AMMUNITION IN THE DUTCH NORTH SEA

An overview of the effects of leaking dumpsites and munition-clearing explosions

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Executive summary

This report can act as a background document and first exploration of seadumped munition for the North Sea Foundation. It gives an overview of the risks associated with munition dumpsites and UXO clearing practices, and a suggestion towards the most relevant next steps for the North Sea Foundation.

- Munition dumpsites have reached the point where they have started leaking toxic substances in the environment. In the Dutch munition dumps, these substances are leaking in incredibly small amounts that dilute very quickly. However, it is important to keep monitoring in case this changes, and to keep up to date with the best monitoring practices.

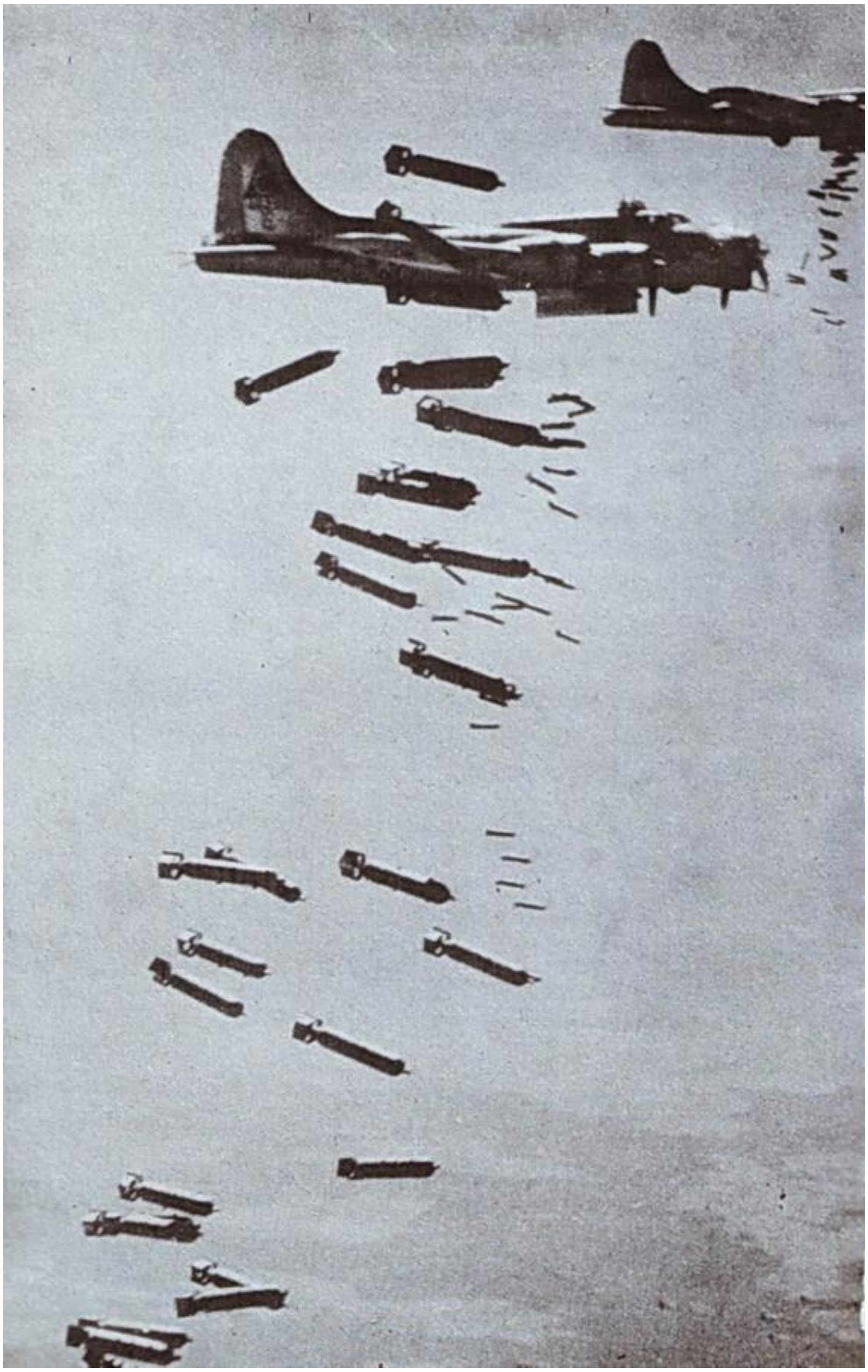
- UXO-clearing is an important task that makes the marine environment safer for all its users. However, the use of explosions can have a harmful effect on sensitive species like the harbour porpoise. The current use of an ADD that can scare individuals away up to 1 km distance is not enough when the range in which harbour porpoises can lose part of their hearing is up to 10 km.

