployed at lumps of loose hexanite, 4-ADNT and 2-ADNT plus TNT itself were found in total concentrations summing up to 260 ng/g mussel-tissue (wet weight) (Strehse et al., 2017). Mariussen et al. (2018) investigated the uptake of TNT in juvenile Atlantic salmon (Salmo solar) and found small quantities of TNT, 2-ADNT and 4-ADNT (< 0.05 mg/kg) in the muscle tissues. The applied water concentrations of TNT in this in situ experiment were 1 and 10 µg/l, respectively. Of note, similar concentrations of TNT were measured in free water at the former dumping ground for explosives Kolberger Heide (Beck et al., 2019). Fish specimens are not as sessile as mussels, but the increasing number of fish farms has to be considered. In aquaculture the fish is kept in a relatively small area and might therefore be more affected by dumped munitions in its vicinity compared to wild living fish.

### 3.2.12 Munitions Clearance Service Providers

Due to their profession, all munition clearance service providers are exposed to the wide range of submerged munition-related threats. On the other hand, their experience and equipment significantly decrease most of the risks. They may, however, be affected by a poorly performed site-examination that is serving as a background information for performed operations. If the clearance operations planning involves using “blast in place” techniques, a possibility of clearance-induced chain reactions must be taken under consideration and avoided.
3.3  Risk to Infrastructure

The risk to maritime infrastructure is related to abovementioned risks to fisheries and offshore industry. Basically, existing infrastructure can be affected mostly by detonation of previously omitted conventional munitions at the site, or by munitions being relocated by currents. It can also be affected by contamination of CWA, which could refer to the risk to personnel or construction – that need to be decontaminated afterwards.

There is also a chance for the anthropogenic-driven relocation and spreading due to natural processes, however they differ in magnitude and type of force. In general, activities capable of moving large objects like bombs or lumps of sulphur mustard will also be sufficient to achieve the spreading of contaminants in solution, as particles or bound to sediment particles. However, some activities affect larger objects more than particles and vice versa. For instance, when bottom dredging is performed in contaminated seafloor, contaminated sediments may be re-suspended and the contamination may spread locally; however, chemical munitions casings may be disturbed, contributing to greater leakage of toxic agents. All relocations can also result in an increased risk for the explosion of conventional munitions and simultaneously, a destruction of an existing infrastructure.

3.3.13  Pipelines and Cables

The experiences documented during the construction of the Nord Stream underwater pipeline (which connects Russia and Germany) demonstrated that underwater munitions represent serious obstacles to infrastructure expansion and the energy sector. Furthermore, it has substantiated the claim that chemical munitions are a threat to developments in areas outside the limits of ‘foul grounds’ and munitions dumpsites marked on navigational charts. Overall, the construction of the pipeline required the clearance of over 100 items in Russian, Finnish, Swedish, and German waters (Nord Stream Report, 2010).

3.3.14  Offshore Buildings and Platforms

The use of the seabed for offshore activities such as resource extraction and construction is rapidly developing and increases the likelihood of encounters with dumped munitions. Offshore construction sites are a good example: where piles are rammed-driven into the seabed there is a possibility to encounter munitions buried deep in the sediment. Available technologies to detect objects in terrestrial soil are insufficient, as are most of the present solutions for underwater detection.

3.3.14.1  Offshore Wind Farms

Construction of offshore wind farms, as well as bridges or any other type of project involving the drilling into foundations in the seabed, must account for potential risks and consequences of encountering munitions or their toxic substances.

3.3.14.2  Drilling Rigs

The increased drilling of boreholes for geological surveys also increases the threat of coming into contact with toxic substances, which might occur if a chemical warfare object is punctured in the process or if examined sediment core samples include sediment which has been contaminated with chemical warfare agent mixtures.

Commented [S94]: can be spread quite considerably depending on sediment type
3.3.15 Harbours

There are notoriously reported discoveries of UXO in majority of Baltic Sea harbours. The following safety relocation and destruction can severely affect any commercial activities. All project managers in harbours that were under attack and extensively used during wartime, also where dumping operations originated (such as in Flensburg or Wolgast) must consider the potential discovery of chemical and conventional munitions in any future harbour development projects. Especially, since the high concentrations of metallic objects in harbour basins can camouflage the presence of munitions. HELCOM recommends approaching construction in ports with comprehensive surveys for munitions, especially in places where dumping is known to have originated. This is especially advised if dredging is required. For instance, in 1995, the Finnish Maritime Administration started to expand the port of Kokkola, on Finland’s Gulf of Bothnia coast, by expanding the channel and reclaiming land. Between 1997 and 2001, the depth of the Kokkola channel was increased to 13m, but operations had to be postponed because munitions were found. [The Kokkola channel had been used by vessels dumping ordnance between 1945 and 1974. In order for the project to continue, various new safety procedures had to be developed and dredging continued via remote controlled machines.]

3.4 Risks to Marine Life

Vast quantities of warfare agents were captured by allied armies, and by decision of the Potsdam conference their dumping at sea was commenced by allied military administrations (HELCOM 1994). The dumping practice was adopted by many nations after WW II in Europe and worldwide for disposing ammunition and other military equipment. As a consequence, dumping sites are scattered vastly along European coasts. Also, in the Baltic Sea hundred thousands of tons of both conventional munitions and CWAs were dumped (Böttcher et al., 2011).

The post-war dumped conventional and chemical munitions in the Baltic Sea are now in different stages of decomposition. Some shells have remained intact whereas others are corroding and their contents are leaking into the environment (see chapter 3.1.2), thus posing a potential health risk for the Baltic Sea ecosystem (Niemikoski et al. 2020; Beldowski et al., 2016b; Briggs et al., 2016). The leakage rate of dumped munitions cannot be estimated as the material used for bomb shells and grenades, containers and barrels for the storage of e.g. CWAs is variable and so are environmental conditions determining the corrosion process at the dumping sites (such as oxygen concentrations, salinity).

In addition to the explosion and security risk, dumped munitions contain cytotoxic, genotoxic, and carcinogenic chemicals associated with conventional explosives, CWAs, and munition structural 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; Beldowski et al., 2016; Edwards et al., 2016; Silva and Chock, 2016; Jurczak and Fabisiak, 2017, Missiaen et al. 2010). 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.

TNT is a yellow solid and chemically stable (Lotufo, 2012; Lotufo et al., 2013). In liquids it is photochemically transformed and metabolized by bacteria into 2-Amino-4,6-Dinitrotoluol and 4-Amino-2,6-Dinitrotoluol by a nitro-reductase (Lima et al., 2011; Lotufo et al., 2013).
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. However, knowledge about different paths and proportions is scarce and should be verified in future exposure studies.

In the marine environment, TNT interacts with sediments and soils, where it was detected in harmful concentrations (Böttcher et al., 2011). Concentrations up to 3.38 mg/L were measured in surface water in dumping areas (Nipper et al., 2009). TNT and its major metabolites have demonstrated toxic effects on fish and benthic invertebrates (Schuster et al. 2020, Koske et al. 2019; Nipper et al., 2009; Lotufo et al., 2009). Therefore, the presence of those compounds in aquatic systems may pose ecological risks and could represent a significant remediation challenge (Robidoux et al., 2003).

TNT, RDX, and HMX represent a major portion of munition material present in terrestrial and marine environments (US EPA, 2012). RDX (Hexogen) exhibits toxicity to biological receptors. It has been manufactured in large quantities during WWII. It is carcinogenic, genotoxic and toxic for reproduction. Biological uptake of HMX (Octogen) has been observed, but no toxicity was evident at any of the levels tested (Rosen and Lotufo, 2010). Effects of exposure to RDX and HMX in the marine environment are largely unknown. Metallo-organic compounds (e.g. fulminates, azides, and styphnates of mercury, lead, and silver) which were used as initiators for detonation of secondary explosives due to their sensitivity are also found in the marine environment (Beck et al. 2018). Their marine environmental behaviour and fate is very poorly known.

Bioaccumulation and toxicity of heavy metals is a well known fact and the amount of lead and mercury in UXO is considerable (Nehring & Koch 2006).

In contrast to explosives, CWAs were invented and produced to harm humans in other ways than detonation and there is accordingly no doubt about their toxicity. However, knowledge about toxicity to organisms from marine and brackish water environments such as the Baltic Sea is scarce both for compounds of explosives and CWAs.

Another serious threat of explosives to the environment is their very high detonation velocity, which produces a shock wave when initiated. The conventional removal by blasting presents a great hazard to the marine environment. Underwater detonations are the loudest anthropogenic point sources of noise in the Baltic Sea and have the potential to cause serious injuries in marine vertebrates at ranges of several kilometres (Koschinski 2011, von Benda-Beckmann et al. 2015) and also on invertebrates. By conversion of solid energetic compounds into a much larger volume of gaseous reaction products, any explosion results in a shock wave characterised by a tremendously steep wave front and a very high-pressure maximum called “overpressure” (chapter 3.1.1).

Animals can be seriously injured by the overpressure of the shock wave which is transmitted directly through water-saturated body tissues. Both the extremely short signal rise time and the high peak pressure in the pressure signature of a detonation are related to control the extent of injury to marine vertebrates. The shock wave can result in primary blast injury (PBI) originating from the compression of tissues or organs by the incoming wave front. High-
amplitude pressure pulses may cause differential tissue displacement disrupting cells and tissues of different density such as muscle and fat. Especially at the interface with gas-filled cavities capable of compression, molecules are displaced resulting in damage to these tissues. Tissues at these interfaces are torn or shredded by instantaneous compression of the gas. Hence, massive damage can occur in lungs, intestines, sinuses, and ear cavities of vertebrate species (Landsberg 2000). Based on experimental data from terrestrial mammals held under water it is assumed that smaller animals are more vulnerable to shock waves than larger ones (Yelverton et al., 1973; Young, 1991).

In addition to the trauma generated by the blasting operations, detonations also increase the concentrations of explosives in the environment. This leads to increases of concentrations of TNT and its metabolites in organisms living close to the now uncontained chunks of explosives (Maser & Strehse 2020).

### 3.4.1 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). Information on fatalities of marine mammals are mostly anecdotal because post-mortem surveys are rare. However, a few documented examples exist. A wide spectrum of injuries including massive bleeding in e.g., acoustic fats of the melon and lower jaw as well as in the ear, dislocation and fracturing of auditory ossicles have been reported in harbour porpoises stranded along the coasts in the area (German Bundestag 2019). The rupture of lung alveoli was the likely cause of death. Animals with damage to the hearing system may be more vulnerable to by-catch and collisions as the findings in 2 further animals with additional blunt trauma and net-marks suggest (Siebert et al. 2020). Mitigation measures by NATO vessels were insufficient to fully deter harbour porpoises from the area (Gallus 2020, Wölfing et al. 2020). In 2011 a time-delayed underwater detonation resulted in the death of several long-beaked common dolphins as their group entered the safety zone prior to the detonation (Danil & St. Leger 2011). Further, in August 2019, after the detonation of 39 ground mines by a NATO mine counter measure group in the marine protected area of the Fehmarn Belt, a number of dead harbour porpoises stranded along the coasts in the area (German Bundestag 2019). Investigations are still ongoing (as of January 2020).

**Besides** severe injury leading to death within days or weeks (cf. Siebert et al. 2020) or direct and immediate mortality by the shock wave, sub-lethal effects such as hearing impairment (acoustic trauma) can also contribute to overall effects. Depending on the severity of the blast and the distance of the animal from the detonation site, acoustic trauma can either be temporary or permanent. Depending on the charge weight and location of the detonation, harbour porpoises can suffer acoustic trauma at distances much larger than 10 km from the blast (von Benda-Beckmann et al. 2015). Such sub-lethal auditory effects can impact the
fitness of affected animals as hearing is vital for their ecology and behaviour. This is especially important for small cetaceans such as the harbour porpoise, which rely on this sense for their orientation and prey acquisition. Increased mortality of detonations can be falsely diagnosed as e.g. by-catch in set nets, due to the animals’ inability to echolocate, meaning that the original cause is overlooked (Siebert et al. 2019).

Any sub-lethal impact leading to reduced survival, growth, or reproduction can negatively impact populations (National Research Council 2005). Such negative population impact was already predicted using a modelling approach based on harbour porpoise density data from the Netherlands and available information on number, location and charge sizes of all explosive ordnance disposal operations conducted by the Dutch Navy over a 1-one-year period (von Benda-Beckmann et al. 2015).

As top predators, marine mammals may consume also prey contaminated with explosives and their degradation products and metabolites. However, since the knowledge about the metabolic pathways for common explosives and their metabolites in the bodies of mammals, their retention time in tissues and body fluids and their way of excretion remains fragmentary, a bioaccumulation of these compounds in top predators cannot be excluded. Further, the toxicity of CWA to humans is well known and also the toxic, mutagenic and carcinogenic effects of TNT are described for humans. Based on close relation between marine mammals and human beings similar sub-lethal effects in both species are most likely.

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As the apex predators, marine mammals are potentially exposed to the negative effects of biomagnification.

### 3.4.2 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 can be accumulated in birds. 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.

There is anecdotal information on fatalities of birds caused by underwater explosions. For example, in 2006, 70 western grebes were killed by six demolition charges of 4.5 to 13.2 kg at 15 m water depth. Necropsied birds showed clear signs of blast injuries. The birds may have been attracted to fish killed or debilitated by explosions and suffered from subsequent detonations (Danil & St. Leger 2011). Since shock waves radiate through water saturated tissues, even a swimming bird may get seriously harmed by a detonation. Diving birds may be at even greater risk.
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3.4.3 Fish

More and more chemicals which were enclosed in warfare materials start to leak and enter the ecosystem. Recent research demonstrated the slow solubility of explosive chemicals dumped in the Baltic Sea (Beck et al., 2019), so that TNT is still present after decades. In addition, the quick biological conversion of TNT into metabolites was shown (Koske et al. 2019b). Consequently, TNT metabolites were found in water sampled in the close proximity of known dumping sites in the ng/L range as well as in benthic organisms such as mussels in the ng/g range (Appel et al., 2018; Strehse et al., 2017; Gledhill et al., 2019, see 3.4.5), which are a potential diet of fish species.

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.

Furthermore, fish and shrimps from dumping sites for CWAs located in the Skagerrak and east of Bornholm were analysed for metabolites of arsenic-containing CWA such as triphenylarsine and Clark I/II (Niemikoski et al., 2017; Niemikoski et al., 2019). The detected concentrations were in the lower ng/g range. The toxicity of the mentioned CWA was tested with the standardized daphnia-Daphnia immobilisation test (Czub et al., 2020).

As mentioned below also mussels responded to the exposure of phenyl arsenic compounds showing impairments on the subcellular and functional level, including cytotoxic, immunotoxic and oxidative stress (Höhner et al. 2019). In other investigations, cod (Gadus morhua) acquired in dumpsites of chemical munitions and CWAs in the Baltic Sea was studied and did not show clear signals of a worse health status when compared to munitions-free reference sites (Lang et al., 2017) – however, no chemical analysis was included in this study. A more recent study a chemical analysis was included, showing that 14% of the cod collected close to the main CWA dumping sites in the Baltic Sea, the Bornholm Basin, contain CWA related compounds in their muscle tissues. For these individuals with detected CWA related
compounds the biomarker response was higher than in those with no detections. Like this, it becomes clear that there can be a direct linkage of uptake and exposure to these compounds and biological effects. Importantly, this stresses the fact that the individual fish are not exposed evenly to the CWA, since the CW are widely dispersed, scattered around the sea bottom (Niemikoski et al., 2020) and fish are mobile species.

These investigations are snapshots of the situation and have covered only few fish species and few dumping sites. There is so far no larger-scale systematic chemical investigation of spatial distribution of TNT, other explosives or CWA and related metabolites in Baltic fish covering further dumping sites and species. However, systematic investigations such as these are urgently needed, to answer the question which species and which regions are the most affected ones. What we need to know is if and in what distance contaminated fish of what species are present outside the dumping sites. In which way does this depend on the number or on the corrosion status of the dumped warfare materials and what does that mean for the fish health or for the seafood consumer? At the moment, there is insufficient data to answer these questions. However, it cannot be excluded that TNT metabolite concentration in seafood may in some cases reach concentration levels of concern.

Because of the importance of fish for human consumption, more research and monitoring is needed. Threshold concentrations have to be developed and adopted. With a systematic risk evaluation as addressed above it would be possible to provide a scientific basis for better management decisions regarding for example munitions delaborations.

Remediation of munitions by detonation also raises serious concerns about shock wave effects on fish and their larvae (Koschinski 2011, Stein 2010), which would directly threaten protected fish species and also have economic consequences with respect to commercial species. At close ranges, underwater explosions are lethal to all fish species regardless of size or internal anatomy. At greater distances, species with gas-filled swim bladders suffer higher mortality than those without swim bladders (Yelverton et al., 1975; Young, 1991; Lewis, 1996). However, due to their bottom contact, flatfish (without swim bladder) might specifically be affected by boundary layer effects from seismic waves preceding the shock waves. I.e. fish are hit by two consecutive pressure waves from below and from above leading to differential tissue displacement and injuries associated with overpressure (see above). Retrieving dead fish at a detonation site is a well-known result of shock waves. "Dynamite fishing", a widely banned fishing technique, has effects that are akin to those of munitions detonation. It is known to effectively kill fish in the vicinity and to create damage to fish habitat such as reefs. In a documented case, only 3 % of killed fish floated to the surface (Gitschlag et al., 2000). Besides direct mortality by the shock wave, sub-lethal effects such as hearing impairment (acoustic trauma) or increased mortality by predation can also occur.

### 3.4.4 Blue Mussels

Bivalves are filter feeding organisms filtering many litres of water every day and as a result concentrating chemicals, either as particles or dissolved in water, in their tissues. In contrast, their ability to metabolize organic contaminants is relatively low, when compared to other marine organisms. Further, mussels are robust and survive under moderate levels of different pollutions. Moreover, repeated sampling of natural occurring specimens is possible, they can be used for laboratory exposure experiments and they are suitable to be transplanted to test areas for controlled biomonitoring. Beyond that, many bivalves are an important diet for other marine species such as fish and diving ducks and can be used as indicators for the entry of
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toxic substances into the food chain (Farrington et al., 1983). Furthermore, blue mussels are
grown in aquaculture or targeted by commercial fisheries for human consumption and as
livestock feed.

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 alarmingly 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).

3.4.5 Other Marine Life

An estimated 2.2 million different species of animals live in the seas worldwide. Fish represent
only approximately 12% of these species, an estimated one-fifth is represented by
crustaceans. The largest group of organisms living in the seas are marine microbes. Due to
this large variety, it is not surprising that only a fraction of these many different species were
investigated with respect to the impacts of explosives, CWAs and other substances related to
warfare materials on the marine life.

Measurable readings of explosive residues were detected in biota from the vicinity of the
dumped warfare materials that may indicate their entry into the marine food chain. For
example, Gledhill et al. (2019) found several kinds of explosives in marine biota like algae and
starfish, which were collected at Kolberger Heide. They found body burdens of HMX, RDX,
TNT and ten other explosives with highest measured concentrations up to nearly 25 mg/g in
starfish.

In addition, explosives like 2,4,6-trinitrotoluene, 1,3,5-trinitrobenzene and 4-nitrotoluene were
detected in feather duster worm, corals and long-spined sea urchins in the area of Isla de
Vieques, Puerto Rico (Barton et al., 2004). Ballentine et al. (2015) showed in a laboratory
exposure study that different marine species, such as the algae bladderwrack and sea lettuce,
Asian shore crab and common periwinkle (a marine snail) are able to uptake, transform and
accumulate TNT and RDX in their tissues.

Despite this research, only little is known about the effects of chemicals released from
munitions on marine biota. Rosen and Lotufo (2010) investigated lethal and sub-lethal toxicity
effects as well as bioaccumulation of TNT and RDX in e.g. two amphipod species
(Eohaustorius estuaries and Leptocheirus plumulosus), and in the polychaete Neanthes
arenaceodentata. In another lab study, algae, polychaetes and sea urchins were exposed to
different types of explosives like RDX, Tetryl and TNT. For the mentioned species LOEC
(Lowest Observed Effect Concentration) were calculated. LOEC is the concentration at which
the first effects on a species become visible or measurable like changes in behaviour,
spawning activity or food intake. For instance, with regard to Tetryl and TNT, LOECs for all tested species were determined between 0.13 - 1 mg/L and 0.18 - 103 mg/L, respectively (Nipper et al., 2001).

Remediation by detonation poses a threat also to marine invertebrates. Shock waves can be deleterious for marine invertebrates even if they do not have gas-filled cavities in their bodies. Even small explosives have the potential to kill all kinds of invertebrates (e.g., Metillo et al. 2016). However, knowledge about the mechanisms involved and the size of effect zones for invertebrates is scarce. Some information can be extrapolated from known effects of other high-intensity acoustic pulses (e.g. seismic impulses which usually contain less energy and have a less pronounced signal rise time compared to underwater explosions of UXO) on different life stages of marine invertebrates.

Due to the lack of systematic studies other studies must be used as proxies to explain possible mechanisms of injuries caused by shock waves. Circumstantial evidence suggests that high-intensity acoustic pulses such as the ones produced during seismic surveys represent a threat to squid species (Guerra et al. 2011). Shock wave injury in squid resulting from underwater explosions is thus also likely. Increased mortality and ultrastructural damage in hair cells, both associated with impulsive noise from seismic surveys, was observed in cephalopods off the Spanish coast. Controlled sound exposure experiments in the laboratory revealed that exposure to low-frequency sounds can result in permanent and substantial alterations of the sensory hair cells of the statocysts, which are the structures responsible for the animals’ sense of balance and position. Such massive acoustic trauma is life threatening (André et al. 2011, Solé et al. 2013a, b).