    - It is much more effective to dampen the sound of the explosion with a bubble screen or a double bubble screen.
    - Even better would be to avoid a deep-water explosion altogether, by using advanced equipement to relocate munition to shallow water, lift it to the surface, or defusing a munition item by cutting through the fuses with a waterjet. This could be done by military personell, but there is also a fairly big group of experts in UXO-clearing companies already familiar with this equipment. Giving them the authorization to to actually clear the munition that they find might speed up the process.

The potential harm of continued underwater explosions is more pressing than the leaking munition dumpsites. Therefore, this report recommends the North Sea Foundation to focus on reducing the harmful effects of underwater explosions. Either by introducing the use of bubble screens in the Harbour Porpoise Protection Plan, or by bringing stakeholders together to stimulate the use of innovative new technologies.

Table of Contents

1. Introduction



Bomber planes from the US air force drop explosives on industrial targets in Germany (Source: Military Images, 2018).

1.1 Project definition

Explosive remnants of war (ERW) can still be found in marine environments worldwide (fig 1). Ranging from munition launched during war that ended up in sea, to intentionally discarded military munition in so-called marine dumpsites. Due to lost, incomplete or absent military records, the exact amount of discarded marine munition (DMM) is hard to quantify, but there is an estimated amount of 1.6 million metric tonne of dumped munition in the German areas of the North Sea and Baltic Sea alone (Böttcher et al., 2011). The fate of these degrading and corroding legacies of war are increasingly becoming a topic of interest. From research project in the Baltic Sea concerning themselves with the danger of toxic chemicals leaking from dumpsites (DAIMON, 2019; Interreg, 2017), fishermen and windpark developers being aware of the risks of accidentally encountering an unexploded bomb at sea (Noordzeeloket, 2021; Bos, 2019), and environmental groups raising awareness about the acoustic effects from munition clearing explosives (NABU Schleswig-Holstein, 2010).

Figure 1. A map of all known chemical munition dumpsites worldwide. Source: Wilkinson I, 2018.

The Netherlands is no exception to this ammunition problem. Munition leftover from World War II is still present in the Dutch part of the North Sea. There is an estimated amount of 11.500 tonnes of dumped ammunition discarded across four locations; one located in the Waddensea (500 ton of dumped material), in the Eastern Scheldt (30.000 ton), and two dumpsites located in the North Sea with a total of 80.000 tons (fig. 2) (BeoBom, 2013; den Otter et al., 2023). At the time, this was a common and legal practice to get rid of excess munition (pers. corr. RWS). Nowadays, the locations of these dumpsites are ‘no-go-zones’, to protect the public and the industry from accidentally encountering the dumped items.