Malformations and delay in development of marine invertebrate larvae have been observed as effect of high-intensity impulsive noise – such as in scallop larvae exposed to playbacks of seismic impulses (Aguilar de Soto et al. 2013). Since explosions also produce high intensity acoustic pulses, occurrence of such types of injuries after the detonation of warfare materials can be inferred from this information. In sensitive areas such as recruitment sites these effects may have serious implications for the viability of a population. In the case of commercial species this would furthermore have economic implications.

1 The relevance for the Baltic Sea is given due to the regular occurrence of several cephalopod species in the Kattegat, Belt Sea and Western Baltic Sea. There are records of Alloteuthis subulata and Eledone cirrhosa in the Kattegat and Loligo spec. (forbesi/vulgaris), Sepiotta oweniata, Sepiola atlantica also in the Western Baltic Sea (depending on salt water inflow) – Uwe Piatkowski, pers. comm.
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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 WW 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 archive in 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 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.

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.

The successive increase in knowledge about the potential impacts of the UXO legacy has led to an urge to address the problem on a strategic level. In order to tackle the challenges raised above, a quality guideline for the handling of UXO in the offshore environment was developed. This quality guideline is posed to serve as a normative reference framework for all stakeholders involved in UXO operations.

UXO detection and removal operations are conducted in various judicial areas, some of which are only weakly regulated. While national law regulates work that is performed in the territorial waters in a fashion similar to that on land, the adjacent EEZ is subject to less regulation, as determined in the United Nations Convention of the Law of the Sea (Office of Legal Affairs - United Nations 2006). In case of Germany labour law is valid in the EEZ (Bundesministerium der Justiz und für Verbraucherschutz 1996) explosives law however, is not (Bundesministerium der Justiz und für Verbraucherschutz 2002). This weak regulatory regime becomes especially noteworthy, when, as in Germany, the majority of offshore wind parks are erected in the EEZ (Federal Ministry for Economic Affairs and Energy (BMWi) 2015). Such a situation results in lower barriers to entry the market, again with the consequence of attracting new actors.
Some aspects of offshore UXO removal are covered in normative or other guiding documents. The most extensive document is an account on assessing and managing UXO risk, published by British construction industry and research association CIRIA. This document focuses on the assessment of probabilities and consequences of UXO encounter and proposes management options (Cooper & Cooke 2015). A technical work aid (Arbeitshilfen Kampfmittelräumung) available in German, details the procedure of UXO treatment onshore. Notwithstanding its limited transferability to the offshore domain, it has been utilized during offshore UXO campaigns in the past (Arbeitskreis Arbeitshilfen Kampfmittelräumung (AK AH KMR) 2014). Other aspects, relevant to offshore UXO clearance, such as diving, hydroacoustic measurements and piloting of remotely operated underwater vehicles (ROV) have been addressed in other documents published by certification organizations and international governmental organisations (e.g. Hagenah & Klaproth 2016; International Hydroacoustic Organization 2005; International Marine Contractors Association 2016) However, no document exists, that comprehensively suggests technical and managerial best practices relevant for the entire procedure of offshore UXO treatment.

In conclusion, new actors enter a market in which only few publications covering best practises or quality standards are available. This constellation ultimately threatens to deteriorate operational quality in the industry. In order to address the challenges laid out above strategically, a quality guideline for the treatment of offshore UXO was developed (Frey 2020).

Key to the composition of a widely recognized quality guideline was the involvement of all stakeholders relevant to the procedure of offshore UXO treatment, that would be affected by the finished quality guideline once it would be published. However, initially a comparative analysis of twelve existing process flow charts, that cover UXO clearance onshore or offshore was executed, with the aim of identifying their weak points, generalizations and redundancies. This assessment served as a basis for the generation of a new holistic four-phase-scheme akin to the basic structure of existing technical work aids. For each of the four phases, the relevant processes and involved actors (i.e. the object) were identified.

In a second step, two workshops with focus on different phases of the four-phase-scheme were organized. Next to the initiation of stakeholder involvement, the workshops' goal was the identification of technologies, personnel and natural conditions (i.e. characteristics), relevant to the clearance of UXO in the offshore environment, as well as the description of detailed requirements for the individual processes. The workshops were attended by domain experts representing employers of the offshore construction industry, survey specialists, UXO service providers, consulting companies working in the field, scientists and public authorities. Additional expert interviews further aided the process.

A primary version of the quality guideline was drafted, which was made available to the domain experts for commenting and annotation. The comments were incorporated in the quality guideline, thereby turning it into a secondary version. In the final step, expert groups met to discuss the last remaining details that had still remained ambiguous during the workshops and could not be clarified during the annotation period. Two expert groups were held in April 2018, two more are due in October/November 2018. The quality guideline is going to be published in the first quarter of 2019. Initial publication is going to take place in German language.

Resulting is a quality guideline, that covers the entire procedure of offshore UXO treatment. The detailed description of the four phases is preceded by a general section. Here, a glossary defines central terms of the guideline and relevant legal and normative works, that are applicable to aspects covered in the guideline, are listed. Next, the relevant actors and their...
competence requirements are presented. The section is concluded by an introduction of pertinent personnel resources.

The following chapters describe one of the identified phases each. The four-phase-scheme is divided as follows:

- Phase I: Pre-Investigation
- Phase II: Technical Investigation
- Phase III: Investigation of Suspected Sites
- Phase IV: Clearance and Disposal

Each phase is further subdivided into processes. The subdivision is depicted in four individual flowcharts. A total of 30 processes covered in the quality guideline are spread over the phases (five processes for Phase I, eight processes for Phase II, nine processes for Phase III and again eight processes for Phase IV). For each of these processes a general description is provided, that focuses on the function of those actors, that are involved in that particular process. The majority of these descriptions is supported by a sequence of operation diagram. The process descriptions are complemented by a delineation of alternative scenarios and, where necessary, by specifications of suitable technologies and their way of application. For processes that require reporting or documentation, respective necessary content items are listed.

The final section is a reference section for quality drivers of deployed technologies or natural conditions. The section provides definitions for these quality drivers and, where possible, sets threshold values, that serve as termination criteria for specific processes. Furthermore, it describes the interrelationships that connect the quality drivers.

The quality guideline is not legally binding and receives its authority through the rigorous process of its generation and the strong involvement of a wide variety of affected stakeholders. The legally non-binding nature provides certain advantages such as higher flexibility, that may facilitate compromise during the generation of the document. The barriers to reaching consensus may be lower for the creation of a non-binding document and its responsiveness to the advancement of technologies and to the expansion of knowledge is higher (Taylor et al. 2014). Nonetheless, the quality guideline’s value for the stakeholders depends on the joint application of the document and its acceptance as a work of reference for future projects. It can be leveraged by different actors to commend its utilization. Public authorities may mention and recommend the guideline in collateral clauses and use it as reference for the approval of work concepts. Employers on the other hand may couple the award criteria of their tender offers to the adherence to the document. Lastly, the service providers for UXO detection or clearance may regard it as a basis for the establishment or strengthening of their internal quality management systems.

### 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).

The detection of warfare materials mainly concerns the thorough investigation of the seabed and the demersal zone, which is the water column near to the seabed. The available methods
are utilized accordingly. Warfare materials can either be present on the seabed or buried in the sediment. The bedrock is the lower limit for the presence of warfare materials as they do not penetrate into solid rock. Some warfare materials such as moored mines were designed to float in the water column when active. However, the moored mines that are present now, are a legacy of past wars. They are therefore not floating, but have either sunk to the seabed or were cleared in post-war efforts.

The detection of warfare materials in the sea is challenging for a number of reasons. The challenges differ, depending on the scale of the area that is subject to the investigation. The sheer size of 377,000 km² makes it economically infeasible to conduct a holistic detection campaign of the entire Baltic Sea (SERDP & ESTCP 2007). This is a consequence of the technological limits of the available technologies, which are laid out in further detail in the following subchapters. Similarly, endeavours to perform full area detection of warfare materials of a single nation’s territorial waters or EEZ are not considered reasonable. At this point, no full area detection campaign that would fulfil the requirements of warfare materials detection has been conducted. Consequently, no planning of large-scale preventive action on a strategic level has been possible. Even if such campaigns would be conducted, the potential mobility of warfare materials would contribute to gradually rendering the acquired data outdated before further measures could be conducted on a larger area. Due the comparatively low sedimentation in the Baltic Sea, this challenge may be secondary, especially for smaller countries. Nonetheless, it is recommended to limit the magnitude of every investigated area to a manageable size and to ensure maintaining a small time gap between detection campaigns and subsequent management options.

As a result of the infeasibility of a global detection campaign, efforts for the location of warfare materials are most commonly conducted as part of offshore economic development endeavours or scientific projects. Depending on the aim of the detection campaign, either one or two steps are performed. If a general overview of an areas is required, conducting a full technical survey of this area is sufficient. Previously gathered historic evidence will allow for an interpretation of the data, roughly indicating which type of warfare material was detected. The result of this step is a list of points, referred to as a ‘target list’, where warfare material is suspected to be present. However, at this point in the process the amount of information for each object will be limited. No single technology that is currently available can doubtlessly discriminate warfare materials from false alarms originating from scrap metal or other anomalies. If the acquisition of detailed knowledge on individual items is the aim of the detection, a second step is therefore performed. Every point of the target list is individually addressed and scrutinized, with the aim of confirming or refuting the target point suspicion. Subsequently, detailed information about the item is gathered and documented.

The following chapters focus on one of the available technology groups each. They describe those that are considered best available technologies and those that have successfully generated results during the execution of economic or scientific projects. Each chapter briefly introduces the mode of operation of the respective method, its area of application and its limitations.

### 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.

The quality of the performance of a magnetometer depends on its ability to detect the magnetic field anomaly and measure the strength of the total field amplitude. In addition to the above factors, which are out of the control of the surveyor, this ability is determined by the controllable distance between the sensor and the object that causes the anomaly. (Winkelmann 2014) Due to the complex dependencies of the multiple parameters laid out above, it is important to note that a precise universal value indication for the measuring range of a particular sensor for a specific object is not possible (Winkelmann & Fischer 2009). Consequently, magnetometers need to be deployed close to the seabed. They are mostly applied on systems that are towed by a survey vessel at a height of no more than 3 m above the seabed. Towing the sensor also allows for the necessary establishment of a large enough distance to the ship, which contains large amounts of magnetic material and is therefore a source of magnetic noise (Dimitru et al. 2017). Not only using a single device but an array of multiple sensors, allows for the coverage of a larger area with each crossing (Chabert w.Y.). Finally, towing the sensor with a survey vessel allows for higher surveying speed, when compared to the use of an ROV. Still, magnetometers may also be deployed with ROV. Magnetometers’ ability to detect anomalies in water and sediment alike, makes their use feasible for the detection of buried objects (Böttcher et al. 2011). If applied correctly, magnetic sensors therefore provide a surveyor with the ability to detect the largest part of warfare material that may be present on top or buried in the seabed and that poses a threat to offshore construction projects. Their comparatively larger measuring range is their biggest advantage over electromagnetic systems (Ruffel et al. 2017). In contrast to hydroacoustic systems, they allow for the detection of objects buried in the sediment on large areas. Consequently, magnetometers are considered a best available technology for the full technical survey of an area, which should however be supported by an
SSS survey. Furthermore, they may be used during relocation of objects during target point investigation. (Frey et al. 2019)

For smaller magnetic objects there is however a lower detection range. These cause a magnetic field anomaly that is too small to be detectable, due to the inevitable distance between the object and the sensor. The main development gap here lies in the availability of platforms that can be deployed closer to the seabed. While ROVs may allow for the required application closer to the seabed, towed systems do not, especially in areas of high bathymetric variability. A further developmental need lies in the reduction of noise (SERDP & ESTCP 2007). Another limitation of magnetic methods is the physical nature of magnetic anomalies. Not only warfare materials create anomalies in the earth’s magnetic field, but also other magnetic objects of anthropogenic and even those of natural origin. The signatures of these different types objects are often not distinguishable. Accordingly, targets detected by a magnetic sensor may be any of these object types. Data of additional sensors is required to enable further discrimination (Chabert w.Y.). The uncertainty connected to the source of the magnetic anomaly remains high, unless a detailed assessment of these target points is performed (Fauser et al. 2018). The susceptibility to the magnetic signature regardless of the cause leads to an additional challenge: If areas of the seabed are covered with or contain a high amount of ferrous material, it is not possible to identify single anomalies that may lie beneath, above or enclosed in this material. The same is true for the detection of warfare materials beneath structures like cables and pipelines or in the close vicinity of other buildings like wind farms or any structures comprising of armoured concrete. (BFR KMR 2018) In summary, the feasibility of magnetometers depends on the degree of natural geologic magnetization or magnetization caused by anthropogenic objects, such as scrap or infrastructure. Finally, magnetometers do not enable the detection of warfare materials that do not contain any or very low levels of ferrous metals, which is e.g. the case for LMB mines (Lauritzen 2013) or lumps of explosive material or other compounds that are not encased due to a release from their container (Frey et al. 2019).

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)

Performance of EM systems depends on their ability to detect the secondary field. It is a main influencing parameter for the measuring range which is smaller than that of magnetic sensors. In consequence, EM sensors have to be applied very closely above the seabed. The electromagnetic field is produced only under the coil, which has the advantage, that conductive materials that are situated sideways of the coil, such as buildings, do not constitute an impediment (AK AH KMR 2018). It does however also mean, that the measured area is limited to the size of the coil (Hollyer et al 2008). Due to the limited range both vertically and horizontally, EM systems are commonly used for the investigation of smaller areas such as suspected points on a target list. Towing EM systems up to 3 m above the seabed would not
lead to any meaningful results. They may therefore be deployed with ROVs. While their ability
to detect buried objects is lower than that of magnetometers, it still constitutes an advantage
over hydroacoustic systems. A large advantage over magnetic sensors in the EM systems’
ability to detect non-ferrous metals, and therefore e.g. LMB mines (Chabert w.Y.). An additional
field of application are areas with high geologic magnetization originating from non-ferrous
materials. As electro-magnetometers are not susceptible to these magnetic anomalies, they
may be applied for the detection of proud or near surface warfare materials. (Frey et al. 2019)
EM systems can therefore also be used to discriminate geogenic magnetic non-metallic
anomalies that were detected with a magnetic sensor in a previous survey.

While, natural magnetic anomalies are not detected by EM systems, anthropogenic scrap
metal will be detected nonetheless. The data obtained from detecting scrap or warfare material
may be very similar, which is especially true for scrap that resembles warfare materials in
shape and size. As a consequence, the discrimination between these objects is very
challenging. (SERDP & ESTCP 2007) Similar to magnetic systems, another limit lies in the
fact that due to the absence of metal in loose lumps of explosives, their detection is impossible
when using EM methods (Frey et al. 2019). The conductivity of salt water conductivity leads to
an overall increase in the noise level during measurements. However, it has been shown that
the conductivity’s effect on target classification is limited. (Bell et al. 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.

Understanding differences in acoustic response between warfare materials and the
surrounding environment is an important quality driver for the successful application of all types
of sonars (SERDP & ESTCP 2007). Another very important quality parameter of hydroacoustic
datasets is their spatial resolution (IHO, 2008), which in turn depends, among other parameters
on the height of the sensor above the seabed, the acoustic frequency, the band width available
for signal processing and the beam width of the transmitted signal. It determines, whether an
object is actually visible on a sonar image. Simplified, the higher the acoustic frequency and
the shorter the pulse length, the higher the spatial resolution, but the lower the range of the
signal (Frey et al. 2019).

**4.3.2.1 Side-Scan Sonar**

A Side Scan Sonar consists of a line antenna (a number of acoustic transducers) mounted on
either side of a tow fish or an AUV. The longer the antennae, the narrower is the cone shaped
beam that is formed. This determines the system’s along track resolution. In very sophisticated
multi-beam systems this results in an along track resolution of about a few decimetres. The
range in this case will be less than 100 m (roughly 200 m total swath width, i.e. the combined
range on both sides), the range resolution about 10 mm. The resulting spatial resolution is
sufficient to detect a large percentage of warfare material.

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The altitude of the tow fish above the seabed has significant influence on the range of the SSS. This quite often causes problems with limited range in very shallow waters like in the German Baltic coastal waters. It is furthermore possible to derive the precision of positioning of detected objects, which depends on the accuracy of the GPS and USBL navigation used as well as the position of the tow fish, which is determined by speed, cable length and the fish’s hydrodynamics. A weakness of SSS is the nadir gap, since the antennae cannot transmit sound underneath the tow fish or AUV. Depending on the altitude a gap of up to a few meters may result. This gap can be covered by a neighbouring line, when appropriate smaller line spacing is selected but this will result in a smaller search area per time unit. Some products integrate an additional nadir gap filler sonar, a downward pointing scanning 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).

The most apparent limitation of SSS is their inability to detect objects that are fully buried in the sediment. Accordingly, SSS are mainly useful in areas of low sediment thickness. In addition, the presence of other types of coverage such as coral or plants, makes detection efforts very challenging (Schwartz & Brandenburg 2009). In addition, even for proud and half-buried objects, shortcomings exist. Even though all these objects are visible in the sonar image, it is very challenging to distinguish between warfare materials and other objects, both natural and anthropogenic (Böttcher et al. 2011). This becomes especially evident in areas with a high density of rubble and debris, which may have a shape similar to larger warfare materials such as ground mines (Frey et al. 2019). The same is true for the detection of small warfare materials of a few cm in size, when present on gravel (Marine Estate & Mineral Products Association 2010).
4.3.2.2 Synthetic Aperture Sonar

As shown above in an SSS the antenna length determines the beam width and thereby the along track resolution, which is at least more than an order of magnitude lower than the range resolution. A tow fish antenna cannot be sufficiently long to increase the along track resolution to a satisfactory level.

A solution for this challenge was to apply the principle of airborne Synthetic Aperture Radar (Skolnik et al. 1980) to sonar technology. Successful synthetic aperture sonar (SAS) imaging requires several challenges to be overcome. The sonar position accuracy must be higher than a fraction of a wavelength along the entire synthetic aperture. At e.g. 100 kHz this an accuracy of around 1 millimetre along tens of metres of travelled distance is required. SAS uses algorithms to interpret measured data of consecutive transmissions and returns as if they would have been generated by a transducer that is multiple times larger than the physical one.

Since the aperture (i.e. beam width) is linear to the antenna length, the result is a spatial resolution of around 30 x 30 mm. Because of the precision requirement mentioned above, the position needs to be determined within millimetre range. The development of SAS is therefore closely linked to the development of precisely positioned AUVs. This requirement cannot be fulfilled when using a tow fish because of the mechanical influence onto the tow cable and the tow fish. A positive side effect of the SAS signal (post-)processing is that along track resolution is constant over range whereas with SSS it decreases with range.

There are however, numerous challenges. When operating an SAS (or any sonar at that) environmental influence (season, weather, etc.) can lead to quite diverse results, even for repeated surveys within the same area. Furthermore, using SAS also leads to a nadir gap. An MBES may be used as a nadir gap filler, which will however produce lower the MBES’ spatial resolution data than the SAS.

4.3.2.3 Multibeam Echosounders

An MBES uses a transducer to transmit a number of beams which insonifies a wide angle of seabed across track with a single ping (typically 10° to 150° swath, resulting footprint is depending on water depth) and a very narrow sector along track (between 0.2° to 5°, depending mainly on frequency and antenna length). The receiving phased array (a receiver which electronically steers its receiving direction) disaggregates the returned signal into multiple beams (typically either 256, 512 or 1024 of them), giving the technology its name. Figure 14 displays this principle and shows that due to beam steering the beam footprint increases for the outer beams. To avoid this issue an equidistant mode can be chosen for acquisition: beam angles vary across the swath, but beam distances on the seafloor are the same; compared to equiangular mode: beam angles are the same across the swath; footprints differ from nadir to outer swath. In equidistant mode, beam resolution can be lower than nadir resolution in equiangular mode. Choosing the best suitable method is depending on survey parameters, such as minimum object size, profile spacing, survey time, etc).

MBES can be either installed on a vessel (hull mounted, in a moonpool or on a pole) or mounted on an AUV. In either case, the position and orientation of the antennae with reference to the motion reference unit (measuring roll, pitch and heave) and the position unit must be determined with utmost precision. It is impossible to use a MBES without those external reference systems.
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 positioning data of target locations. It may therefore be applied in monitoring programs of known dumping sites (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.

Figure 14: MBES principle of work.

The (red) projector transmits a beam which is very wide across track but very narrow along track, marked in orange at the bottom map. The returned echo is received by the (blue) phased array which forms very narrow beams across track, marked in blue at the bottom map. The intersection of both represents the spatial resolution of the system.

4.3.2.4 Sub-bottom Profiler

Sub-bottom profilers (SBP) are used to acoustically image the seafloor and subseafloor. Their relatively low frequencies (roughly between 2 and 40 kHz) allow them to penetrate into the sediment. The main types of sub-bottom profilers include conventional echosounder (pinger), chirp, and parametric echosounder (PES). They can be installed at the ship’s hull, towed behind the ship or attached to the side of the ship. Pingers emit a very short, single high frequency pulse, whereas chirps emit a pulse which varies its amplitude and frequency over time (a so-called frequency-modulated sweep) which allows optimal extraction of information from the bottom sediment. The PES, however, emits two very high frequency wavelets (around 100 kHz), whose interaction generates by nonlinear interference a new secondary signal with
the resulting difference frequency (roughly between 6 and 12 kHz). This secondary signal is ideal for the detection of (small) objects buried below the seabed.