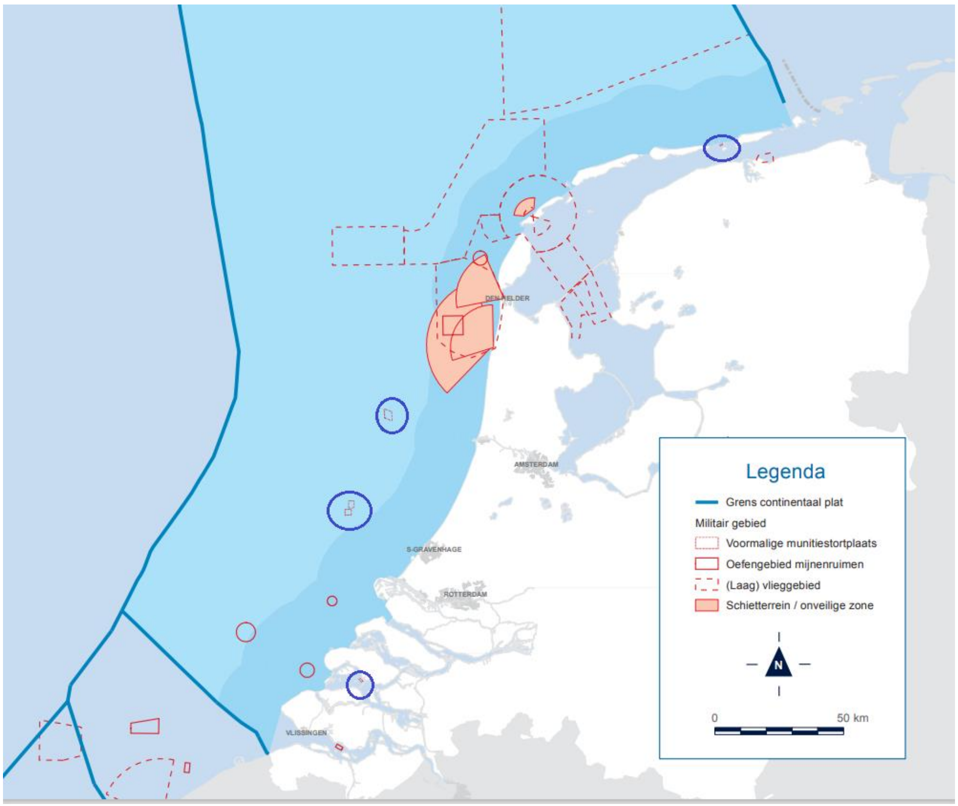


Figure 2. A map of the military areas of the Dutch Economic Exclusion Zone. The munition dumpsites are circled in blue. From North to South: Waddensea dumpsite, 500 tonnes of material. IJmuiden dumpsite, 30.000 tonnes of material. Hoek van Holland, 50.000 tonnes of material. Eastern Scheldt, 30.000 tonnes of material.

However, the munition can still end up causing problems. After over 70 years of slow degradation, the metal hulls have potentially started to corrode to the point where the explosive load is exposed (Jurczak & Fabisiak, 2017; Pfeiffer, 2012). For example, the Belgian dumpsite Paardenmarkt, containing mostly chemical weapons, started to leak musterdgas in 2019 (Derycke, M., 2019). While there are no chemical weapons in the Dutch dumpsites, the TNT from conventional weapons is a toxic substance that can dissolve in seawater as well. The monitoring of these dumpsites falls under the responsibility of Rijkswaterstaat (RWS), who measures the concentration of munition compounds in the seawater surrounding munition dumpsites every 5 years (Hennis-Plasschaert, J. A., & Schultz van Haegen-Maas Geesteranus, M. H., 2014). While the measured concentrations are still low, research from dumpsites around the world suggest that even low concentrations can lead to adverse health effects in marine species.

Aditionally to the documented dumpsites, a large amount of bombs on the North Sea are undocumented and can be encountered accidentally. These are unexploded ordnances (UXO's), scattered on and in the seabed as a result of military actions during the war. Many of these items have been found in the North Sea over the course of the past 20 years (fig. 3). When disturbed, these munition items could still explode, leading to dangerous situations. In 2005, a fatal accident occurred when three Dutch fishermen lost their life after their fishing ship accidentally fished up a WWII bomb (ANP, 2005). This incident specifically has led to a closer cooperation between Dutch and Belgian mine-clearing ships, and the increased vigilance of fisherman has led to more reports of found UXO's (Ministerie van Defensie, 2014). With the increased activity on the North Sea, in the form of fishing, dredging and the increasing amount of windparks at sea, multiple commercial companies have sprung up to provide historical research surveys and seafloor mapping to identify UXO hotspots and risky objects. At time of writing, 16 companies are certified in the Netherlands to perform such identifying research (VOMES, 2023). In the Netherlands, the resulting found munition is cleared by the EOD-department of the Navy (Kustwacht Nederland, 2022). The clearing of found munition is still often done by explosion, leading to loud sounds and shockwaves that can be harmful to marine species.