The principle of the PES is illustrated in Figure 20. The PES can be operated from very small vessels. The transducer is normally attached to the side of the ship, and only a signal recording unit and a precise positioning system is needed on board. The generated secondary signal has a short signal length (0.07 – 1 m/s), with a small beam width (±1.5 and ±2.5° depending on the transducer arrangement), and virtually no side lobes during transmission. Penetration depth will highly depend on the bottom sediments (for soft muddy sediments penetration can be up to 50m). The system has a high vertical resolution of 10-15 cm, and a horizontal resolution of 5-25 cm (depending of the mode and speed). Thanks to the short pulse length it is suitable for very shallow water environments. Additionally, the narrow footprint of parametric systems also decreases the occurrence of diffraction hyperbolae from small objects (Schneider, D. et al., 2016). Contrary to pingers, the full waveform is recorded which allows to detect phase inversions.

Figure 20. Principle of non-linear acoustics (Wunderlich & Müller, 2003)

The resolution of the parametric echosounder allows the detection of small objects on the seafloor, 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.
Other geophysical techniques capable to detect UXO include magnetic and electromagnetic methods, which use the characteristics of ferrous material objects. However, these techniques do not provide a dimensional image of the object nor an accurate depth information, whereas deeper objects often go undetected. Most of the dimensional results from these methods are empiric and model based (e.g. iron mass and depth) and allow for a general overview of the buried (ferrous) objects, but not for a specific object signature. The PES, on the other hand, is able to pinpoint the burial depth of the object and a better dimension estimation (Figure 21). In contrast with magnetics and electromagnetics methods, it can discriminate an object individually, ruling out the most common ambiguities (i.e. a big object with a high signature or a group of objects that together have a high signature; a big, buried object or a small, shallow object). Since it is possible to generate 3D imaging from dense coverage 2D profiles, this will facilitate the interpretation of the object dimensions.

Figure 21. Left: 2D PES profile showing two buried objects buried 1 m and 2 m below the seabed (blue arrows). Right: 2D PES profile showing objects exposed on the seabed (green arrows).

The PES can also provide valuable information on the sedimentary background of the site, and may help to distinguish between different materials of the buried objects. However, its small beam width makes searching for objects rather time-consuming (especially during the interpretation), and penetration in gas-rich or hard sandy layers is not optimal. Moreover, the applicability of the multi-transducer PES system is limited by the required ultra-high positioning accuracy (which will highly depend on weather conditions (waves) and vessel and wind speed), the limited area of coverage (on average 250 x 250 m) and the limited water depth.

4.3.3 Optical Methods

Optical underwater sensing methods are usually based on visible light, i.e. electromagnetic radiation with wavelengths in the range of about 400nm to 700nm. In clear and shallow water passive visual sensing can be applied by using cameras mounted to autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), towed platforms or by divers. In deeper waters (certainly for more than a few tens of meters), or in case the composition of the water limits the sunlight illumination of the seafloor, the capture systems must be equipped also with active illumination. The seafloor is then photographed from a certain distance and objects on the seafloor, or those sticking out of the seafloor, or seafloor deformations as well as
characteristic appearance can be observed. Either single photos are captured for later analysis, or as recently done, systematic mapping campaigns are accomplished for larger areas. In such visual mapping campaigns, subsequent photos (or videos) of the seafloor are arranged in a way that they show significant overlap (e.g. 80%), such that each photo can be registered with the previous/next image. The footprint of a single photo covers only a few square meters, meaning that a single tow or transect will only map a narrow seafloor corridor. Larger areas are therefore typically scanned in a “lawnmower fashion” going back and forth while making sure that the footprint of neighbouring tracks overlaps (e.g. by 50%), this way mapping many parallel lines. These photos, often thousands of them, can then be registered using computer vision technology (Jordt, 2015) to generate virtual orthophotos of an entire area, jointly with a 3D digital elevation model of the seafloor. Depending on distance and resolution of the camera, lighting conditions and water quality, these methods reach centimetre to (sub-)millimetre resolution. At the same time, the image registration process can also provide the micro-navigation of the camera platform (visual odometry) to facilitate also the registration of other sensors (e.g. magnetic, acoustic) that do not provide localization by themselves and have to rely on external sensors.

Optical data can be used in different ways. Single images can be inspected by skilled experts or can be scanned by machine learning approaches. Machine learning approaches have to be trained with a huge number of positive and negative examples. Both for skilled experts, as well as for computers, the often-varying capture conditions pose a challenge: Depending on the distance, the water composition and the lighting regime, the appearance of objects can significantly vary between different seasons or capture campaigns. One solution to this issue is to compensate the water and lighting effects (“image restoration”), which can be accomplished using heuristics or using physical models of underwater light propagation. Trained experts can also inspect raw photos.

Rather than inspecting single images with a limited field of view, thousands of photos can also be registered to obtain digital elevation models and virtual orthophotos. While compensating all lighting effects in murky water is still subject of research, in general such colour-enhanced large-scale machine vision mapping methods provide a larger overview of an area, and the 3D shape information of objects can support detection, classification and interpretation when being viewed by an expert in a 3D viewer, or can be used also for applying AI techniques. Since the cameras have to be protected from the surrounding water, they have to be enclosed in a water-proof housing and view the environment through a glass window. Depending on the shape of the window (e.g. flat port or dome port) light rays into the camera will undergo refraction when passing the water-glass-air boundaries. Since the camera is used as a sensor (and not only for watching) it has to be calibrated properly to allow later for bias-free mapping of an area.

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.
Due to the physical properties of water shorter and longer wavelengths than those of visible light undergo strong attenuation when traveling through the medium and lead to very low signal-to-noise ratios. Underwater optical measurements outside the visible spectrum, e.g. ultra-violet or infrared, are only feasible at very small distances (centimetres to decimetres), and are thus impractical for mapping because of the small area inspected. Depending on the composition of the water (algae, particles, stirred-up sediment) also the range of optical methods in the visible spectrum is usually limited to about 1m to 3m (e.g. Baltic Sea) and rarely higher than 5m to 10m (crystal clear water). Also, visual methods can only "see" objects that are not entirely buried.

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.

A recently developed method uses solid-phase extraction (SPE) to eliminate the seawater matrix and preconcentrate trace levels of dissolved explosives (Gledhill et al., 2019). This approach allows confident detection of explosive compounds at the ultra-trace levels required for environmental samples, but limited availability of the analytical instrumentation may limit a wider application. Nonetheless, SPE preparation can help improve analytical capabilities of other detection technologies for both conventional explosives (Jönsson et al., 2007; Sun et al., 2011; Rosen et al., 2018) and CWA compounds (Kanaujia et al., 2007).

Novel detection methods employing Molecularly Imprinted Polymer (MIP) and electrochemical sensor systems have been tested for explosive detection in seawater (Atlas Elektronik, 2015; Baudoin et al., 2017). Limited information is currently available on the sensitivity and specificity of these methods.
Passive samplers have also been successful at accumulating explosive compounds from seawater (Rosen et al., 2018; Lotufo et al., 2018; Warren et al., 2018). These samplers comprise a sorbent which may be held within filter membranes. They accumulate dissolved compounds over time, providing a time-integrated sample which helps eliminate temporal variability in compound levels associated with heterogeneous plumes in the water column (Rodacy et al., 2001; Camilli et al., 2009). It is however not possible to calculate ambient seawater explosive concentrations from the passive samplers as the diffusion rates to the sorbent are very difficult to ascertain. These samplers’ applicability is therefore limited to the detection the presence of explosive compounds, without allowing for an assessment of the degree to which they are present.

Conventional munitions compounds in biotic tissues from the Baltic Sea have been extracted with acetonitrile, and measured by GC-MS (Strehse et al., 2017; Appel et al., 2018) or LC-MS (Gledhill et al., 2019) (see 3.4.3).

4.3.5 Bioindicators and Biomarkers

By definition, a bioindicator is a species or an ecological community that is monitored over time for changes in abundance or health, giving evidence on the status or quality of a particular environment. The organism used as bioindicator should be sensitive to the pollution in its environment. If pollutants are present, the organism may change its morphology, physiology, behaviour or even dies. However, mostly robust organisms able to survive expected level of pollution are used in common environmental monitoring programmes. Further, selected bioindicators should be abundant, wide spread and easy to sample and handle so that they can also be used in lab experiments to investigate mechanistic intoxication and e.g. how the substances are accumulated and/or metabolised.

In contrast to pure physical or chemical assessments, bioindicators are able to display biological reactions of measured environmental changes and help to correlate pollutant concentrations to certain health effects. Accepted tools to measure the health effects are biomarkers defined as biological responses to environmental chemicals at an individual level or below. Biomarkers provide means of translating environmental levels of pollutants into biological terms. Biomarker can be used to assess effects of pollution on different levels of the investigated organism, ranging from changes in gen-, or enzyme expression over enhanced cell death events to accumulation of metabolic end products and damages of tissue, organs up to the development of diseases and tumours.

Responses of the organisms on lower organisational level, like increased gen- or enzyme expressions are usually correlated with lower doses of pollutants and short time of exposure. In contrast changes on tissue, organ or individual level are more likely the results of higher doses and require a long exposure time. The severity of measured effects is also connected to the organisational level where the investigated effect was detected. Effects on organ or individual level are more severe and often irreversible compared to effects on lower organisational level, such as e.g. increasing accumulations of certain metabolic products or increased cell death.

Of course, there are different sensitivities of organism to certain chemicals, both of individual level and between different species, however, the modes of protection against certain groups of chemicals are comparable also in not closely related species. Like that organisms can cope with many different toxic threads. As a results specific response to pollutants are rare and thus a one-biomarker approach is usually not suitable. It is therefore recommended to use several
biomarker measuring on different organisational level to fully assess the biological effects of a pollutant or a mixture of pollutants.

There are numerous potential bioindicator species available depending on the part of the marine ecosystem intended to be investigated. Regarding the analysis of potential negative health effects of marine munitions laying on or buried in the sediments on organisms, bottom dwelling organisms would be the best choice. These species get most likely in contact with solid explosives still trapped in corroded munition shells or get exposed to the dissolved fraction of explosives in the vicinity of open munition bodies. Very suitable bioindicator are sessile species, such as blue mussels or tunicates, directly displaying the pollution level of a certain area. Filter feeding blue mussel are of special interest, since the life on the sediments and are able to filter huge amounts of seawater, increasing the chance to accumulate toxins and pollutants from the surrounding water column. Also, stationary crab species could be used for biomarker assessments. In fish non-migrating flatfish species like dab are widely used in environmental assessments of sea bottoms.

As mentioned above, organisms used as bioindicator are preferably abundant and geographically wide spread. However, the strong salinity gradient in the Baltic Sea hampers the distribution of many marine species. For example, Mytilus edulis the common marine blue mussel is distributed only in the Skagerrak and Kattegat until the little Belt area. In contrast, the closely related Mytilus trossulus inhabits the less saline areas in the eastern and northern parts of the Baltic Sea. In between large areas are inhabited by hybrids of the two species with changing gen compositions. Also, flatfish like the common dab are limited to the more saline areas in the west of the Baltic Sea. Specimen caught from the edges of their habitat are usually smaller with lower condition factors and thus being in different physiological status like their cousins from more saline areas, making it difficult to compare biomarker results. Overall, the selection of certain bioindicator species is limited to relatively small areas and comparisons between dump sides from different Baltic regions are restricted to general interpretations rather than absolute values.

Another factor limiting the deployment of bioindicators in the Baltic Sea is the dramatic level of eutrophication resulting in larger oxygen depletion zones in the deeper areas of the central Baltic Sea. Depletion zones are more or less permanent and only every now and then re-oxygenated when larger inflows of North Sea waters happen. In these areas the macrozoobenthos is inexistent. By accident, also the largest dumping sides of chemical warfare agents are situated in this areas. An assessment of the sites by benthos bioindicators as done in other dumping areas in impossible due to the hostile conditions in the lower water layers. Here, pelagic organisms were used to assess the bio-effects of chemical warfare agents in the field. However, even if e.g. cod is diving into depletion zone and get occasionally in contact with the warfare components, measured effects are not comparable with a situation under good oxygen conditions.

Overall, the use of bioindicators and biomarker is an essential measure to track the effects of pollutants deriving from dumped munition. Without these results a holistic risk assessment including an environmental aspects is impossible. However, the special hydrological qualities of the Baltic Sea are a challenge when applying bioindicator. The Baltic Sea areas have to be divided in sub regions, that bioindicators adapted to the respective environmental conditions are used. This is increasing the efforts for the biological effects assessments, since effects under different abiotic condition may vary substantially. Furthermore, also the most sensitive organisms should be named for each region to guarantee a region-specific risk assessment.
And finally, some region, like the oxygen depletion zones are difficult to assess solely with field sampling, here additional lab experiments should be conducted to generate threshold for the risk assessment.

4.4 Modes of Clearance

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 Von Benda-Beckmann et al. 2015).

In order to obtain a stable detonation, a sufficient amount of material has to be present, so equilibrium (i.e. maximum detonation velocity) can be achieved. Therefore, a critical mass is needed below which the detonation cannot be sustained. The geometry should be such that the critical diameter – this is the diameter below which there will be no steady state detonation – is exceeded. High order detonation is also affected by the confinement of the explosive, since this can act as a focusing effect for the detonation reaction with the shock wave being directed inwards and thus enhanced and driven, while accelerating it towards the maximum velocity.

As a consequence of an efficient reaction most, though not all, of the explosive will be consumed and residues will remain as the end products of the reaction chain. These contain significant quantities of gas but also solids such as aluminium compounds. Resulting end products depend on the composition of the detonating explosive material.

A variant of the high order detonation is the consolidated detonation. A consolidated detonation is executed when numerous warfare material objects are detonated at the same time and at the same location (Schwartz and Brandenburg 2009). Several reasons from cost-reduction to local seafloor condition (detonation only possible in one place) or safety reasons (risk of unintended sympathetic detonations) might lead to the decision to conduct one consolidated, rather than several individual explosions. The overall impact of the detonation is higher when numerous objects are detonated simultaneously.

Warfare materials were designed for terminal effects and thus pose a significant hazard, since a stimulus may also produce an unintentional high order effect. Many warfare materials in the sea will have an explosives initiation train and confinement. The measures taken should consider those specific risks.

One approach would be to remove the initiation and fusing system. Even though this may be affected by water and rendered inoperative, it cannot be assumed that this is the case. Accordingly, removal of the fusing system needs to be assessed for risk and avoided if the level of uncertainty is judged to be unacceptable.
Another option would be the effective reduction of the mass of explosive material and removing its confinement. If warfare material can be disrupted in a controlled manner, the designed confinement is destroyed and the high order detonation risk is reduced. Disruption can also remove a sufficient amount of the explosive material to reduce its mass below that needed to promote and sustain high order detonation.

**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.

When dealing with warfare materials in the sea, which may have been damaged, the risks of both low order or high order detonation should always be considered. Attempts to disrupt or move such warfare material can lead to an initiation stimulus and a violent reaction, which would be sufficient to do damage and produce risks to life despite not being the full operational effect. While water can act as a damper to the reaction, it may also act as a form of confinement and so the effect may be greater than in air, especially if a bubble is generated. In addition, such a low order detonation may itself act as a stimulus to other warfare material, if the material is located in close proximity to the initial detonation, leading to sympathetic reaction and to a full high order event.

A low-order detonation requires an energetic impulse, e.g. through a booster charge. It is possible to place such a charge in such a way that the warfare material object opens and detonates in low order. However, the risk of an unintended high-order detonation of the object taking place can never be fully excluded. Nonetheless, a low-order treatment under water can be executed more effectively than on land.

During low order detonation, the explosive material operate in its designed mode. It therefore leads to the release of unreacted, partially reacted or completely reacted materials into the environment. Unreacted or partially reacted materials may pose a further risk in disposal. It is therefore highly desirable to assess the risks of any form of detonation and attempt to completely avoid it through careful disarming and dismantlement. (Fickett and Davis - Detonation Theory and Experiment, 1979)

**4.4.3 Deflagration**

Reactions within energetic materials – explosives, propellant etc. – can take several forms. These forms are generally governed by the speed of reaction and range from high order detonation to simple combustion. Deflagration is normally defined as a very rapid form of combustion but one in which the chemical reaction velocity does not exceed the speed of sound in the material.

It is therefore fast and destructive and can in some cases lead to detonation where, for whatever reason, the reaction accelerates to a supersonic rate. This acceleration can be produced by several factors such as an increase in the quantity of material available for reaction, geometry, or the confinement of the energetic material, where the pressure is increased locally inside the reacted and unreacted material.
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Damage to the material can allow the reaction rate to accelerate. Such damage produces compression hotspots or sufficient porosity to increase the reaction rate. Such increases can give rise to what is called Deflagration to Detonation Transitions and these can be unpredictable and hence a source of risk.

Rapid combustion or deflagration can be used for destroying dumped materials. A shaped charge of modest size can be used to weaken the shell and initiate deflagration rather than a high-order detonation. The acoustic output of a deflagration is much smaller compared to a detonation and there is no shock wave. (Robinson et al. 2020). Thus, deflagration could provide disposal options where risks of a high-order detonation for material or environment are considered high. However, deflagration is associated with other specific risks such as contamination of the marine environment (Koschinski, 2011). Another drawback of using deflagration as a disposal method is the increased risk of Deflagration to Detonation Transitions under certain conditions of the confinement, including the combination of casing and water.

The rate of deflagration combustion is therefore unpredictable and depends both on the local environment and the confinement. It should therefore not be used regularly for planned destruction of warfare materials. If it is considered as an option, then it is essential that the risks described above be thoroughly considered in the planning phase.

**4.4.4 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 3.4), 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 (Table 7).

In EU Member States, the Habitats Directive (Source 1) regulates the protection of specially protected habitats and species. It requires a system of strict protection for the species listed in Annex IV which includes inter alia all species of cetaceans. Among other aspects, this covers the prohibition of all forms of deliberate capture or killing of specimens of these species in the wild. The Birds Directive (Source 2) likewise prohibits deliberate killing or capture of wild birds by any method including deliberate destruction of, or damage to, their nests and eggs or removal of their nests. The EU Marine Strategy Framework Directive (MSFD) covers inter alia the introduction of energy into marine waters, including underwater noise and has a special relevance for underwater explosions, which are the loudest anthropogenic underwater point source of impulsive noise (Koschinski, 2011). The aim of the MSFD is that by 2020 noise levels “do not adversely affect the marine environment” within the EU.

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 mine sweeping activity 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).
Resolution no. 8 (2016) by the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) “Addressing the Threats from Underwater Munitions” (ASCOBANS, 2016b) encourages Contracting Parties to support research, investigating the risk to marine animals and habitats from underwater warfare materials, and recommends that international guidelines should be developed, including those advising on safe recovery methods and mitigation measures, when no alternatives to detonations are feasible.

Table 7: Summary of available mitigation methods for reducing the impact of underwater detonations on marine animals

<table>
<thead>
<tr>
<th>Planning stage</th>
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</thead>
<tbody>
<tr>
<td>Perform an impact assessment and develop mitigation strategy for unavoidable detonations</td>
</tr>
<tr>
<td>• Involve nature conservation and fishing agencies</td>
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<tr>
<td>• Determine the radiation of sound and shock waves with a suitable model</td>
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<tr>
<td>• Analyse the vulnerability of species and habitats in the affected area</td>
</tr>
<tr>
<td>• Determine impact and safety zones for wildlife</td>
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<tr>
<td>• Consider possible effects of seismic waves and shock waves to nearby sensitive habitats</td>
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<tr>
<td>• Analyse options for relocating warfare materials or postponing detonations</td>
</tr>
<tr>
<td>• Develop a site-specific deterrent strategy</td>
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<tr>
<td>• Analyse effectiveness of acoustic deterrents</td>
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<tr>
<td>• Analyse suitability of technical mitigation measures</td>
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<tr>
<td>• Plan of pre- and post-detonation surveys</td>
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<tr>
<td>• Plan protected species observer schemes and passive acoustic monitoring (PAM)</td>
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<tr>
<td>• Develop safety procedures</td>
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<table>
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<tr>
<th>Measures before detonation</th>
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</thead>
<tbody>
<tr>
<td>Pre-detonation survey</td>
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<tr>
<td>• Perform air based marine mammal survey in greater area</td>
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<tr>
<td>• Perform PAM covering the wider area for a representative period of time</td>
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<tr>
<td>Use of acoustic deterrents for marine wildlife</td>
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<tr>
<td>• Consider variations in scaring distance</td>
</tr>
<tr>
<td>• Relate likely scaring distance to danger area</td>
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<tr>
<td>Protected species observers (PSOs)</td>
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<tr>
<td>• Employ PSOs to cover the safety zone and stop detonation in case of sighting</td>
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<table>
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Measures after detonation

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Table 7 provides a toolbox of mitigation methods to reduce the impacts of underwater detonations on marine animals from which a set of suitable methods should be chosen based on a case-by-case assessment. Performance monitoring is required for all mitigation measures in order to document the fulfilment of legal conservation requirements such as those mentioned in 5.3.1 and to enable further improvement of mitigation methods. The following chapters explore some of these mitigation options during clearance of warfare materials.

4.4.4.1 Detonation Risk Assessment and Mitigation Strategy

In the planning stage, a proper detonation impact assessment and a mitigation strategy should be developed in cooperation 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

It includes a number of steps (Table 7). Only in case of imminent danger posed by warfare material to humans when swift action is required, such an assessment may not be possible. Strict standards should be applied to the assessment of whether danger is imminent. This signifies that upon initial examination, sufficient corroborating evidence appears to exist. Especially if the presence of mines or other munitions has been known for a long time, imminent danger is generally difficult to invoke as a justification for urgency (Wissenschaftliche Dienste, 2020). For cases of imminent danger, previously developed standard procedures should apply. These should be based on readily available information (e.g., from databases on animal occurrence and general knowledge on sensitivity of animals) and be developed involving various stakeholders and responsible authorities.

The first step in an impact assessment is a thorough determination of possible impact zones (e.g., for marine vertebrates with respect to injury and hearing impairment) based on a site-specific shock wave and noise propagation model and current knowledge of shock wave impact on biota. An adequate safety margin should be established as part of the safety procedures in a precautionary manner (Dos Santos et al., 2010).

The vulnerability of species and habitats in the affected area should be analysed. In the Baltic Sea, seal haul-outs, occurrence of harbour porpoises and sensitive areas for fish species (spawning grounds etc.) are of special concern (HELCOM, 2019a), as these are especially vulnerable to the shock waves originating from detonations. Furthermore, seabird colonies need to be considered, since swimming or diving birds can be injured by underwater detonations (Koschinski, 2011). In some cases, the effect on terrestrial animals or habitats should also be analysed. For example, coastal colonies of cliff-dwelling birds might be affected by seismic shocks of explosions, such as the bank swallow whose tunnels including eggs or juveniles could be buried by ground shaking. Not only sensitive animals should be taken into account but also MPAs in general (Frey et al., 2019), even if the detonation occurs outside the MPA but the radiating sound or shock waves are predicted to affect the MPA. Also, nearby sensitive habitats, such as reefs and other habitats with fragile benthic species, might be
affected by an underwater detonation or subsequent sedimentation of fine material, which would require including them in the impact assessment.

As part of the mitigation strategy, possible alternatives to blasting should be considered and best available techniques be identified. To date, a variety of munitions items can already be salvaged without risk to humans. Other items that are not assumed safe to transport are usually detonated (see 4.4.1). Methods where robots take care of the handling to enable delaboration may at some point be available and allow salvaging of unsafe to handle items (see RoBEMM project in 5.8.5.5). Currently, only about 20 to 30 % of the Baltic Sea area affected by munitions can be cleared due to the prevailing danger and current resource intensity associated with munitions disposal. Within the next ten years, the improvement of clearance technologies and an increase of available resources could significantly grow the percentage of munitions that can be recovered safely, largely without danger for humans and the marine environment (Abbondanzieri et al., 2018).

If a detonation cannot be avoided, spatio-temporal mitigation is a very effective protective measure by avoiding most vulnerable areas or time periods and postponing or relocating safe to handle warfare materials before executing detonations. In order to safeguard protected marine species when executing detonations underwater, time and place of detonations which have the least impact on the environment should be determined (Dolman et al., 2009). Detonation in air (on a sandbank) can be considered if munitions are located close to shallow areas.

Before detonation, the suitability of technical mitigation measures should be analysed. Appropriate measures should be based on best available technique (BAT) and best environmental practice (BEP) (HELCOM, 1992). If a detonation in sensitive areas or during sensitive times cannot be avoided, this is of utmost importance to protect the environment. A technical mitigation measure (see 4.4.4.2) in combination with the use of deterrents (see 4.4.4.3) may be very effective.

Pre-detonation surveys (air based and passive acoustic monitoring (PAM)) of the wider area well in advance of the detonation for a representative period aid the analysis on which species and how many individual animals might be affected by detonations and whether it is possible to keep them at safe distance using acoustic deterrent devices (see 4.4.4.3) (Yelverton et al., 1973; Yelverton et al., 1975; Goertner, 1982; Thiele and Stepputat, 1998; von Benda-Beckmann et al., 2015b). Noise sensitivity of species has been addressed by HELCOM (2019a) (see 3.4).

The implementation of a protected-species observer scheme in order to maintain a safe “exclusion zone” around the blast is one of several components of a comprehensive mitigation strategy. Procedures for a safe abortion of the detonation in the case of a sighting within the impact zone should be developed. This mitigation measure relies on the thorough determination of possible impact zones, a skilled observer team, and suitable visibility conditions (calm sea, good light). For small cetaceans such as harbour porpoises, visual monitoring is usually complemented with PAM in order to increase the likelihood of an animal being detected in the impact zone, which may have a radius of several kilometres depending on factors such as charge weight, depth and orientation of the animal (von Benda-Beckmann et al., 2015b). The advantage of PAM is that it is performed continuously under water whereas a visual detection is only possible in a short time window during surfacing. However, the acoustic detection distance for harbour porpoises is only up to a few hundred metres (Kyhn, 2010) and thus is shorter than the
visual detection distance, which is only up to a few hundred metres (Kyhn, 2010). PAM is of no use if animals do not vocalise or are orientated away from the hydrophone. Seals cannot be reliably monitored acoustically, since they mainly vocalise during the short mating period (Van Parijs et al., 1999). Aerial platforms and unmanned devices, such as drones with live video feeds, may also be considered for observations.

Post-detonation air and beach surveys in the wider area around the detonation site should be performed. This enables the evaluation and documentation of the mitigation strategy and supports the recovery of dead specimen and veterinary care in the case of injured animals.

4.4.4.2 Technical Mitigation Measures

The most common 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 (Figure 15; when used to mitigate underwater detonations, the pipe-laying vessel which also provides the air is positioned outside a specific safety zone and thus the pressure pipe for air supply is much longer than in this image). 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; Nüetzl, 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” (a type of hexanite) 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%.

The principle mechanisms responsible for the pressure reduction by the bubble curtain result from the compression and relaxation of the bubbles by the shock wave (Grandjean, 2011). The adiabatic compression of the bubbles results in a temperature rise and thus sound energy is absorbed by conversion to thermal energy. Some of the thermal energy is then transferred to the surrounding water by cooling. Oscillation of bubbles re-releases some of the absorbed sound energy to the water with a loss of energy and a time delay due to the higher viscosity of water compared to air. The relaxation of bubbles creates rarefaction waves, which decrease pressure. Overall, these effects reduce the pressure peak and distribute the energy over a longer period of time. Furthermore, part of the sound energy is reflected inwards back to the detonation site. The efficiency of bubble curtains depends on their diameter, width and shape, air volume stream, bubble size, and on the water depth. Its performance can be monitored by
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using pressure sensors located inside and outside the bubble ring. The bubble curtain is an effective and practical method and can be cost-efficient if adequately planned.

Today’s bubble curtain systems are robust and the entire handling of the bubble curtain can safely be done from only one vessel and without divers. The pipe-laying vessel is fitted with a driven winch, which is used to install a circular or elliptical nozzle pipe ring on the sea floor. By means of a pressure pipe that is long enough for the vessel to stay out of the danger zone the pipe ring is supplied with air. Compressors located on the vessel are used to supply air into the nozzle pipe. The air-supplying vessel is held in position by a dynamic positioning (DP) system to avoid anchoring on top of dangerous warfare materials.

Figure 15 Double bubble curtain as a protective measure against impulsive construction noise at offshore windfarm “Veja Mate” (© Hydrotechnik Lübeck GmbH).

In current systems, the operational depth of a bubble curtain is limited to a depth of about 40 or 50 m by the hydrostatic pressure and by currents. The optimum pressure difference between pressure inside the hose and hydrostatic pressure is 3 to 4 bar (Nehls et al., 2016). Further, sufficient air volume stream should be provided. At greater depth an increased air volume stream and thus more compressors are needed due to compressibility of air bubbles. During rising, the volume of the air bubbles increases causing them to split. Bubble drift by currents may require the use of an elliptical layout of the nozzle pipe. All of the currently available bubble curtain systems are reusable.

In the German EEZ, the use of bubble curtains is mandatory for the execution of detonations when offshore construction sites are secured by EOD companies against warfare materials hazards. Bubble curtains are also recommended by numerous nature conservation agencies in the United States for the protection of rare or commercially relevant fish species (Keevin and Hempen, 1997; Keevin et al., 1997; Keevin, 1998) and have recently been used in Norway to protect salmon in a commercial fish farm (Grimsbø and Kvadsheim, 2018). Bubble curtains were also used for clearance of warfare materials during installation of the Nord Stream 2 gas pipeline in the Finnish EEZ whenever the net explosive weight of warfare materials to be cleared exceeded 22 kg (Sitowise OY, 2018).

However, even a damped shock wave can harm marine life with the remaining pressure. Furthermore, it needs to be mentioned, that any detonation, especially of old warfare material, releases toxic warfare materials constituents into the water due to incomplete combustion. This cannot be prevented using a bubble curtain (Pfeiffer, 2009). When bubble curtains are used,
it is advised to use oil free compressors to avoid introduction of oil into the sea by the air stream.

In shallow waters, other dampening strategies could be applied. A part of the energy could be redirected to the surface by positioning the warfare material in a crater. However, this practise is much less effective than the use of a bubble curtain. Another approach may be lifting warfare materials and detonating them close to the surface (von Benda-Beckmann et al., 2015a). Furthermore, the placement of a rigid ring (cofferdam) around the warfare materials (rigid shockwave shaper) or an air cushion on the top (collapsible shockwave shaper) (Wallace, 1982) have been discussed as options. However, these approaches require further development and examination of their shockwave reduction potential.

4.4.4.3 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).

The range of customary gillnet pingers is only a few hundred metres, and they only deter certain species, such as the harbour porpoise (Culik et al., 2001). Dolphin deterrent device (DDD) pingers are louder and thus the deference distance for harbour porpoises can be assumed to be greater (Morizur et al., 2009; Kingston and Northridge, 2011). DDD signals have to be adjusted to the species, which is to be deterred from a detonation site. Systematic studies of the deterrent effect and range with respect to harbour porpoises are lacking.

Seal scarers are effective for harbour porpoises, but much less effective with respect to seals. Thus, it is not recommended to rely on the deterrent effect on seals. Mikkelsen et al. (2017) experimentally found that harbour porpoises exhibited avoidance reactions at ranges of up to 525 m from seal scarer signals at a reduced acoustic output. Contrary to this, seal observations even increased during sound exposure within 100 m of the speaker. Results of different studies with respect to seal scarer effectiveness to seals are contradictory (Jacobs and Terhune, 2002; Fjälling et al., 2006; Graham et al., 2009). The strong repellent effect on harbour porpoises has however been confirmed in multiple studies (Johnston, 2002; Olesiuk et al., 2002; Kastelein et al., 2010; Brandt et al., 2013a; Brandt et al., 2013b). For marine mammals, the motivation to exploit a food source, habituation and learning all seem to influence the scale of avoidance of seal scarers (Götz and Janik, 2010). In conclusion, electronic acoustic scaring devices are not suitable for deterring other species than harbour porpoises.

The effect of explosive scaring charges is not proven. So-called “fish scaring charges” of 20 g explosives were used during munitions clearance for the Nord Stream pipeline in the Baltic Sea (Nord Stream, 2011). Also on some mine hunting vessels, scare charges are part of the mitigation strategy. However, no flight response has been reported in numerous experiments conducted so far (Lewis, 1996; Keevin and Hempen, 1997). It is also questionable whether marine mammals can be safely scared away from a detonation site by use of scare charges as effects of scaring charges on marine mammals are inconclusive and not well understood (Jefferson and Curry, 1994; Continental Shelf Associates, 2004; Moore et al., 2006). According to the results of recent investigations in Fehmarnbelt, it must be assumed that harbour
Porpoises do not clearly react to small detonations as a deterrent measure (Wölfing 2020). There is clear evidence in mammals that a startle response is elicited by sudden intense acoustic stimuli (Yeomans et al., 2002). However, the startle response is mediated by a synaptic reflex and not the result of a behavioural decision such as avoidance or fear conditioning which would be needed for a deterrent device to be effective (Götz and Janik, 2011).

It should further be considered that, similar to the effect on human divers, even a charge of less than 20 g can be harmful to marine life at ranges of up to a few hundred metres (Young, 1991). Depending on the size of the charge, the species and distance between charge and the animal, scaring charges may thus contribute to injury or mortality. Moreover, in areas where detonations occur on a regular basis marine mammals or birds could be even attracted by scaring charges. They might learn that following such detonations, leads them to killed or debilitated fish, which are an easy to exploit food source. They could therefore be subsequently exposed to and killed by further explosions (Continental Shelf Associates, 2004; Danil and St. Leger, 2011).

In explosions of warfare materials with charges of a few hundred kilograms of explosives, the effective deterring range of neither of the scaring methods mentioned above cover the full impact zone of injury and hearing loss. The conclusion of these findings is that, due to the discrepancy between deterrent radius of devices and impact radius of detonations, scaring devices are only suitable as an additional measure for mitigation, e.g. in combination with a bubble curtain (see 4.4.4.2).

4.4.5 Salvaging

The best option for avoiding negative impact to the marine environment in general and marine vertebrates in particular is to recover the warheads instead of blasting them in place (Koschinski & Kock 2009). Some new methods and technologies have been presented at the three International Dialogues on Underwater Munitions and the MIREMAR conference (Minimising Risks for the Environment in Marine Ammunition Removal in the Baltic and North Sea, Neumünster/Germany, 16-18 November 2010, www.miremar.de) including remotely operated salvage robots, underwater jet cutting, in situ destruction in mobile detonation chambers or treatment of energetic compounds using ultraviolet radiation as well as transport or treatment in salvage pressure containers or reactors. However, all of them still require further development. With current technologies it is not always possible to use recovery methods, as certain ammunition items are not safe to handle. Detonations may be necessary when the safety of personnel dealing with the munitions cannot be adequately assured. The monetary expenses of utilising safe recovery methods rather than detonation, should not be the only determining factor because true costs (e.g., for environmental damage or damage/contamination of commercial stocks) may far outweigh the immediate expenses.

4.4.5.1 Extraction by Dredging

Extraction by dredging is the underwater surface abrasion of sediments and smaller UXOs. It constitutes a full volume clearance, during which a previously defined area is completely swept up to a certain depth. The dug-out material (dredge spoil) is analysed for UXOs, which are removed before the sediments are dumped again. As the BMUB catalogue (2014) explains, larger UXOs have to be identified and extracted before extraction by dredging takes place (e.g. manually by divers). For the dredging process, safety standards are to be chosen in a way that loss of equipment and injury of workers can be excluded. Therefore, the largest potential
explosion (unintended, due to the mechanical stress during dredging) has to be anticipated (BMUB and MMVg, 2014).

Dredging operations can be performed with clamshells (dredge spoil is loaded on tug) or suction (dredge spoil flushed through pipes) (Schwartz and Brandenburg, 2009). The separation of explosive items can be done either by using a strainer with a mesh size appropriate to filter out the smallest relevant UXOs (to be defined beforehand based on survey and UXO identification) or by a combination of geophysical measures (magnetometer) and eye-sight (BMUB and MMVg, 2014). Disadvantages of dredging include the very high costs, heavy disturbance (destruction) of local marine environment, and increased efforts for workers' safety given that spontaneous detonation cannot be disregarded as a possible risk (BMUB and MMVg, 2014).

4.4.5.2 Extraction by Electromagnets

The procedure of utilizing underwater electromagnetic extraction of UXOs, another full-surface recovery, is described by BMUB and MMVg (2014) as follows: Electromagnets with built-in flushing nozzles are fastened to a swimming platform (ship or pontoon) and lowered to the seafloor, where waterjets from the flushing nozzles drive the magnets into the ground. The maximum penetration depth depends on the seafloor sediment characteristics and usually does not exceed a few decimetres. Magnetic material is pulled towards the electromagnet and is thereby separated from the soil. New technologies allow monitoring and preventing possible losses during the extraction movements, where friction- and weight-induced resistances have to be overcome by the electromagnetic force. The extracted material is then brought up on the platform and UXO is separated from scrap material. Protection against spontaneous detonation has to be ensured. Several limitations have been detected by BMUB and MMVg (2014): The use of Electromagnets is only suitable for near-surface extraction in relatively loose sediments. Uncontrolled movements of explosives can lead to detonations and (with older equipment) to loss of items. Due to a magnetization of the area, a follow-up magnetometer scan is not possible. If the munitions casings are heavily corroded, explosive material may remain in the sediment or drop out when lifted.

4.4.6 Transport

Ordnance that is not safe to handle (e.g. with an armed fuse or a sensitive main charge such as picric acid) shall not be recovered aboard a manned vessel unless an appropriate containment system is used to mitigate the risk to personnel. (UNMAS, 2014). A general problem of the surfacing of munitions from deeper water levels is the sudden change of ambient pressure, which may for some explosives lead to spontaneous detonation, or for heavily corroded shells to mechanical failure and leakage (Pfeiffer, 2012). The use of transport containers mentioned above addresses this problem. Another risk posed by the surfacing and transportation on ship and land is the drying of UXOs. Pfeiffer (2012) describes that the complex and often unclear chemical constitution of old munition can potentially react when dried, therefore arguing for deliberate wet arrangements (Pfeiffer, 2012).

Munition that is not safe to transport but safe to handle under water, may be moved under water, in order to remove munition from the vicinity of infrastructure or to perform a consolidated detonation of several munition items, or a detonation in a less sensitive place (e.g. on a sand bank or in a confined area). If it is not safe to handle ammunition under water, currently the only option is to blow it in place (BIP).
A major advantage of BIP is that no handling or transportation of the UXO is required. Due to the small number of exposed workers, BIP is considered a very safe disposal method very safe for personnel (Schwartz and Brandenburg 2009).

### 4.5 Other Tools

#### 4.5.1 Monitoring

Since 1979 monitoring has been established as part of the Helsinki Convention and has also been addressed by the Baltic Sea Action Plan (BSAP) (HELCOM, 2007). To fulfil the Marine Strategy Framework Directivity (MSFD) European states need to monitor their national waters and determine the Good Environmental Status (GES) of local habitats (Zampoukas et al., 2014). As munition dumpsites inevitably became part of the marine environment and TNT is part of the list of chemical contaminants in the marine environment (Tornero and Hanke, 2016, 2017), which require monitoring, all kind of processes related to them need to be analysed and understood (Zampoukas et al., 2014). Generally defined as a permanent observation of a system or processes, monitoring allows detection of long-term changes and developments, which are not possible via single measurements. Sea-dumped munitions monitoring should ideally provide information on condition, migration and spreading of munition shells, release and spreading of toxic compounds into the environment and uptake of toxic compounds into the food web, including seafood consumers.

Moreover, data from a successful monitoring may not only serve for observation purposes, but provide data for prediction models, risk assessment and risk-management analyses as it will be incorporated inside the ‘Decision Support Tool’, developed within the DAIMON project.

All three topics have been processed by the German UDEMM project (BMBF funded) for a shallow water dumpsite containing conventional munition in the Baltic Sea. In parallel, continuous research of CWA dumpsites is performed by CHEMSEA, MODUM and DAIMON projects. Base line studies prior to monitoring, help to characterize dumpsite areas regarding seafloor properties, munition occurrences, hydrodynamic forces, habitats and physical-chemical properties and have been performed by Czub et al. 2018; Kampmeier et al., 2020. Based on such studies, suitable methods and sensitive areas were identified for a long- and short-term ad-hoc monitoring on various scales ranging from feature scale (<100m; munition objects and cluster), local scale (100 – 3,000m; munition dumpsites) to regional to coastal scale (>3,000m; bays and entire coastlines). Ideally, all three spatial levels should be considered in a full monitoring set-up.

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 **samplers** 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 analyze 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 makes it possible to analyze 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). The term biomonitoring is used inter alia in ecology to describe the periodic measuring of the stock and state of health of organisms as well as their communities with the aim of determining the quality of environmental conditions. Modern analytical methods enable detection of many pollutants in very low, ecologically relevant concentrations.

For a marine monitoring water and sediment samples can be analyzed and the measured concentrations of a pollutant like explosive chemicals, CWA or (heavy) metals can be used to evaluate the severity of contamination in a specific area with dumped munitions. Nevertheless, the presence of contamination with regard to its impact on the environment is generally not meaningful and do not answer the question if these compounds enter marine biota and/or accumulate in the marine and human food web.

Biomonitoring is differentiated in active and passive biomonitoring. For a passive biomonitoring, marine animals are collected in suspected burdened areas and analyzed 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 site 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.

The difficulty of performing an active biomonitoring is the clever choice of a suitable species. The test organism should, on the one hand, be able to accumulate the contaminants coming into question and should, on the other hand, be robust enough to survive in the test area throughout the study.

For a number of reasons mussels (bivalves) are particularly suitable for the detection and monitoring of chemicals that leach from corroding munitions in the marine environment. Mussels are widespread representatives of the marine fauna, they are benthic and sedentary organisms and they constitute a main source of food for fish, birds, crustaceans and starfish. In addition, their filter feeding lifestyle and their slower metabolic rate favour the absorption and bioaccumulation of explosives. Further, they are a resistant species, which can thrive even in unfavourable conditions. Finally, bivalves are important sea food species and can be used as indicators for the entry of toxic substances into the marine food chain even at low concentrations. Biomonitoring with mussels offers the opportunity for long-term studies to predict potential risks for the ecosphere and for human seafood consumers (Farrington et al., 2016; Salazar and Salazar, 1995). Mussels are used in national and international mussel watch programs since more than 40 years to monitor a wide spectrum of contaminants (Farrington et al., 2016), e.g. heavy metals, pesticides, persistent organic pollutants (POPs) and pharmaceuticals (Regoli et al., 2016; Álvarez-Muñoz et al., 2015; Zuykov et al., 2013). During the last years it turned out that mussels are very suitable bioindicator species for the monitoring of explosives and CWA (Strehse and Maser, 2020).