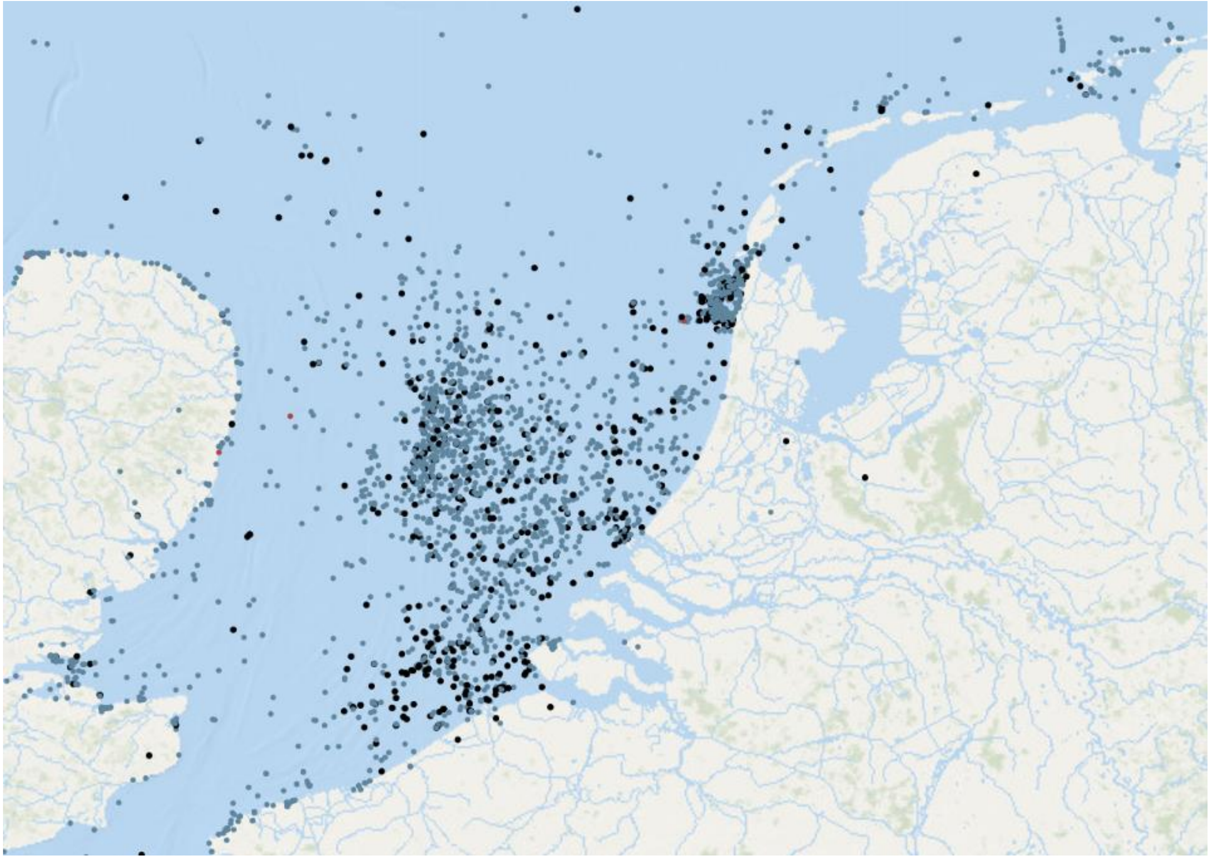


Figure 3: A map of muntion encounters in the North Sea from 1999 to 2020. Source: OSPAR, 2020

During and right after WWII, the sea-dumping of munition was done with a worldwide 'out-of-sight, out-of-mind' attitude. Now, over 70 years later, these bombs still prove to cause problems to human safety and to the environment. This illustrates how we continue to learn about the world we live in and the impact that human activities have on the environment. With this increasing understanding comes also the responsibility to adjust our actions and policies. This report aims to provide an overview of the human and environmental risks associated with DMM and UXO's through the lens of the most recent research available. Next, the policies that the Netherlands currently has in place will be analyzed for their effectiveness and the additional impact they might have on the environment. The result of this report will be a series of policy recommendations to monitor and clear munition in a way that is effective, safe and with minimal additional environmental damage. These recommendations will be presented in an action plan geared towards The North Sea Foundation (NSF).

1.2 The North Sea Foundation

This advisory report is the result of an internship taking place at the North Sea Foundation (NSF), a Dutch non-governmental organization focussed on the conservation and sustainable use of the North Sea. They are an independent, science-based organisation who value collaboration to find solutions for challenges on the North Sea (Stichting de Noordzee, 2022). Their work takes many different forms, from researching and collaborating with stakeholders who aim to sustainably use the North Sea for energy and food production, to establishing and monitoring protected natural areas, and campaigning against pollution on the beach, in rivers and at sea. This project takes place in team

Clean Seas, and aims to better understand the impact of munition-related pollution and the possible ways of minimizing this impact. This report is the first in-depth look at sea-dumped munition for NSF. It will provide much needed background information on munition-related issues worldwide, the current status of munition dumpsites and clearing in the Netherlands, and a final advice section that gives NSF direction on whether munition-related issues should be put on the agenda for NSF.

1.3 Goal and Research Questions

The goal of this project is to provide NSF with an in-depth look at the effects of discarded ammunition in the North Sea and to identify if there is room for improvement in the current monitoring policies and disposal methods used by the Dutch government. To reach this goal, this report provides an overview of the risks associated with marine munition in general, whether these risks are present in the Dutch north sea, and which policies are currently in place to manage these risks. These policies will then be analyzed for their effectiveness and whether adjustments need to be made.

For this report, the following main question has been used:

What are the environmental and human risks of leaking ammunition dumps and the clearing of ammunition in the Dutch North Sea and what steps can the North Sea Foundation take to reduce future harm?