Within the frame of the CHEMSEA Project blue mussels (Mytilus edulis) were deployed in the dumping area of Bornholm and analysed for CWA, CWA metabolites and a selection of biomarkers (Beldowski, 2014). The first biomonitoring with blue mussels (Mytilus spp.) for explosive chemicals was established in the German dumping ground of Kolberger Heide. The area served as test site to develop new methods and workflows for detection, monitoring and assessment during the German project UDEMM. Divers placed moorings with mussel bags at varying positions near a pile of about 100 moored mines distributed over an area of approximately 70×30 square metres. After recovery, the bioconcentration levels of 2,4,6-trinitrotoluene (TNT) and its main metabolites 2-amino-4,6-dinitrotoluene (2-ADNT) and 4-amino-2,6-dinitrotoluene (4-ADNT) were measured successfully in mussel tissues by using a GC/MS-MS analytical method (Maser and Strehse, 2020; Appel et al., 2018; Strehse et al., 2017). This method is described in detail within the ‘Practical Guide for environmental monitoring of conventional munitions in the sea’ (Greinert (Ed.), 2019) and could serves as an orientation guide for future monitoring projects.
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4.6 Case studies

4.6.3 Case study 1: Kriegers Flak Offshore Wind Farm

4.6.3.1 Project background

The Kriegers Flak Offshore Wind Farm (OWF) is located in the Danish Baltic Sea ca. 13 km off the island of Møn, Denmark, and will produce up to 600 MW (Reference to overview map). The European Energy company Vattenfall own and operate the wind turbine generators (WTG) and inter array cables, whereas the Danish Transmission System Operator, Energinet, own and operate the substations and export cables. The decision to establish Kriegers Flak OWF was taken in March 2012 by a broad coalition of political parties in Denmark and Energinet initiated baseline investigations and the Environmental Impact Assessment to be included in the tender for concession. Parallel to this, Energinet began planning and design of the substations and export cables. Vattenfall won the concession in 2016 and started the detailed planning and design of the OWF (maybe reference to timeline).

4.6.3.2 UXO Risk mitigation

Unexploded Ordnance (UXO) risk mitigation has been performed on all locations where seabed interactions were planned for the offshore installations by Energinet and Vattenfall, respectively. The risk mitigation builds on desk studies, risk assessments and data requirements detailed by specialist consultancies. The mitigation by both companies builds on the ALARP principle, i.e. that the risk is reduced to a level that is As Low As Reasonably Practical.

Desk studies were performed for the OWF site and the export cable routes until landfall by consultants specialized in UXO risk mitigation. The desk studies looked at the historic contamination in the area, and the planned installation activities’ risk was assessed against different types of ordnance potentially present in the area, identifying the Minimum Threat Item, i.e. the smallest item likely to be present in the area which poses a threat to the offshore installation activities. For the substation areas the minimum threat item was the German 250 kg SC bomb and for the WTG installation zone the British 250 lb general purpose bomb was identified. For the export and inter array cables it was the German EMD mine, which was identified as the minimum threat item (maybe reference to figure). A geophysical survey was designed to enable detection of the identified minimum threat items and larger items, using magnetometry (as only ferrous objects were identified to be present in the area), side scan sonar and multibeam bathymetry enabling detection of both buried and surface items.

The geophysical survey for the export cable routes and the substation area was performed by Energinet in 2016 and for the wind farm area the survey was conducted by Vattenfall in 2017. The data from both survey campaigns was analyzed and magnetic targets were picked. The magnetic targets were evaluated in relation to the minimum threat item and potential UXO (pUXO) targets was appointed. Before selecting targets for physical inspection using a ROV (remotely operated vehicle), a rerouting exercise was performed to avoid as many targets as possible, given that avoidance was the preferred risk mitigation strategy for both companies. This resulted in inspection of 85 pUXO targets for the export cable routes and substation installation areas and 170 pUXO targets for the WTG and inter array installation areas, locating five and two confirmed UXO items, respectively (maybe reference to picture of found UXO).

All confirmed UXO items were successfully disposed of by the Danish Navy EOD Services.
After the successful geophysical survey, inspection and EOD campaigns the results were evaluated by specialized consultants and an ALARP certificate was issued per asset to be installed, confirming that all reasonable mitigation actions have been performed and the risk to installation activities have been reduced to ALARP.

4.6.3.3 Discussion

The risk mitigation strategy applied for the Kriegers Flak OWF and grid connection illustrates some key areas to focus on for offshore risk mitigation.

Project risk profile. Working with the heritage from war or military activities in the marine environment is very different from the situation onshore. For terrestrial construction projects it is common practice to carry out mine clearance operations leaving sites completely free of munition items. For offshore projects it may require a disproportional amount of time and resources to guarantee a site being completely free of munition items. Therefore, project risk managers are encouraged to accept working with the ALARP principle when mitigating the threat from munitions in the marine environment. It improves the process to have a clear risk profile early on in an offshore construction project, where the potentially present types of munition are related to the planned activities enabling the compilation of a proportional mitigation plan detailing survey requirements and other mitigation measures to achieve ALARP.

Timing of activities. A successful UXO risk mitigation process starts with careful planning of the activities to be performed and early identification of the threat level for the site. The project benefits from performing initial UXO desk studies and risk assessments at the earliest convenience as it is important to plan marine UXO activities such that UXO survey and EOD campaign are performed in a timely manner before commencement of construction activities. Where the seabed is dynamic with e.g. sand waves this issue becomes increasingly important.

Organization. Managing the UXO risk requires an organization with capacity to understand the risk, procure surveys and EOD services as well as processing results in Geographical Information Systems. A concessionaire or developer should ensure availability of such resources in the organization. Alternatively, it may be considered to leave the UXO risk management and mitigation to the installation contractors.

Scope for EOD campaign. A challenge often encountered during the UXO risk management process arises when the results of a geophysical UXO survey are translated to the scope for an inspection and EOD removal campaign. The UXO survey itself rarely identifies UXO items with high certainties. Instead a list of target locations is found to indicate the presence of pUXOs. Subsea inspection of buried items consumes significant amount of time and money. An effective way to limit and control the scope of the inspection and EOD campaign include a careful examination of the list of targets performed by qualified specialists.

4.6.3.4 Recommendations

Both Vattenfall and Energinet learned that the ALARP-based approach to manage the UXO risk establish a least cost and least time impact on the project execution. Furthermore, the companies prefer to “own” the UXO risk management process instead of leaving the responsibility to installation contractors. Finally, both companies aim at commencing the initial UXO desk study in early project stages to allow project managers to take real decisions related to the UXO risks.
Warfare Materials in the Baltic Sea – Model Chapter Germany

Vattenfall and Energinet encourage developers of marine infrastructure projects to take advantage of described experiences.

### 4.6.4 Case study 2

#### 4.6.4.1 Introduction

The eastern part of the German Baltic Sea can be considered as a high priority area for wind energy, hence, several Offshore Wind Parks (OWP) were planned in the Exclusive Economic Zone (EEZ) in recent years.

In May 2014, a German transmission grid operator, responsible for the grid connection of the offshore wind farms within the 12-mile zone (12-sm zone) and the German EEZ in the Baltic Sea, awarded the contract for the production and laying of the submarine cables for the "PROJECT" cluster grid connection to an Italian cable manufacturer.

Subsequently, Heinrich Hirdes Explosive Ordnance Disposal (HH EOD) was contracted for the UXO survey, identification and clearance operations along the export cables routes. The scope of the works to be performed comprised all services required for the construction of a predefined corridor cleared from potentially hazardous explosive ordnance in accordance with German legislation and the requirements from the client.

This case study summarizes the UXO clearance operations during the above-mentioned project which was completed successfully by HH EOD from 2014 to 2016 in the Baltic Sea. The clearance concept involved mainly the use of work class remotely operated vehicles (WROV) and divers for very shallow waters. The clearance corridor varied in between 20 and 230 m along the export cable routes.

The project was particularly interesting due to a variety of operational and technical challenges, which are outlined below. All of these could be approached and solved successfully by the involvement and good cooperation of several parties, suppliers and the utilization of many different survey and clearance equipment suites/techniques.

#### 4.6.4.2 Water depths

Due to the great variation of water depths along the planned cable routes and the associated requirements, several vessel units with different specifications were deployed for the survey, explosive ordnance detection and clearance activities. At the peak of the project at the beginning of 2016, up to ten different vessels (including guard vessels and auxiliary units) were operational for the project, all subject to thorough marine coordination.

One of the biggest challenges was the necessity to clear targets in very shallow water depths at around ~3 m, whilst trying to maintain a high productivity. Over the course of the project, specialized positioning techniques were developed and installed on the ROVs, in order to enable ROV based clearance solutions to operate in waters up to 3.5 m, which was not possible before.

Bad subsea visibility is one of the common challenges, which needs to be taken into account for offshore UXO clearance projects. On all HH EOD projects, state of the art sonar technology is being installed on the ROVs to enable UXO experts the identification of potential UXO items.
4.6.4.3 Boulder fields

During the review and assessment of the initial survey data (by means of passive magnetometry), it became apparent that large sections of the project area were covered with boulder fields showing very high magnetic responses.

Stones (especially boulders made of granite, gabbro, etc.) often have a magnetic signature similar to that of explosive ordnance or metal objects. A distinction between explosive ordnance/metal and stones from magnetic measurement data is therefore not possible or only possible to a very limited extent because of the low, insufficient physical contrast in this respect.

A physical contrast, however, is evident in the electrical conductivity of the different bodies. UXO and other metal objects have an electrical conductivity that is approximately five orders of magnitude higher than that of stones/geological features. This physical contrast can be used to distinguish between stones and metal objects (ferrous and non-ferrous metals) by (active) metal detector systems.

Therefore, a large-scale survey by means of active Time Domain Electro Magnetic (TDEM) was performed on the boulder fields which resulted in the discrimination of relevant UXO targets and irrelevant geogenic anomalies – the number of target locations to be investigated could be reduced significantly. Figure X shows the comparison of anomalies based on MAG (left) and TDEM (right).

![Figure 16: Comparison of anomalies based on MAG (left) and TDEM (right)](image)

The combined use of passive gradiometer multi-channel systems (fluxgate magnetometers) and active TDEM detectors was used to detect explosive ordnance. Magnetometry data served as a basis for UXO investigation in areas where no boulder fields obstructed the single object evaluation. Where magnetometry showed boulder fields and cluttered areas, the more time-consuming approach of EM data acquisition was used to distinguish boulders from metal objects and again enable single object evaluation. Thereby, the combination of the two different detection methods ensured optimum object evaluation for the determination of potentially dangerous explosive ordnance.
4.6.4.4 UXO

The project was characterized by a high density of ammunition finds, in total 3553 suspicious target locations were investigated for the presence of possible explosive ordnance in accordance with the assignment. 378 targets were identified as explosive ordnance; depending on the assessment of their transport and handling safety, these were either recovered and handed over to the governmental authorities or demolished on site.

Among the identified explosive ordnance, the majority were grenades of various calibres, including 37 times 20 - 37mm, 70 times 37 - 88mm and 230 times 88 - 150mm, mainly of German and Russian origin. In addition, several large explosive ordnance items were identified, including five water bombs, three rockets or parts thereof and nine bombs of various types. Six of the bombs were identified in the shallow water area as HS293 Henschel gliding bombs. In addition, seven empty ammunition cases and twelve different explosives, detonators or pyrotechnics were found and recovered.

A total of 10,805 kg of conventional ammunition was transferred in the project, with a net explosive mass (NEM) of 1860 kg.

4.6.4.5 Suspected chemical agents

At one target location, a presumed mine bomb SC500B was identified, which was classified as not safe to handle and thus designated for in-situ demolition.

An explosive charge was subsequently placed on the UXO by means of a ROV in order to bring it to detonation in a controlled manner.

During the as-left inspection of the blasting site, it became apparent that the explosive ordnance had not been fully implemented as planned, rather the outer shell had only burst open, a yellowish, wax-like mass was visible inside the bomb’s body. Furthermore, the marine growth on the bomb was removed by the pressure wave of the detonation, thus very unusual constructive characteristics of the bomb became recognizable.

At that time, it could not be ruled out that the contents of the bomb could consist of a chemical warfare agent. For safety reasons, the operations were ceased immediately, the ROV was recovered and decontaminated.

After the discovery, it was decided to take a sample of the filling in compliance with all given safety standards for laboratory tests. Luckily, the tests revealed that the ingredient was not a warfare agent, but probably an experimental incendiary substance (not self-igniting). The remains of the UXO could thus be recovered without hesitation and handed over to the governmental authorities.

Although there was no direct suspicion of chemical warfare UXO items in the project area, the offshore project team was prepared for the worst-case scenario.

4.6.4.6 Recommendations

- The project highlighted the importance of a tailor made UXO clearance concept, which needs to be developed prior to the operations in order to be prepared for the highly diverse environmental parameters on site and to meet the specific project requirements of the client.
- Combination of several survey and clearance methodologies is important.
Time and effort should be spent on the survey activities prior to the clearance campaign, a larger survey corridor might generate flexibility for rerouting around potential target clusters.

Once a relevant UXO target is identified, it should be properly disposed of rather than lifting and shifting it outside the corridor as this might complicate future activities in the area.

UXO risk assessment should be in place in order to define reasonable UXO thresholds. Important questions: Which types of UXO could do harm to assets and personnel during future activities? What is the nature of the activity and which equipment is involved?

Continuous research towards new and innovative clearance methods is required, to offer customers fast and efficient explosive ordnance clearance solutions in the offshore sector.
5. National and International Efforts and Activities

The national and international efforts and activities are grouped according to the relevant International Governmental Organizations (IGOs) and HELCOM member states. Each of the IGOs and HELCOM member states is covered in a separate chapter, each of which follows the same structure. First relevant authorities are introduced and the legal situation is outlined. Next ongoing management activities (as covered in chapter 4 of this assessment) are described. The third section always addresses other ongoing activities, such as expert groups, political initiatives and long-term research. The fourth section deals with current scientific and technological development projects that are publicly funded. Finally, past activities and noteworthy research projects are highlighted.

The first section of each IGO or HELCOM member state addresses the relevant authorities by applying unified terminology for certain activities that are relevant to submerged warfare materials and introducing those public bodies that are responsible for these activities or supporting them. It presents these public bodies and activities in the form of a matrix. The following table defines the activities that are address in the matrixes. If an activity is not mentioned in a specific matrix, this activity is not relevant to that IGO or state.

5.1 United Nations
- Correspondence
  - As of 08 October 2008 (A/C.1/63/4)
- Resolution adopted by the General Assembly
  - On 20 December 2010 (65/149)
  - On 20 December 2013 (68/208)
  - On 21 December 2016 (71/220)

5.2 NATO

Ongoing activities are related to NATO units, especially the Standing NATO COUNTERMEASURE GROUPS that are conducting historic ordnance disposal operations (HOD) as one of their regular tasks. In addition, there are regularly scheduled manoeuvres of and with naval forces of the member states to reduce risks to humans and infrastructure posed by munitions and explosives of concern in European marine water bodies.

Beside that NATO’s Science for Peace and Security (SPS) Programme has funded the project MODUM. The Science & Technology Organisation (STO) has recently appointed a research task group “Impact of munitions and explosives of concern (MEC) on maritime safety, security and sustainable remediation” (AVT-330) expected to finalise a report by End of 2021.

5.3 European Union

Regarding the tasks according to treaty of the European Union, aspects related to “munitions in the sea” are interacting with various fields. So far, no clear leadership can be recognized nor within the European Parliament neither the European Commission.

However, some European Directives are clearly addressing related aspects and thus both the European Commission and the Governments of the Member States are concerned.
5.3.1 Authorities and Legal Situation

Maritime spatial planning

Maritime spatial planning (MSP) works across borders and sectors to ensure human activities at sea take place in an efficient, safe and sustainable way. That is why the European Parliament and the Council have adopted legislation to create a common framework for maritime spatial planning in Europe. (DG MARE)

Integrated Coastal Zone Management

Coastal zones are among the most productive areas in the world, offering a wide variety of valuable habitats and ecosystems services that have always attracted humans and human activities. The beauty and richness of coastal zones have made them popular settlement areas and tourist destinations, important business zones and transit points. Currently, more 200 million European citizens live near coastlines, stretching from the North-East Atlantic and the Baltic to the Mediterranean and Black Sea. (DG MARE)

European Habitat Directive

Together with the Birds Directive, it sets the standard for nature conservation across the EU and enables all 27 Member States to work together within the same strong legislative framework in order to protect the most vulnerable species and habitat types across their entire natural range within the EU. (DG ENV)

Marine Strategic Framework Directive


Since than numerous activities to define and increase the quality status of marine habitats where undertaken. Some Member States have included munition related aspects in their national implementation programmes, following the recommendations of JRC as of...

In Invitation of the EEAS and DG ENV a colloquium “The Challenges of Unexplodes Munitions” (Brussels 20 February 2019) has addressed concerns in line with DG HOME, MOVE, MARE, DEVCO and many regional and national entities, active in marine nature conservation.

5.3.2 Ongoing Management Activities

5.3.3 Other Ongoing Activities

JPI Oceans

On European level, Joint Programming Initiatives (JPI) are the result of structured and strategic process of voluntary agreement, on common visions in order to address major societal challenges, by EU member states, associated countries and international partners. JPI Oceans focuses on achieving a state of healthy and productive seas and oceans.

As a result of discussions between the most relevant stakeholders, it has been decided that JPI Oceans will conduct activities along three lines:

Science Support- By combining different scientific disciplines, JPI Oceans intends to support the development of a service to forecast changes in the sea state in relation to munitions.
Simulation of the impact of removal, dispersion and detonation on human health, on the environment, and on economic activities will also be investigated.

Technology Transfer- JPI Oceans will analyse different technologies and procedures for intervention to support decisions by operators and policy makers. The development demonstration of technologies and procedures can be used to increase safety, improve the efficacy and reduce the environmental impacts of interventions. JPI Oceans will provide support to exchange findings between different disciplines, projects and initiatives.

Exchange of Knowledge- Panels of experts will support transfer of knowledge and experiences of dealing with munitions in the sea.

5.3.4 Current Projects

INTERREG-DAIMON

DAIMON (Decision Aid for Marine Munitions) is an international project consisting of partners from Poland, Germany, Sweden, Finland, Norway, Lithuania and Russia, and cooperating experts worldwide, united by the goal to solve the problem of underwater munitions. This project is part-financed by the EU INTERREG Baltic Sea Region Programme 2014-2020. The question which DAIMON takes up is how to proceed with the identified and mapped warfare objects. Remediation or no action are subject to heated disputes among the decision-making bodies. Since there cannot be a general answer to this question, DAIMON will analyse identified and localized objects with artificial intelligence incorporating large amounts of spatial and non-spatial datasets based on latest scientific research. For each detected munition object, the software will formulate a risk assessment, incorporating information about the localization and overall state of the ammunition, the surrounding environment and state of biological pollution/damage. Furthermore, it will recommend possible actions, such as recovery & destruction, accumulation, encapsulation, capping, blasting or non-action. DAIMON follows an integrative approach and incorporates the results of former projects (e.g. CHEMSEA) for an efficient use of data and a consequential development of knowledge.

5.3.5 Past Projects and Activities

INTERREG-CHEMSEA

CHEMSEA investigated official and unofficial dumping sites using hydro-acoustic detection and magnetic surveys to find links between objects on the seabed and magnetic field disturbances, to examine currents and to sample sediment so as to characterise the natural conditions of the sites. Mapping involved categorising objects, selecting those needing further investigation and feeding coordinates of munitions and contaminated sediment into maps. Toxicity studies aimed to investigate biological uptake of chemical warfare agents (CWA) under varying conditions. Cages were deployed where the concentration of munitions was highest before accumulation and biological effects of chemical substances in fauna were measured. CHEMSEA reviewed national CWA legislation and formulated guidelines for munition handling as well as hazardous waste and contaminated sediment disposal. A regional contingency plan was drawn up comprising of codes of conduct in the event of an accidental catch of chemical munitions at sea or their being washed up onshore. Models were developed for both scenarios, leading to the standardisation of national response procedures and plans. Awareness levels of groups at risk of contact with CWA were evaluated, including fishermen and offshore workers. Training was aimed to spread knowledge of chemical munitions dumped at sea along with best practices for minimising threats.
MODUM

The Monitoring of Dumped Munitions (MODUM) project aimed to establish a cost-effective monitoring network to observe munition dumpsites in the Baltic Sea, using Autonomous Underwater Vehicles (AUVs) and Remotely Operated Underwater Vehicles (ROVs), and utilizing research vessels of partner institutions as launching platforms.

Information: http://www.iopan.gda.pl/MODUM/

MERCW

5.4 Russian Federation

5.5 Denmark

5.5.5.1 Authorities and Legal Situation

The Royal Danish Navy

Contact: E-mail: fko@mil.dk, Phone: +45 7284 0000

Further information: https://www2.forsvaret.dk/eng/Organisation/Navy/Pages/Navy.aspx

Danish Defence’s Joint Operations Centre

Contact: E-mail: E-mail: fko-joc@mil.dk, Phone: +45 7281 2300

Further information: https://www2.forsvaret.dk/omos/organisation/operationsstaben/operationscenter/Pages/default.aspx

Danish Emergency Management Agency

In case of bycatch of chemical munitions, the responsibilities of the Danish Emergency Management Agency (DEMA) are to:

- The regional DEMA Rescue Centre performs the cleaning of the vessel.
- The Duty HazMat Officer from DEMA Chemical Operation gives advice on chemical warfare agents.
- The DEMA Chemical Operation can perform chemical analysis of bycaught chemical warfare agents.

Contact: E-mail: brs@brs.dk, Phone: +45 4590 6000

Further information: https://brs.dk/eng/Pages/dema.aspx

The Danish Fisheries Agency

In case of bycatch of chemical munition, the responsibilities of the Danish Fishery Agency are to:

- Estimate the value of the fish catch in case an economic compensation is required.
- Provide the Royal Danish Navy with information on location of bycatch.
- Ensure contaminated fish are not released for sale.
- Assess in collaboration with the Danish Emergency Management Agency if the cleaning procedures have been sufficient for the vessel to be released to continue its fishing activities.
- Ensure rightful depreciation of the fish quotas.
Laws and regulations

The following ministerial orders apply to the issue of warfare materials in the sea:

- Ministerial order concerning landing of fish from areas with chemical munition (Ministerial order no. 775 of 10/08/2009) (The Danish Veterinary and Food Administration). This order only covers the ICES subdivision 24-32 in the eastern part of the Baltic Sea.
- In case of bycatch of chemical munition, the procedures described in Ministerial order no. 775 of 10/08/2009 have to be followed. The bycatch is reported to the Danish Defence’s Joint Operations Centre that informs the Danish Fisheries Agency’s local unit in Rønne about the vessel ID and which harbour it will enter to be cleaned. A representative from the Danish Fishery Agency will be present onboard the vessel.
- Ministerial order concerning sailing safety during entrepreneur work and other activities in Danish waters (Ministerial order no. 1351 of 29/11/2013) (Danish Maritime Authority)
- Ministerial order concerning ban against sailing, anchoring and fishing etc. in certain areas of Danish waters (Ministerial order no. 135 of 04/03/2005) (Danish Maritime Authority)

Note that the ministerial orders apply to different geographical judicial areas. Some apply to Danish coastal waters, some include the EEZ and some only refer to sub areas of these.

In addition to the ministerial orders mentioned above, the Danish Fishermen’s Occupational Health Services have provided documentations on precautions and on first aid related to the bycatch of munitions that should be followed.

5.5.5.2 Ongoing Management Activities

Ongoing activities on munition assessment
None

Clearance methods
In general historic ordnance/explosives are assessed to be unstable and relocation impairs unacceptable risks. Thus, the typical disposal is typically by blasting by the Royal Danish Navy’s Clearing Diving Team.

**Historic files studied**

No published studies.

**Number of items cleared**

The number of items encountered and cleared (blasted) in the North Sea are reported annually to OSPAR according to their reporting guidelines. There is no similar reporting scheme to HELCOM. The Danish Environmental Protection Agency is responsible for the reporting.

**Funding of the activities**

The Danish Government

5.5.5.3 **Other Ongoing Activities**

Denmark continues to participate and contribute to the HELCOM and OSPAR work on the topic. The Danish Environmental Protection Agency and the Danish Centre for Environment and Energy are represented in the HELCOM Submerged working group. In general, Denmark will continue to be supportive towards achieving a common approach for management of warfare materials in the sea in the regional conventions.

The Danish Centre for Environment and Energy (part of Aarhus University) is involved as expert group on the subject and act as technical support for the authorities.

5.5.5.4 **Past Projects and Activities**

The Danish Centre for Environment and Energy (part of Aarhus University) participated in NATO funded research in the Baltic Sea with partners around the Baltic in the project “MODUM – Towards the monitoring of dumped munitions threat” and published findings on the topic.

5.6 **Estonia**

5.6.5.1 **Authorities and Legal Situation**

Governmental agencies operating at sea or having tasks related to the maritime domain based on national legislation are as follows:

- Defence Forces (www.mil.ee)
- Rescue Board (www.rescue.ee)
- Police and Border Guard Board (www.politsei.ee)
- Maritime Administration (veeteedeamet.ee)
- Heritage Board (www.muinsuskaitseamet.ee)
- Environmental Board (www.keskonnaamet.ee)
- Environmental Inspectorate (www.kki.ee)
- Estonian Emergency Response Centre (www.112.ee)

Each of the mentioned respective agencies have their own tasking varying from state defence, maritime security, maritime safety, environmental protection to preservation of national heritage objects (including wrecks etc.).

**Cooperation between Estonian Navy and Rescue Board**

Based on national legislation, the Estonian Navy (part of Estonian Defence Forces under the Ministry of Defence) has the sole responsibility to react to situations connected to historic and
modern warfare materials, when such situations occur in the maritime domain. However, a very close cooperation with the Estonian Rescue Board (operating under the Ministry of Interior) is ongoing.

The Rescue Board deals with explosive material, munitions and ordnance on land. When explosive material, munitions and ordnance is located in harbour areas or inland water bodies Estonian Navy and Rescue Board cooperate, assisting each other with their respective capabilities and expertise.

Emergency Response Centre

For the public a single 24/7 initial point of contact is the Estonian Emergency Response Centre (112) where citizens shall report all encounters with possible warfare materials both on land and at sea.

Laws and regulations

Currently there is no overarching single permanent legal act in place to cope with all possible challenges when dealing with warfare materials. There are however a number of interagency cooperation agreements that provide a sufficient basis.

5.6.5.2 Ongoing Management Activities

There are currently no dedicated governmental funded long-term national projects or programmes to systematically and effectively deal with the challenges posed by remaining warfare materials in the sea.

BOSP membership

Activities dealing with the issue of warfare materials left form the previous armed conflicts within the current limits of maritime areas falling under Estonian jurisdiction are in conjunction with the activities of Estonian Navy. Estonia is a member of BOSB (Baltic Ordnance Safety Board) and based on collective effort carried out within the framework of BOSB regular, targeted historic ordnance disposal activities take place in a form of both multinational mine/ordnance clearance activities and national activities carried out by Estonian Navy.

OPEN SPIRIT

The OPEN SPIRIT series of activities rotates between respective Baltic nations in such a manner Estonia hosts this activity every third year. The Estonian Navy is making an effort to combine its national mine countermeasure training activities with domestic efforts to gradually, on a tailored, systematic and effects-based approach, reduce possible risks to maritime safety and infrastructure posed by warfare materials. These activities are targeted to most risk prone areas. However, they are time and resource consuming. Hence, given the best available knowledge regarding the likely amounts of warfare materials in the sea, these activities will most likely continue to a near future.

Construction Projects

The Estonian Navy regularly advises different governmentally owned and commercial entities, both international and domestic, who have interest in maritime infrastructure development projects within Estonian waters. Examples of such projects could be harbour construction and dredging works, laying of underwater communication and electricity cables, underwater pipelines, different types of aquaculture, offshore wind farms and other similar developments requiring work carried out on the seabed. A number of case-by-case assessments are
conducted yearly to advice the above entities on the possible risk areas and risks posed to underwater construction by warfare materials in the sea.

5.6.5.3 Past Projects and Activities

Structured surveying and clearance

A number of dedicated warfare material clearance activities have taken place within the Estonian maritime area since 1994. The very first of such events took place in 1994, when the Estonian Navy together with the Royal Swedish Navy charted a number of previously known Soviet era explosives dumping grounds within the Estonian maritime areas in the Gulf of Finland area near Tallinn and Paldiski. Afterwards a series of MCOPEST (in total 5), OPEN SPIRIT (in total so far 8), FINEST (in total 3) activities and a vast number of different national, bi-lateral and international historic ordnance disposal activities were carried out in Estonia under the lead of Estonian Navy. The result of these activities is that about 1200 items of warfare materials of different types were located and identified but due to different objective reasons only about one third of them were cleared. Most of the located and identified warfare material left in place are either in water depths great enough not to pose a risk to surface shipping or have been located in close proximity to different existing underwater installations (namely underwater cables).

Construction projects

In recent years a number of different calibre warfare materials (ranging from naval mines, costal artillery shells to small calibre munitions) have been located during harbour construction and corresponding dredging works. These types of situations have significantly improved the cooperation on a national level between different national authorities, namely Estonian Navy and Estonian Rescue Board.

Societal Awareness

There are currently no dedicated governmentally funded long-term projects or activities ongoing in order to raise the societal awareness regarding possible munitions and ordnance.

The Estonian Ministry of Interior together with the Rescue Board carries out seasonal public media campaigns with the aim of instructing public and citizens on how to act when possible warfare materials are found (call 112 or specific phone number found on the Rescue Board website). These activities generally target population on land as there is a significant amount of land-based warfare materials found yearly.

The Estonian Navy carries out information days with the aim of raising awareness within specific target audiences. Main target group for these information days so far were primarily civilian leisure and hobby divers who may come into contact to historic munitions at sea.

As a joint agreed venture between the Estonian Navy and the Maritime Administration all navigation material (including navigation charts) published by the Maritime Administration has a notice on them stating that all maritime areas currently under Estonian jurisdiction should be considered as Former Mined Areas.

5.7 Finland

5.7.5.1 Authorities and Legal Situation

Finnish Defense Forces
The clearance of wartime materials (including chemical weapons) is in responsibility of Defense Forces by law (Explosives Decree 28.5.1993/473, 84 §:

“The Defense Forces should take possession of explosive material, which has or on the basis of its quality warrants reason to believe that it has belonged to either Finland or to the armed forces of a foreign country. Defense Forces shall ensure its proper and safe transport, storage and disposal.” (Unofficial translation from the original text in Finnish)

The clearance is under the responsibility of Finnish Navy and Army engineers in cooperation with the Army’s CBRN Defense Special Unit, which is complemented with a deployable CBRNE laboratory. The needed detachment for the task will be formed according to the situation assessment. The current official instructions of Defense Forces that are applied to old chemical weapons clearing consists of precautions regulations, guides and manuals related to the clearance and protection missions in general. However, these documents cover only marginally the clearance of chemical weapons in particular. The applied procedures will be chosen based on the national and international operations models on the clearance of chemical weapons.

Laws and regulations

In the case of found warfare materials, the chain of action will proceed as follows in accordance with the following legislation (Act on Defense Forces, 11.5.2007/551, Act on Defense Forces assistance to the police 5.12.1980/781):

- The finder notifies the Coast Guard, police or Rescue Department
- The notified authority sends request for assistance to Defense Forces (for example, to the Southern Finland Military Province)
- Order will be issued to Finnish Defense Force detachments for the clearance and protection mission

No other applicable legislation that concerns warfare materials was found.

5.7.5.2 Current Projects

DAIMON and DAIMON 2

Currently the Finnish Environment Institute (SYKE) and the Finnish Institute for Verification of the Chemical Weapons Convention (VERIFIN) are involved in the “DAIMON 2” (2019-2021) extension project dealing with the further development and training of the use of a Decision Support System (DSS) for marine management produced during the DAIMON project. In 2020 SYKE and VERIFIN give trainings on the DSS and EcoTox Toolbox to Finnish authorities, decision makers and other possible interested stakeholders dealing with marine munitions. The goal of the project is to transform the DAIMON toolbox into standard operation procedures (SOPs) for environmental impact assessment of chemical and conventional munitions in offshore area.

5.7.5.3 Past Projects and Activities

SYKE and VERIFIN and have participated in numerous EU projects related to chemical and conventional munitions in the Baltic Sea region.

CHEMSEA

During the CHEMSEA project it was proven for the first time, that leaking chemical warfare agents (CWAs) cause biological effects in marine biota using in situ experiments. As a part of the project, a guideline concerning old munitions in the seafloor was produced for the fishermen.

During the DAIMON project, VERIFIN developed novel chemical analysis methods for studying uptake of arsenic-based CWAs, such as Clark III, Adamsite and triphenylarsine (component of arsine oil) by marine biota. During the project it was demonstrated for the first time that degradation products of CWAs are accumulating in different marine biota species. 100 Atlantic
cod samples that were collected from the Bornholm CWA dumpsite were analysed and results showed that 13 % of the analysed cod muscle samples contained CWA-related phenylarsenic chemicals in low ng/g level. In addition to that, based on the analysis of different cod organs and bile samples, preliminary data on biodistribution of phenylarsenic CWAs in cod was gained. VERIFIN also identified novel phenylarsenic chemicals, that originate from Clark I, Adamsite, phenyldichloroarsine and triphenylarsine in sediment samples collected from different CWA dumpsites in the Baltic Sea area. These chemicals are most likely produced by microbial activities in marine sediment. In addition, new biomarker methods were validated and a larger set of marine animals from different dumpsites were analysed in SYKE.

Finnish fishermen’s guide

By recommendation of the Baltic Marine Environment “Protection Commission, the Helsinki Commission (HELCOM), the Finnish fishermen’s guide (see appendix 1.) was prepared during the years 1995 - 1996 by the Ministry of Environment together with the Ministry of Agriculture and Forestry, the Ministry of Social Affairs and Health, the provincial government of Åland, the Finnish Defense Forces and its Technical Research Centre, the Poison Information Center, Institute of Occupational Health, University of Helsinki, Federation of Fisheries, and Federation of Finnish Fishermen's Association. The guide was prepared on the basis of the similar guide used in Sweden, adapting it to the Finnish conditions, and following the HELCOM recommendations. The guide was distributed by the Federation of Fisheries starting in January 1997. While the guide is still available from Federation of Fisheries, it has not been actively promoted in recent years. No known dangerous situations involving chemical weapons occurred for Finnish fishermen in the 2000s, probably because fishing of Finnish fishermen in risk areas has been very infrequent.

5.8 Germany

5.8.5.1 Authorities and Legal Situation

Germany is a federal republic. Due to this political setup, the location at which warfare material is present determines whether either the federal government or the government of one Germany’s five coastal states is responsible. In other words, responsibilities are different, depending on whether the warfare material is present in a harbour area, estuary, beach, coastal or open water. Consequently, the authority that is required to handle an issue may vary, depending on the geographic location of warfare material. Table 8 displays public bodies of Germany that are either responsible for activities or supporting these activities, which are relevant to warfare materials in the sea.

<table>
<thead>
<tr>
<th>Public Body</th>
<th>Activity</th>
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</thead>
<tbody>
<tr>
<td>BSH</td>
<td></td>
</tr>
<tr>
<td>WSV</td>
<td></td>
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<tr>
<td>LKA.SH/</td>
<td></td>
</tr>
<tr>
<td>LBA.</td>
<td></td>
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<tr>
<td>State EOD Service</td>
<td></td>
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<tr>
<td>State Harbour</td>
<td></td>
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<tr>
<td>State Police</td>
<td></td>
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<tr>
<td>Navy</td>
<td></td>
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<tr>
<td>State Government</td>
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<tr>
<td>BLANDO</td>
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<tr>
<td>BLE</td>
<td></td>
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<tr>
<td>CCME</td>
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<tr>
<td>MSZ (GLZ-See)</td>
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<tr>
<td>DGUV</td>
<td></td>
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<tr>
<td>LVNLSH</td>
<td></td>
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<tr>
<td>Customs</td>
<td></td>
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<tr>
<td>UBA</td>
<td></td>
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</tbody>
</table>

Nautical charts | X
Sea traffic management | X
<table>
<thead>
<tr>
<th>Port safety (DA)</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>(X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOD mapping</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
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<tr>
<td>EOD assessment</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOD risk management</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>EOD remediation</td>
<td>X</td>
<td></td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>EOD national reporting</td>
<td>(X)</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
</tr>
<tr>
<td>MSP</td>
<td>X</td>
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<td></td>
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<tr>
<td>MSFD</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fishery</td>
<td>(X)</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Endangered species</td>
<td>X</td>
<td></td>
<td>X</td>
<td>(X)</td>
</tr>
<tr>
<td>Occupational Health and Safety</td>
<td>X</td>
<td></td>
<td>X</td>
<td>(X)</td>
</tr>
<tr>
<td>Law enforcement</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Maritime Casualty Investigation</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>Wreck management</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>Responsible or managing body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(X)</td>
<td>Actively supporting body, without being legally responsible</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**State EOD Service**

Within German territorial waters the legal basis for the detection and clearance of warfare material is the German Explosives Law (SprengG). The bodies listed in Table 9 are responsible for explosive ordnance disposal and may carry out clearance operations in the territorial waters of their federal state. They handle their mission with their own resources only to a certain extent. If workload is exceeded, private companies or consortia of service providers are contracted in, on a case by case basis. Private sector contributors serve under supervision of the responsible regulatory state authority. State EOD services may define requirements for the
detected by and clearance of warfare materials, when conducted by other organizations. They may furthermore monitor compliance with these requirements on board the vessels used in their respective territorial waters. This is especially relevant, when new technologies are used or organizations that were previously unknown are commissioned with detection and clearance services. The legal basis for these bodies are provisions made by the respective federal states. All warfare material recovered within state territory or which has been imported to a harbour is confiscated by the locally responsible state service.

Table 9: German coastal federal states and state EOD services

<table>
<thead>
<tr>
<th>Federal State</th>
<th>Responsible body</th>
<th>Contact information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bremen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamburg</td>
<td>Kampfmittelräumdienst der Feuerwehr Hamburg</td>
<td></td>
</tr>
<tr>
<td>Mecklenburg-West Pomerania</td>
<td>Munitionsbergungsdienst</td>
<td></td>
</tr>
<tr>
<td>Lower Saxony</td>
<td>Kampfmittelbeseitigungsdienst</td>
<td></td>
</tr>
<tr>
<td>Schleswig-Holstein</td>
<td>Kampfmittelräumdienst</td>
<td></td>
</tr>
</tbody>
</table>

Outside German territorial waters no single body is responsible for explosive ordnance disposal.

**German Federal Maritime and Hydroacoustic Agency (BSH)**

The German Federal Maritime and Hydroacoustic Agency (BSH) is active in several activities that are relevant to warfare material in the sea, some of which are presented here. Before the execution of the detection of warfare material, a permission to carry out research activities is in accordance with §132(1) BBergG is required.

Contact:

For the execution of detonations, a mitigation concept addressing the expected noise mitigation and deterrence measures needs to be handed in. The BSH furthermore maintains the National Noise Register for the North Sea and the Baltic Sea. Information about conducted detonations are reported to the BSH.

Contact:

All detected warfare materials and subsequent management activities within the scope of offshore projects have to be reported to the BSH.

Contact:

Before the execution of detection and clearance activities of warfare materials a notice to mariners are released. In the EEZ notices to mariners are published by the BSH.

Contact: customer@bsh.de

Information:
https://www.bsh.de/EN/TOPICS/Shipping/Navigational_information/Notices_to_Mariners/Notices_to_Mariners_node.html

**Central Command for Maritime Emergencies**

In order to cope with the challenging multifaceted accountabilities and responsibilities, the German Federation and the coastal states have established the Central Command for
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Maritime Emergencies (CCME) in Cuxhaven, as a 24/7 central access to multiple maritime agencies in Germany. The German Waterways Police Reporting and Coordination Centre of the Maritime Safety and Security Centre is part of the CCME and operates a central marine munitions reporting office where all detected warfare materials and subsequent management activities have to be reported to. Prior to execution, all detonations of warfare materials have to be registered with the same body. In addition, the reporting office has to be presented with verification of proper disposal of munitions and munition components.

Contact: mlz@havariekommando.de

Further information: https://www.havariekommando.de/EN/

State Government Bodies responsible for Occupational Health and Safety

The bodies listed in Table 10 define requirements for adherence to the Safety at Work Act within and outside German territorial waters.

<table>
<thead>
<tr>
<th>Region</th>
<th>Responsible body</th>
<th>Contact information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Saxony and part of the EEZ off the coast of Lower Saxony</td>
<td>Gewerbeaufsichtsamt Oldenburg</td>
<td></td>
</tr>
<tr>
<td>Schleswig-Holstein and part of the EEZ off the coast of Schleswig-Holstein</td>
<td>Staatliche Arbeitsschutzbehörde bei der Unfallkasse Nord</td>
<td></td>
</tr>
<tr>
<td>Mecklenburg-West Pomerania and part of the EEZ off the coast of Mecklenburg-West Pomerania</td>
<td>Landesamt für Gesundheit und Soziales Mecklenburg-Vorpommern</td>
<td></td>
</tr>
</tbody>
</table>

Method statements for detection and clearance operations have to handed over to the body, responsible in the respective geographic area for plausibility checking and commenting. All occupational safety incidents have to be registered with these authorities.

Federal Waterways and Shipping Administration (WSV)

The five coastal states of Germany are tasked with law enforcement, safety and security, with one exception: Safety of maritime traffic remains with the Federal level, where the Federal Waterways and Shipping Administration is responsible.

Furthermore, before the execution of detection and clearance activities of warfare materials a notice to mariners are released. Within German territorial waters notices to mariners are published by the bodies listed according to the Electronic Waterway Information Service of the Federal Waterways and Shipping Administration.

Contact:

Information: https://www.elwis.de/DE/dynamisch/BfS/

German Armed Forces

While the German Armed Forces (Bundeswehr) are not responsible for any activities which are relevant to warfare materials in the sea. However, they are involved in some instances.
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German Federal Environment Agency (UBA)

The task of the German Federal Environment Agency (UBA) is to ensure that citizens are able to live in a healthy environment with clean air and water, free of pollutants to the greatest extent possible. UBAs work centres around gathering data concerning the state of the environment, assessment of the environmental status, investigating relevant interrelationships and making projections – and then, based on these findings, providing federal bodies such as the Ministry of the Environment with policy advice. UBA also provides the general public with information and answers questions on all of the various issues it addresses. Apart from these activities, UBA together with other relevant federal and federal states institutions implements environmental law such as the Marine Strategy Framework Directive (MSFD) in Germany.

Regarding the issue of warfare materials in the marine environment, UBA is financing external research to analyse TNT and its metabolites in sediment and organisms such as mussels, fish and marine mammals in all coastal waters continuously since 1990 using samples from UBAs environmental specimen bank. Data on hazardous substances are reported to the Marine Environmental Database (MUDAB) of UBA and are assessed and reported to the EU, Regional Sea Conventions (RSC), including HELCOM, and the public. UBA itself conducts standardised eco-toxicity tests on TNT and its metabolites in its labs and derives Environmental Quality Standards (EQS), to determine if environmental concentrations of these substances are harmful to the environment. In case of occurrence of harmful concentrations above EQS, UBA would suggest measures to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, e.g. to remove the source of pollution, such as clearance of warfare materials.

Contact: Anita Künitzer – anita.kuenitzer@uba.de

Information:

Central reporting unit for munitions in the sea

The central reporting unit for munitions in the sea is integrated in the Joint Centre of the water police of the coastal federal states, which is part of the Maritime Safety and Security Centre in Cuxhaven. It was established in 2012, following a recommendation of the Cross-Administrative Working Group “Munitions in the Sea” in their 2011 report on warfare materials in German waters.

The unit records the occurrence of warfare material, parts thereof and suspicious objects that are found in German waters, along the German coast and in the German EEZ. It operates day and night and distributes the recorded data, photos and descriptions to other responsible bodies on federal and state level. Incoming data are based on the observations citizens make and from the police stations that are part of the joint centre of the water police. Other reports originate from vessels of authorities and companies that are commissioned to maintain the maritime water ways. These may encounter warfare materials during surveys and dredging. A significant amount of data is furthermore provided via the discovery and clearance reports of the state EOD services of the coastal federal states and private EOD companies. The latter usually encounter warfare materials during preparatory and developmental work at the sea floor for the construction of pipelines, wind parks and cables.

The central reporting unit furthermore generates yearly statistics that distinguish between the EEZ, coastal waters and internal waters in the North- and Baltic Seas. Heavy fluctuations between years are a result of two factors. Firstly, the contamination with warfare materials varies between areas that are investigated. Secondly, the intensity of investigations preparing
the construction of wind parks and pipelines is driven by the construction activity and therefore fluctuates between the years. A recorded number of the central reporting may refer to a single larger object or it may refer to a cluster of small arms ammunition.

Contact: wsp@msz-cuxhaven.de

Information: http://meldestelle.munition-im-meer.de

5.8.5.2 Ongoing Management Activities

This section describes all activities that are directly related to the management of warfare materials in the sea (see chapter 4). This includes assessment methods, technical investigation with the aim of detecting munition and the clearance of warfare material.

Archival Work

The German Military Archive in Freiburg stores 51 km of relevant files of which a well-functioning team can check 5-6 m with nearly 350 individual files over the course of one week. In a total of 16 research weeks from 2010 till 2018, 1,166 files concerning ammunition at sea were copied and scanned. Complemented by nearly 240 files from the UK National Archive in Kew and from the Royal Navy, a solid knowledge base was established. In 2018, two weeks were spent for research in the German Military Archive in Freiburg. A total of 25,917 pages of nearly 650 different documents were scanned. The focus of WWI documents lies on mine warfare in the central and eastern Baltic Sea and artillery fights in the area of the Baltic isles. WWII documents focus on mine warfare and air defence in the western Baltic Sea. They contain a large number of pages regarding minesweeping in the entire Baltic Sea, air strikes and artillery fights. Furthermore, information regarding air-defence alongside the German coastline against the Allied bombers and the calculation of misfired artillery shells was acquired. Some documents provide information regarding the storage of ammunition during the final months of war and the way to the dumping areas.

5.8.5.3 Other Ongoing Activities

This section describes other ongoing activities in Germany, that are not directly related to the management of warfare materials but are related to this issue in general. These are ongoing and not project related and therefore not limited in time. Table 11 displays German ongoing activities and projects and their field of application in the issue of warfare materials in the Baltic.

<table>
<thead>
<tr>
<th>Activity or Project</th>
<th>AMUCAD</th>
<th>Group “Munition in the Sea”</th>
<th>BASTA</th>
<th>ExPoTec</th>
<th>MUN/SEE</th>
<th>ReBEHM</th>
<th>UDEMM</th>
<th>Mercury Pollution</th>
<th>Munitect</th>
<th>SOAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mapping</td>
<td>X</td>
<td></td>
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<tr>
<td>Environmental Impacts</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Munition’s Migration</td>
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<tr>
<td>Coordination</td>
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</tr>
</tbody>
</table>

Table 11: German activities and projects and their field of application in the issue of warfare materials in the Baltic
AMUCAD

The Ammunition Cadaster Sea (AMUCAD) is developed by EGEOS GmbH in close consultation with the MELUND. It deals with the acquisition, management and analysis of a wide variety of ammunition related datasets for the North and Baltic Seas. Therefore, a large amount of historical and modern datasets is acquired and integrated into the system and new technologies like artificial intelligence/visual analytics are used for interpreting and connecting these datasets. AMUCAD is part of several national (ERPAD) and international (DAIMON, NSW) research projects whose results will be implemented and further developed. It is designed for use in administration, research as well as businesses and provides a central information system for different applications such as marine spatial planning, offshore infrastructure development and monitoring of environmental aspects.

Contact: Jann Wendt – jann.wendt@egeos.de

Further Information: https://www.amucad.org

Cross-Administrative Working Group "Munitions in the Sea"

A cross-administrative working group drives the “German Programme on Underwater Munitions”. In 2008, today’s Ministry of Energy, Agriculture, the Environment, Nature and Digitalization (MELUND) of the state of Schleswig-Holstein, initiated the collaboration and it continues to serve as leading partner. The group initially functioned as a platform for state ministries of interior and marine protection to share knowledge and to consult discuss public relations. Federal agencies joined the group in 2009. The group’s first task was the generation of the report “Munitions in German Marine Waters – Stocktaking and Recommendations”, which has since been amended on an annual basis. Furthermore, the German governing body for the implementation of the European Marine Strategy Framework Directive (MSFD) commissioned the working group with the facilitation and oversight of the implementation of recommended measures and with managing this societal challenge. The working group has managed to establish a national point of contact for munitions encounters in marine waters. It actively contributes to scientific projects in Germany and Europe and to activities within NATO, HELCOM, OSPAR and JPI Oceans. The group meets three times every year.

Members: State ministries of interior and marine protection, Federal Ministries, BSH, German Armed Forces, CCME

Contact: munition@meeresschutz.info

Further Information: www.underwatermunitions.de

Digital Ocean Lab

The development of new and efficient technologies for the detection of UXO requires appropriate testing facilities. Tests in real working areas are time- and cost-consuming as they depend on the weather and sea conditions. Therefore, the network is involved in the conception and construction of an “underwater munition garden” in a testing area just outside of Rostock (Germany) in the Baltic Sea. On the one hand, basic technologies for a better comparability are provided, such as power supply, underwater positioning, and communication...
systems. On the other hand, real conditions are necessary to show the full capacity or faults. Water pressure, waves, currents, strong corrosive environments, as well as biofouling, have to been considered in relation to the high risks and costs due to failures of ROVs, sensors, etc. Currently there are no official standards for technologies or human safety regarding the dangerous working field of UXO in the sea. To avoid acting negligently, standardization and certifications are desirable. One step towards the needed reproducibility was taken at the planned “munition garden” in the Digital Ocean Lab (DOL) with a ground-breaking ceremony held on the 9th of August 2019 in Rostock.

SiM e.V

In February an expert panel on chemical agents in the sea was established. The newly registered association, Nationales Informationszentrum chemische Kampfmittel (SiM e.V.), has various members from academia and corporations involved in unexploded ordnance, and semi-state organizations like GEKA Munster, as the only organization in Germany that is allowed to handle chemical agents with the purpose of destroying them. Two of the three executive board members are from the network Munitect and are working on these goals:

- knowledge conservation and collection, archiving
- determination of state-of-the-art techniques for identification and disposal of chemical agents
- consultation of official administrations
- development of health and safety guidelines on board (with official liabilities)
- support of sciences and new generation scientists

SiM e.V. will soon be available at: www.nickev.org

5.8.5.4 Current Projects

The following research and technological development projects are currently being conducted or have been approved in Germany.

BASTA

Existing approaches for the detection of submerged warfare material (see 4.3) are time consuming and costly. They suffer from limited objectivity and acknowledgement of uncertainties, which is partly due to the lack of an industry standard for data acquisition and handling. This resulted in high heterogeneity in process chains and data workflows. BASTA (Boost Applied munition detection through Smart data inTegration and AI workflows) aims at advancing the approach for munition detection both on local and a larger scale. The project seeks to advance data acquisition through ultra-high-resolution 3D sub-bottom profiling (SBP) and intelligent AUV-based magnetic mapping as part of an adaptive and iterative survey approach. In addition, it will foster sustainable use of survey and historical data within the multi-sensor database of AMUCAD.org. Conducting data analysis of Big Data by means of artificial intelligence will lead to new approaches in detection and identification of munition. Finally, new tools, methods and workflows will be discussed with stakeholders, with the aim of formalizing recommendations for munitions detection for industry and government players.

Project partners: GEOMAR Helmholtz Centre for Ocean Research (Lead), Flanders Marine Institute, EGEOS GmbH, G-tec SA

Funded by: European Maritime and Fisheries Fund - “Blue Economy” (2020-2023)
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Contact: Prof. Dr. Jens Greinert – jgreinert@geomar.de

ExPloTect

Unexploded ordnance and relic munitions on the seafloor represent intrinsic explosion and security risks, and also contain cytotoxic, genotoxic, and carcinogenic chemicals. There is a critical need to clear undersea munitions due to these hazards. Direct chemical sensing of explosive material provides an unequivocal signature for objects requiring clearance and chemical contamination release from munitions. Despite the clear need for real-time chemical detection technology, existing methods cannot detect multiple chemical compounds simultaneously, and they are all subject to interferences from non-target compounds. ExPloTect (Ex-situ, near-real-time explosive compound deTection in seawater) will develop a prototype system for shipboard, near-real-time detection of dissolved explosive compounds and chemical warfare agents in seawater. The underlying concept of ExPloTect is a flexible platform adaptable to explosive compounds such as trinitrotoluene, as well as chemical warfare agents. The technology will be based on a high-performance liquid chromatography-mass spectrometry method demonstrated extensively by GEOMAR in the Baltic Sea during the UDEMM project.

Project partners: GEOMAR Helmholtz Centre for Ocean Research (Lead), K.U.M. Umwelt- und Meerestechnik Kiel GmbH, RPS Explosives Engineering Services
Funded by: European Maritime and Fisheries Fund - "Blue Economy" (2020-2023)

Contact: Prof. Dr. Eric Achterberg – eachterberg@geomar.de; Dr. Aaron Beck – ajbeck@geomar.de

MUNISEE

Anti-aircraft grenades were used on a large scale in the Baltic Sea near the coast during the World War II. These anti-aircraft grenades contained highly toxic mercury(II) fulminate as a primary explosive, which now contaminates the Baltic Sea. In a 10 km² area near the former marine anti-aircraft gun (FlaK) training centre Dänisch-Nienhof, up to 1.5 million mercury-containing anti-aircraft grenades were fired between 1939 and 1945. Some 70% of these shells detonated during use, releasing up to 2 tons of highly toxic elemental and ionic mercury (Hg⁰ and Hg²⁺) into the environment. Most of this mercury likely accumulated in sediments off Dänisch-Nienhof. Undetonated grenades are also likely present, containing an additional ton of mercury. MUNISEE (Weltkriegsmunition: Quecksilberquelle im Ökosystem Ostsee [World War Munition: Mercury source in the Baltic Sea ecosystem]) investigates the degree of Hg contamination from historical FlaK ammunition use in coastal Dänisch-Nienhof. In particular, the release of organic and inorganic Hg from ammunition-polluted marine sediments in the Bay of Kiel and its transfer into the food chain is investigated.

Project execution: GEOMAR Helmholtz Centre for Ocean Research

Contacts: Prof. Dr. Eric Achterberg – eachterberg@geomar.de; Katherine Gosnell – kgosnell@geomar.de

Pilot study “Lübecker Bucht”

On behalf of the „Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung“ (Schleswig-Holstein, Germany) a pilot study is carried out in the period from
August 2019 to December 2020 in the Bay of Lübeck. The aim of this study is to establish methods for the routine monitoring of explosives and active ingredients from pharmaceuticals. Water samples are taken monthly at different locations, blue mussels and passive sampling devices are used periodically. The measured values will be evaluated under toxicological guidelines.

5.8.5.5 Past Projects and Activities
The following noteworthy projects and activities that are already finished have been conducted in Germany.

RoBEMM
The project RoBEMM (Robotic underwater salvage and disposal process with the technology to remove explosive ordnance in the sea, in particular in coastal and shallow water) was driven by the idea of developing a procedure that allows for the inexpensive clearance of warfare materials from the seabed. It was the declared target that the clearance should be performed in a fully automated fashion. Another aim was to ensure on-site disposal, which would prevent the transport of hazardous explosive materials both at sea and land. During the project, tests for friction and impact sensitivity of explosives were conducted. These indicated, that treatment of the warfare materials in question had to be conducted in a very sensitive fashion. The main result was a concept for the treatment of warfare material with a delaboration unit which allows for the safe handling of explosives under water. Furthermore, a quality guideline for the treatment of offshore warfare materials and a concept for a testing ground were developed.

Project Partners: Heinrich Hirdes EOD Services GmbH (Lead), Automatic Klein GmbH, Fraunhofer Institute for Chemical Technology, Institute for Infrastructure and Resources Management of Leipzig University

Funded by: German Federal Ministry for Economic Affairs and Energy (2015-2019)

Contact:

UDEMM
The UDEMM (Umweltmonitoring für die Delaboration von Munition im Meer [Environmental monitoring for the remediation/delaboration of munitions on the seabed]) project investigated strategies for monitoring the environmental impact of underwater munitions, before, during, and after remediation. UDEMM focused on 1) hydroacoustic and visual monitoring of ammunition, 2) oceanographic modelling of munition chemical transport and dispersion, 3) release, biogeochemical cycling, and fate of munition chemical compounds (MC) in water column and sediments and 4) biological enrichment of MC in mussels. Study regions included Kolberger Heide, Bay of Kiel, and the southwest Baltic Sea. High resolution seafloor imaging showed extensive but heterogeneous presence of munition objects throughout the study area Kolberger Heide. Munition objects showed little movement over the study period; open explosives have been detected in a local area and identified as contamination hotspots. Water column chemical gradients demonstrated unequivocal release and spread of MC throughout Kolberger Heide but also throughout the SW Baltic, as it could be measured during a three-week research cruise (POS530). A numerical model incorporating MC release and degradation successfully predicted the observed regional-scale distribution of MC. Mussels transplanted to the Kolberger Heide site showed clear bioaccumulation of MC, highlighting the potential ecological risk of chemical release from underwater munitions. UDEMM resulted in the release of the Practical Guide for Environmental Monitoring of Conventional Munitions in the Seas.
Warfare Materials in the Baltic Sea – Model Chapter Germany

Project partners: GEOMAR Helmholtz Centre for Ocean Research (Lead), Institute for Baltic Sea Research Warnemünde, Institute for Toxicology and Pharmacology for Natural Scientists of Kiel University

Funded by: German Federal Ministry of Education and Research (2015-2019)

Contact: Prof. Jens Greinert – jgreinert@geomar.de

Further information: https://udemm.geomar.de

Mercury and dimethylmercury pollution in the ecosystem of the Kiel Fjord as a result of historical use of air defence ammunition

The project determined the distribution of mercury (Hg) in the waters and sediments of the southwest Baltic Sea derived from munitions deployed over 70 years ago, and how much has moved into the food chain. The study focused on a region off Kiel where more than 1.2 million mercury-containing anti-aircraft grenades were shot from World War II artillery training grounds, which now litter the seabed. Seafloor magnetometer data and multibeam imaging indicated a large number of likely munitions objects on the seafloor in the Bay of Kiel and at Dänisch-Nienhof. Higher concentrations of Hg were measured in sediments and biota from munitions-contaminated regions compared with control sites. Concentrations and isotope signatures of Hg and methyl-Hg in fish indicated bioaccumulation of suspected munitions-derived pollution, although natural isotope fractionation processes were also evident in the data.

Project partners: GEOMAR Helmholtz Centre for Ocean Research (Lead), Ministry of Energy, Agriculture, the Environment, Nature and Digitalization of Schleswig-Holstein, Institute for Toxicology and Pharmacology for Natural Scientists of Kiel University


Contact: Prof. Dr. Eric Achterberg – e achterberg@geomar.de

MUNITECT

Munitect was established in 2016 as a network of SMEs and research institutes that all share the vision of a high-performance and cost-effective sensor platform to facilitate efficient, safe and risk-free detection of old military munitions. An improved accuracy of classification, as well as targeted development of procedures for cost-efficient end systems, is a challenge the network partners would like to take on. The partners represent the manufacturer and customer side regarding the UXO-safety of activities in the economic exploitation of the North and Baltic Sea. The Federal Ministry for Economic Affairs and Energy of Germany has supported Munitect for the past four years as an R&D-orientated (ZIM-) network. The almost 20 partners approach the complex issue of UXO with different working teams, who share a joined innovation roadmap and meet frequently. Munitect is supported by an advisory committee from different public sector institutions. In the near future Munitect shall be the nucleus to establish an industry association for “munition in the sea” in Germany.

Funded by: German Federal Ministry for Economic Affairs and Energy (2016-2020)

Contact: info@munitect.de

Further information: https://www.munitect.de
SOAM

The project SOAM (Berührungsfreie Sondierung von Gewässeruntergründen zwecks Auffindung von Altmunition und anderen Gefahrstoffen zur Gewährleistung der gefahrenlosen Gründung von Offshore-Windenergieanlagen (WEA) [Contactless investigation of the ground of bodies of water in order to detect explosive remnants of war and other hazardous materials with the aim of ensuring hazard free foundation of offshore wind farms]) focused on the technical investigation of warfare material. The aim was to test appropriate sensors and to establish intelligent data evaluation. An AUV should be equipped with integrated analytical sensor technologies and tests of the detection capabilities of this AUV should be conducted.

Project partners: Clausthaler Umwelttechnik-Institut GmbH (Lead), Challenger Technologies Dr.-Ing. Klaus Koehler, Michael Clemens + Ingenieure, ATLAS ELEKTRONIK GmbH, Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD 71) in Eckernförde

Funded by: German Federal Ministry for Economic Affairs and Energy (2012-2015)

Contact:

5.9 Latvia

5.9.5.1 Authorities and Legal Situation

5.9.5.2 Ongoing Management Activities

5.9.5.3 Other Ongoing Activities

5.9.5.4 Current Projects

5.9.5.5 Past Projects and Activities

OPEN SPIRIT 2018

The first operation OPEN SPIRIT in 1998 was developed from the former operation Baltic Sweep. Baltic Sweep was a bilateral exercise between the German Navy and the Latvian Navy in 1996. In this operation, three German minehunters checked an area in front of the entrance to Riga Harbour. 21 mines were found and disposed. One year later, the Royal Swedish Navy joined the operation to check the same area as in 1996.

In 1998 the operation got a new form. The operation area was in Estonian territory waters and 5 nations, Estonia, Germany, France, Belgian and the Netherlands participate in a common work and disposed 31 mines. From this time, the operation OPEN SPIRIT was held every year in the waters of Estonia, Latvia and Lithuania. But the aim was and is always the same: Reduce the risk at Sea from dumped ammunition.

The result of all operation was dominated from disposed mines. Mostly moored mines and a smaller number of ground mines from Germany and Russia, were disposed. A special branch were some captured France and Netherlands mines in WW II. Reactivated by German Navy,
the mines were laid in the “NASHORN” minefield between Tallinn and Helsinki. Other ammunitions as torpedoes, depth charges, antisubmarine rockets, and artillery shells were found, marked and disposed.

In 2018, OPEN SPIRIT took place in Estonian waters. From 11. to 25 may, 17 units with a crew of 800 sailors found and disposed 90 mines, bombs, torpedoes, depth charges and artillery shells. The three oldest objects were two German airdropped TeKa-mines and one UC 200 mines, all three were laid in August 1917. The TeKa mine was develop for laying by submarine, but the transport system in the submarine torpedo tube don’t work correct. A first try to lay the mine with airplane was successful and the decision for the first airdrop minelaying was given to the Fliegerstation Windau. Airplanes from type Gotha laid in July and August 1917 in the north part of Irben Strait 72 TeKa mines.

Similar as BALTIC SWEEP and OPEN SPRIRIT operations were the Swedish- Estonian- Latvian and Lithuanian Mine Countermeasure Operations. From 1995 till 2009, the Royal Swedish Navy and the Navies from the three Baltic States reduced the risk of ammunition with bilateral, later joint by NATO Forces, operations. In 18 operations 670 UXOs were found, marked, documented and disposed. The operations areas were the territorial waters from the three Baltic states.

5.10 Lithuania

5.10.5.1 Authorities and Legal Situation

Responsible for aspects concerning warfare materials in the sea

The following authorities are responsible or relevant for aspects concerning warfare materials in the Baltic Sea:

- Ministry of National Defence of the Republic of Lithuania (www.kam.lt)
- Ministry of Environment of the Republic of Lithuania (www.am.lt)
Responsible for the treatment of incidents

In case an incident with warfare materials in the sea occurs, the following institutions are responsible for the treatment of this incident:

- Lithuanian Armed Forces (Maritime Rescue Coordination Center)
- Klaipeda State Sea Port Authority
- The State Border Guard Service at the Ministry of the Interior of the Republic of Lithuania
- The Fire and Rescue Department under the Ministry of the Interior of the Republic of Lithuania
- Municipal administration

Laws and regulations

The following laws and regulations apply to the issue of warfare materials in the sea:

- Law on the protection of the environment of the Republic of Lithuania;
- Marine Environmental Protection Law (Baltic Sea Environmental Strategy, Regional cooperation, Pollution prevention requirements, Pollution incident liquidation)
- Work plan for the elimination of pollution incidents in the maritime area

Action plan for the implementation of water field development 2017–2023 programme

The Environmental Protection Agency plans to carry out monitoring of the effects of the chemical weapons dumped in the Baltic Sea, to take part in the activities of international organisations to share experience and information, to evaluate monitoring data regarding the effects of chemical weapons and to initiate coordinated activities in the Baltic Sea region to solve the problem. The period for the implementation of this measure is from 2017 until 2022.

5.10.5.2 Current Projects

DAIMON 2

The Lithuanian Environmental Protection Agency is an Associated Organisation of the Interreg Baltic Sea Region project "Decision Aid for Marine Munitions - Practical Application" (DAIMON2), running from 2019 until 2021. The aim of the DAIMON 2 is to cooperate closer with the target group, offering methodologies from the scientifically renewed DAIMON EcoTox Toolbox. These have the capacity to become the new Standard Operation Procedures for the environmental impact assessment (EIA) for offshore economy projects in areas contaminated by dumped munitions.

Project execution: Environmental Protection Agency

Contact:

5.10.5.3 Past Projects and Activities

TC project RER/0/016

A part of the chemical warfare material dumpsite in the Gotland Basin within the western part of the Lithuanian exclusive economic zone, 70 nm (roughly 130 km) from the Lithuanian coast (on the Klaipėda-Ventspils plateau slope), was investigated for the first time in the scope of a national Lithuanian project. Expeditions took place in October 2002, June 2003 and August
2004. The aim was to confirm whether chemical warfare material was dumped in the waters of the Lithuanian EEZ and to perform an environmental impact assessment by evaluating the condition of the environment and biota in the area under investigation. Arsenic in sediment samples from the chemical munitions dumpsite was assessed together with scientists from the Marine Environment Laboratory, the International Atomic Energy Agency and Monaco (TC project RER/0/016). Studied parameters did not show changes in the environmental state at the dumpsite. Higher arsenic concentrations were found dumpsite, compared to other sites. However, arsenic concentrations were low relative to other investigations of sediments in the Baltic and North Seas.

Project partners: Ministry of National Defence of the Republic of Lithuania, Ministry of Environment of the Republic of Lithuania, the Centre of Marine Research (now: Environment Research Department of the Environmental Protection Agency under the Ministry of Environment of the Republic of Lithuania) and the Institute of Geology and Geography.

Funded by:
Contact:
CHEMSEA

. Using data, that were obtained during cruises to chemical munitions dumpsites, an assessment of the potential hazard of chemical munitions at the dumpsite in the Lithuanian EEZ was made. Sediment and water samples were taken during the cruise with research vessel "Vėjūnas" in 2013 and Arsenic concentrations in sediments, which act as an indicator of contamination by warfare agents, were assessed. Warfare agents were analysed in sediment samples by the VERIFIN (Finland) laboratory. As a result, arsenic concentrations in sediments of the chemical munitions dumpsite were in line with the concentrations found during a previous study of the dumpsite in 2003. It was furthermore found that the number of the macrozoobenthos species has decreased notably (from 10 in 1981–1993 to 3 in 2013). Additional chemical warfare agents (Clark I/II-related; Triphenylarsine and PDCA-related) were also found in sediments in one of investigated stations.

Project execution: Marine Research Department of the Environmental Protection Agency under the Ministry of Environment of the Republic of Lithuania
Contact:
MODUM

MODUM (Towards the Monitoring of Dumped Munitions Threat) project, funded by NATO Science for Peace and Security (SPS) programme, has started in 2013, ended in 2016. The project aimed at the establishment of the monitoring network observing Chemical Weapons dumpsites in the Baltic Sea, using Autonomous Underwater Vehicles (AUV's) and Remotely Operated Underwater Vehicles (ROV's), and utilizing existing research vessels of partner institutions as launching platforms. Two cruises (in 2014 and 2015) to the chemical munitions dumpsite in Gotland were undertaken by R/V “Vėjūnas”. New equipment for the monitoring of dumped chemical warfare materials such as an Autonomous Underwater Vehicle (AUV) was successfully tested.

Project execution: Marine Research Department of the Environmental Protection Agency under the Ministry of Environment of the Republic of Lithuania
Contact:
DAIMON

DAIMON (Decision Aid for Marine Munitions) – a flagship project of the EU Baltic Sea Region Strategy, financed by EU Baltic Sea Region Interreg, has started in 2016, ended in 2019. DAIMON has focused on the evaluation of risks associated with individual munitions, categorization of threats, and possible remediation methods. Risk assessment/categorization methods were applied in field studies in the Gulf of Finland, Bornholm and Gdansk Deeps, Little Belt and Skagerrak to produce examples of evaluation in different regions of the Baltic Sea. As the main result, an easy-to-use software “Decision support system” (DSS), based on the research carried out within the project, was created and presented to stakeholders in the Baltic Sea countries, including Lithuania, to provide them with a tool for the efficient management of the problem in their respective EEZ. The tool aims at making the knowledge gained in previous projects related to dumped munitions available to decision makers in the Baltic Sea area. Environmental Protection Agency under the Ministry of Environment of the Republic of Lithuania was a Project Partner of DAIMON.

Project execution: Environmental Protection Agency under the Ministry of Environment of the Republic of Lithuania

Contact:

5.11 Poland

5.11.5.1 Authorities and Legal Situation

The issue of warfare materials in marine areas is extremely complicated and therefore requires interdisciplinary cooperation between many authorities.

Ministry of National Defense

The institution responsible for the clearance of warfare materials in Polish maritime areas is the Ministry of National Defense and organizational units subordinated to it or supervised by it. Pursuant to Part A of the National Crisis Management Plan, the Navy is responsible for the identification and elimination of threats related to dumped chemical warfare. Also, in accordance with the order of the Navy Commander No. 148/SIM of 30 October 2013, the 3rd Coastal Defense Flotilla and 8th Coastal Defense Flotilla are the bodies responsible for the clearance of the Polish maritime areas from warfare materials. These bodies have the capabilities, scientific and research potential and command specialized subunits of chemical forces that are capable of monitoring various threats, including those arising from the presence of warfare materials and other hazardous objects on the seabed of Polish maritime areas.

Ministry for the Environment

At the same time, it should be noted that in accordance with the Law of 4 September 1997 on government administration departments, the Ministry for the Environment is the body responsible for monitoring compliance with environmental protection requirements and examining the state of the environment. In accordance with Law of 20 July 1991 on the Inspection of Environmental Protection, the Inspection of Environmental Protection was established to monitor compliance with environmental protection regulations and to examine and assess the state of the environment. In accordance with the provisions of Law of 4 September 1997 on government administration departments, the Ministry for the Environment is the body responsible for environmental protection and the rational use of its resources, as well as the management of natural resources. In addition, pursuant to Law on the Inspection
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Inspector of Environmental Protection, the Chief Inspector of Environmental Protection performs tasks in the field of conducting state environmental monitoring and conducting laboratory activities. In accordance with the Part A of National Crisis Management Plan, the Ministry for the Environment conducts general supervision over environmental protection, including marine environment protection, while in accordance with Part A of National Crisis Management Plan, the Chief Inspector for Environmental Protection is responsible for monitoring and assessing the quality of the marine environment. With reference to the issue of identification and monitoring of hazardous materials in Polish marine areas and assessment of the scale of the threat, the role of the State Environmental Monitoring created by the Law of 10 July 1991 on the Inspection of Environmental Protection should be also indicated.

Maritime Administration

According to the provisions of Law of 21 March 1991 on maritime areas of the Republic of Poland and maritime administration the maritime administration authorities are responsible for the prevention of pollution of the marine environment as a result of sea-based activities.

Maritime Offices

Under the Regulation of the Minister of Infrastructure and Development of 7 May 2015 on the determination of objects, devices and installations included in the infrastructure providing access to the port with a basic significance for the national economy the directors of maritime offices are responsible for identification of hazardous materials in territorial waters and undertake actions involving detailed monitoring of water bodies with the purpose of determining where shipping and offshore infrastructure (fairways, anchorages, breakwaters, quays, etc.) are to be located. The detailed scope of the control is regulated by the Regulation of the Minister of Maritime Economy of 23 October 2006 on the technical conditions of use and the detailed scope of inspections of offshore hydrotechnical constructions. The directors of maritime offices also monitor the areas in the vicinity of selected wrecks, which may pose a threat or potentially contain fuel. These activities are implemented by air surveillance and satellite monitoring, which enable the detection of pollution on the sea surface.

5.11.5.2 Ongoing Management Activities

Various offshore projects

In the areas of the ports of Gdansk and Gdynia, hydrotechnical works are carried out. These are preceded by a detailed survey of ferromagnetic objects on the sea bed. As a result of these activities, commercial business entities, the Director of the Maritime Office in Gdynia and the Polish Navy are gradually cleaning the port basins of warfare materials.

The Director of the Maritime Office in Szczecin is responsible for the investment titled “Modernization of the Swinoujście-Szczecin fairway to a depth of 12.5 m". For the purpose of this undertaking the “Safety Plan for Shipping” was developed, which contains procedures that were agreed upon with the contractor in the event of finding and handling hazardous materials found. Before the implementation of investments, under which dredging works are carried out, Szczecin and Swinoujscie Seaports Authority SA commissions the execution of a magnetic survey of the seabed in the port area. The aim of these works is the detection and identification of objects that may pose a threat to people and equipment (warfare materials and other hazardous objects). In 2019, these works were carried out in the Dębicki Channel and in the Kaszuby Basin in the port of Szczecin as part improving the access to the port in Szczecin in the area of the Dębicki channel and improving the access to the port in Szczecin in the area
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of the Kashubian Basin”. Removal of the warfare materials is carried out by the construction works contractor. These works are financed from funds allocated for the implementation of the above investments.

5.11.5.3 Other Ongoing Activities

In 2018, on behalf of the Minister of Maritime Economy and Inland Navigation, the Director of the Maritime Office in Gdynia appointed a working group for the threats related to the wreck of a German vessel from the World War II t/s Franken. The working group consists of representatives from the Navy Hydrographic Office, the General Command of the Armed Forces, the Maritime Search and Rescue Service, the Chief Inspectorate for Environmental Protection, the General Directorate for Environmental Protection, the Maritime Offices in Gdynia, Stupsk and Szczecin, and the Ministry of Maritime Economy and Inland Navigation.

5.11.5.4 Current Projects

5.11.5.5 Past Projects and Activities

Fishermen’s Guide

In 2019 a group of experts updated the “Instructions for the crews of fishing vessels in the event of passively fished or the removal of chemical warfare from the sea”.

PATROL 18

On 17 October 2018, the nationwide exercises PATROL 18 took place in Dziwnów. During the exercise, activities were carried out that would be implemented in case of a threat of chemical, biological and radioactive contamination. The main purpose of the exercise was to improve the procedures for activating the individual elements of the National System of Contamination Detection and Alarming by exercising scenarios of events introducing crises to develop expert assessments and analyses, recommendations for further proceedings, to check information exchange procedures as well as to coordinate the activities carried out by individual services and institutions. One of the elements of the exercise was to respond to the case of finding barrels with unknown substances in fishing nets, which lead to the contamination of the crew and the equipment. Considering the effects of the substance on humans, the possibility of contamination of the unit with CWAs was determined.

5.12 Sweden

5.12.5.1 Authorities and Legal Situation

Swedish Armed Forces

The Swedish armed forces assist civil authorities (i.e. police, coast guard and emergency services) in munition clearance of warfare material in the sea. Ammunition Warfare material that cannot be classified and finds at sea that cannot be identified are not allowed not be cleared without permission from and according to the regulations from of the armed forces. The marine tactical staff is responsible for the assistance to the coast guard and emergency services of finds located at sea. If the find or object containing CWA is deemed to also contain an explosive substance, the Swedish armed forces (marine tactical staff) are furthermore obliged to support in locating, identifying, indicating, decontaminating and neutralizing it and the Swedish EOD and Demining Centre is responsible for the assistance to police, coast guard and emergency services with finds located on land. Furthermore, the Swedish armed forces are responsible for the disposal of ammunition and unexploded ordnance (UXO)warfare
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materials inside a military area or an area that is closed off for military activities. The role of the Swedish armed forces are governed by the Regulation (2002:375) of support to the society by the Swedish armed forces (Förordning (2002:375) om Försvarmaktens stöd till samhället).

Swedish Coast Guard

The Swedish coast guard is responsible for disposing of chemical warfare agents (CWAs) in Swedish territorial sea waters and the economic zone (EEEZ) as well as the lakes Vänern, Vättern and Mälaren. In addition, they are responsible for disposing of CWA: s on a ship, which is not that must not be located inside a port area. If the find or object is deemed to contain an explosive substance, the Swedish armed forces (marine tactical staff) are obliged to support in locating, identifying, indicating, decontaminating and neutralizing it.

Swedish Police

The Swedish police is responsible for the disposal of ammunition and unexploded ordnance (UXOs)/warfare materials, of civilian as well as military origin, on civilian land. They are also responsible for munition clearance of warfare materials in connection with a crime or suspicion of a crime, including inside a military area or an area that is closed off for military activities. The armed forces can support the police after a request for assistance. After an accident with military explosives on civilian land, decision of on clearance or other action is taken by the police.


Swedish Coast Guard. 2007. Kemiska stridsmedel till sjöss (Chemical warfare agents at sea).

Swedish National Police. 2007. Rikspolisstyrelsens författningssamling, rikspolisstyrelsens föreskrifter och allmänna råd (Swedish national police statutes, regulations and general guides regarding police measures concerning suspicions dangerous objects).

5.12.5.2 Ongoing Management Activities

Management of Wrecks

The Swedish Agency for Marine and Water Management (SwAM) is responsible for coordinating the investigations as well as the recovery of environmentally hazardous substances and lost fishing gear (ghost nets) from shipwrecks in Swedish waters. There are about 17 000 shipwrecks along the coasts of Sweden and the Swedish Maritime Administration classified 3 000 of these as possibly hazardous for the environment, 300 as hazardous for the environment and 30 of them as an acute environmental threat. Shipwrecks leaking oil or petroleum products pose risk to marine life in Swedish waters. In addition to shipwrecks containing oil there are wrecks containing CWAs in Swedish waters. In an area west of the island of Måseskär in Skagerrak, 28 ships were scuttled after World War II. Over the years, low levels of CWAs were detected in sediment and in fish, indicating that the ships contain dumped CWAs. In 1992, low concentrations of sulphur mustard were detected in the sediments in the area, and in 2016 and 2017, low concentrations of the chemical warfare agent (CWA) Clark I was found in Norwegian lobster, flatfish and shrimps. Degradation products of Clark I were found in approximately 12 % of the sampled organisms. Further studies are performed to investigate which wrecks contain CWAs, the extent of the contamination and their potential impact on the environment. In 2019 SwAM performed additional exploratory fishing, both in the Måseskär area and in the Gotland deep. At Måseskär fishing’s of Norwegian lobster,
shrimp and hagfish were performed close to three wrecks prior not investigated. At the Gotland deep cod and flatfish were fished close to known positions of dumped CWA objects. Analysis results are expected early 2020.

5.12.5.3 Current Projects

Sweden is part of the DAIMON 2 project, with Chalmers University of Technology as a partner.

5.12.5.4 Past Projects and Activities

CHEMSEA
The Swedish Maritime Administration (SMA) was a partner of the CHEMSEA project. During the CHEMSEA project the SMA conducted several research cruises with vessel Baltica to detect and verify CWA in the Gotland deep.

DAIMON
During the DAIMON project, Sweden participated with Chalmers University of Technology as a partner and SwAM as an associated partner.

In the DAIMON project Chalmers University of Technology developed the risk assessment tool VRAKA-CWA. VRAKA-CWA is a risk-based decision support tool that combines measured or collected dump site specific information with expert knowledge on how a leakage event may occur due to anthropogenic and natural underwater activities, e.g. construction work, trawling, anchoring, diving and landslides. The risk is calculated using well established methods, Bayesian updating, applied in environmental risk assessment, and other fields. Parameters considered are the probability of release, the toxicity of the specific CWA and the amount of CWA on the sea-floor at the location in question. The result can be used to e.g. compare and rank different contaminated sites, identify the human activities and natural phenomena that are most likely to cause damage to and leakage from the warfare material on the sea-floor and to identify and evaluate possible mitigation measures.
6. Recommendations

Numerous measures should be applied, to control the effects of warfare materials in the Baltic Sea:

1. Desktop studies: historical and contemporary document research
2. Survey: investigations of contaminated areas and wrecks (e.g. sonar, magnetometers, underwater video, divers, chemical and biological sampling)
3. Documentation: GIS supported data collation e.g., position, type, quantity of potentially hazardous objects their condition, and whether an object has been destroyed/salvaged.
4. Decision support: processing of georeferenced information e.g., by DAIMON DSS
5. Risk assessment and measures: Evaluation of hazardous objects on the seabed and in the sediment based on decision support results. Risk assessment, definition and, prioritisation of clearance requirements for hazardous submerged objects. Balancing of associated risks of site-specific remediation options (e.g., leave as it is, monitoring, recovery).
7. Development of national contingency plans for dealing with hazardous submerged objects in an open transparent process, that is based on best available science.
8. Development and selection of Best Available Techniques (BAT) and Best Environmental Practices (BEP) of environmentally friendly, secure and cost-effective low-noise and low-pollution practices and technologies for the remediation of hazardous submerged objects (e.g. robotic technologies). Continuous evaluation of technical and scientific progress.

6.1 International Ammunition Cadastre

An integral part of coordinating efforts is a centralized ammunition cadastre including results of previously conducted and ongoing research, management and analysis options for historic data from archives as well as risk determination and monitoring tools for decision making regarding UXO management and for monitoring of affected areas. The following functionalities should at least be provided:

- Mapping of so far known historic datasets (maps, documents, reports) which include spatial information;
- Recording, management and analysis of historic documents/texts based on actual data/text mining technologies
- Management and visualization of actual datasets (bathymetry, side scan, geomagnetic, video) for evaluation, analysis and monitoring purposes;
- Spatial planning capabilities for administrative use;
- Incorporation of relevant national and international datasets (e.g. wind parks, Cable, pipelines etc.) from centralized data portals (EMODnet, HELCOM Data & Maps) and national authorities;
- Risk determination and decision support tools following integrated assessment approaches;
- Addition of information from new cruises and measurements and if necessary declaration of hotspots
6.2 Archive Work

**Topics:** national and international archive work and context-based interpretation

6.3 Marine Spatial Planning

Marine spatial planning is a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process.

Topic: Ammunition its effects on humans and environment should be an integral part during national and international processes of marine spatial planning

6.4 Consumer protection

- Increase data catalogue → more studies
  - Laboratory experiments
  - Monitoring of hot spots (dumping grounds, blast grounds) for the entire compound spectrum (TNT, RDX CWA, etc.)
    - On a regular basis
    - Continuous monitoring (not only point in time)
    - Close the gap availability in ecosystem → availability to seafood consumers
    - What about those areas that are not hotspots?
  - Reassessment of literature → reassessment of risk to seafood consumers

6.5 Harmonizing Definitions

- Z.B e.g., (chemical) waste originating from sea dumped chemical weapons

6.6 European Quality Initiative

Three ways of endorsing high quality execution of offshore UXO treatment were identified. These ways encompass the generation of a European quality guideline, the establishment of a dissemination platform and the provision of offshore testing infrastructure. Central to all these ways of endorsement is the internationalization of upcoming efforts, due to the international nature of the industry that is targeted by the quality initiative.

Firstly, European quality guideline should be developed. However, it must not be a simple translation of the existing German document. Its generation needs to be subject to a widening of scope in order to be able to account for the situation of all European countries as regards their UXO history and distribution, the natural condition of their affected waters and their legal and normative situation. A sufficiently abstract document will be necessary. This document shall be accompanied by instructions on how national groups can deduce a national document, that meets their own specifications. This European quality guideline should be adjusted and updated in regular intervals.

Secondly, a dissemination platform for the exchange of information should be established. This platform may be both physical and digital. Annual quality workshops could be conducted. They have the potential to facilitate the dialogue between affected stakeholder groups and across nations. This way a multitude of different perspectives are contributed to the discussion of best practices and high-quality execution of UXO treatment. Based on feedback by participants of the dissemination platform, workshops might be organized, that cover selected focal areas.
The workshops may be coupled with a symposium, that serves as a gateway to provide scientific findings and progress to the industry and to facilitate corporation between research bodies and private companies. Results and insights that are gained during the workshops or symposia, may be published and organized using a web platform. The web platform could furthermore be used as a library for questions regarding UXO treatment but also as a means of communicating about practical challenges and newly applied solutions.

Finally, further emphasis should be placed on providing testing infrastructure, that is necessary for conformity assessment. Tests may be conducted for equipment, in order to validate its technical parameters or to verify its suitability for specific tasks. They may also be conducted for companies, giving them the opportunity to prove their ability to execute selected processes of UXO treatment. These tests would increase confidence of employers and authorities in UXO survey and clearance companies and allow for a certification of products or companies. In addition, UXO service providers could test their equipment for its applicability in certain scenarios.

6.7 Harmonizing UXO Risk Management

It should be aspired to find a common foundation for risk management in the offshore UXO context. Currently a discrepancy between probabilistic and deterministic approaches to risk assessment exists. Furthermore, a gap between the methodological potential of risk assessment and the application of risk-based approaches in reality is apparent. These gaps can be closed by assessing the requirements for a risk assessment taking place in the context of offshore UXO treatment and comparing them with existing approaches that are applied in other industries. The result could be the development of new approach or the adaptation of an existing one, that can be found in the existing methodological catalogue.

6.8 Management Options

For detonations which cannot be avoided, standard mitigation procedures should be developed on the basis of best available science. These standard procedures would then have to be used in scenarios in which a case-by-case impact assessment is not feasible. This may be the case when facing imminent danger or for general use in conservation management and marine spatial planning.

In the light of the increasing need to remove warfare materials in the Baltic and the negative consequences of detonation practices for the marine environment, it is necessary to develop environmentally friendly and cost-efficient approaches for their treatment or ways to mitigate the impact of existing removal techniques.

Although indicators are still under development, it can be assumed that Good Environmental Status can only be achieved by an extensive reduction of underwater detonations or by applying a comprehensive set of suitable mitigation measures.

Substantial knowledge on the occurrence, life cycle parameters and behaviour of migrating marine species is essential to these analyses. Known feeding, migration, nursery, spawning, summering or overwintering areas of sensitive species can be entered into a database for the purpose of preparing military exercises or munitions clearance, for developing standard procedures for future cases of imminent danger, but also for general use in conservation management and marine spatial planning. If information is lacking, assume animals could be present any time of the year. Ways of disseminating and making use of these information need to be developed.
6.9 Monitoring Programme

6.10 Identification of Areas of Concern

6.11 Define BEP