To further answer this question, the following subquestions have been used:

1) What are the direct and indirect risks associated with leaking ammunition dumpsites?
2) What are the risks associated with UXO encounters and UXO clearing?
3) What is the current Dutch policy regarding monitoring of dumpsites and clearing of UXO?
4) Are there alternatives to monitoring and clearing, and how do these compare to the current approach?
5) What actors are involved in ammunition monitoring and ammunition clearance, and what is their influence on policy and or practice?
6) What steps can NSF take to influence these actors, with the goal of reducing environmental harm from ammunition related effects?

1.4 Approach

The basis of this report will be an extensive scientific literature review of the release of munition compounds from degrading ammunition and the effects of tnt in the environment. Additionally, this report will review the different methods of clearing munition and the environmental effects of these different methods. Whenever possible, studies from the North Sea have been used, but a large amount of research has been conducted in the Baltic Sea. While there are differences between the Baltic and North Sea, for the purpose of this report these differences are negligleble, unless otherwise stated. This report will also make use of interviews, either with scientific experts in the topic of dumped munition, technical experts of commercial uxo clearing companies, parties that encounter munition, and possibly also policy makers. The total list of interviewees can be found in the appendices (Appendix C).

1.5 Formal framework

This report results from the internship that takes place within the Science, Business & Policy track of the Marine Biology Master's program, University of Groningen. The goal of this internship is to learn how to integrate the policy aspects of an NGO with scientific knowledge of marine biology, to provide an independent advice-report. The advice is aimed at the North Sea Foundation as the internship provider. The final report aims to have a balance of 50% scientific and 50% policy aspects. This internship took place from January 9, 2023 to June 30, 2023 and lasted effectively 25 weeks. The supervision of this project was split between supervisors from the University of Groningen and from NSF. All of them can be found in table 1.

Table 1. Overview of internship supervision.

Name	Institute	Function	Role supervision
Marijke Boonstra	The North Sea Foundation	Senior Project Leader Clean Seas	Workplace supervisor*
Dr. Willem van de Poll	University of Groningen, Marine Biology	Lecturer	Scientific Supervisor
Dr. Karin de Boer	University of Groningen, Science, Business and Policy Master's track	Lecturer	SBP-supervisor
Ewout van Galen	The North Sea Foundation	Head Program Coordinator	Secondary workplace supervisor*

**) Marijke Boonstra left The North Sea Foundation halfway through the internship. She remained supervisor for this project, but some workplace-supervisor duties were taken over by Ewout van Galen.*

1.6 Reading guide

Chapter one gave a small introduction to the topic and the framework of this internship report. The following chapters will explore the topic of munition as follows:

Chapter 2 will provide necessary background information, including a scientific overview of the risks associated with munition dumpsites and underwater explosions.

Chapter 3 will focus on the Dutch dumpsites. It will provide an overview of the locations, the current policies and monitoring practices, the current risks and will end with an overview of possible improvements.

Chapter 4 will focus on the UXO encounters in the Dutch Economic Exclusion Zone. It will provide an overview of the amount of encounters over the past years and the disposal methods used. It will provide the national and international policy agreements and the sound mitigations that are currently in place for underwater explosions. It will provide multiple sound mitigations strategies that are available and explore why these are not currently in use.

Chapter 5 will summarise the findings from chapter 3 and 4. It will provide The North Sea Foundation with an overview of the most promising possible improvements and a suggestion on how to start implementing these improvements.

2. The effects of underwater munition

Keynotes chapter 2

- *Munition dumpsites are leaking all over the world. Most detected concentrations are below quality standards and LC50 levels. New in situ research does suggest a higher level of liver damage in species near munition dumps.*
- *Underwater explosions mostly occur due to accidental contact or controlled clearing explosions. Without sound-mitigating factors, these can be very harmful to species like the Harbour Porpoise.*

On arrival at the ammunition dumping ground off Cairnryan, near Stranraer, Wigtonshire, Scotland, members of the Royal Army Ordnace Corps (RAOC) place shells on gravity rollers that take the ammunition over the side of the ship and into the sea. Note the man in the background who is simply throwing ammunition overboard. (source: IWM, H 42208)

2.1 Historical and legal context

In 1863, the chemical trinitrotoluene (TNT) was first developed as a dye (Wilbrand, 1863). It wasn't until the 1900's that this explosive started to be used in German and British munition. Not long after that, 1913 rolled around and the First World War started. The production of TNT and other conventional explosives like RDX, alongside the use of chemical weapons, skyrocketed. This hightened production continued during the Second World War.

Unfortunately, the dangers of World War I & II munition are still present due to the many ways in which munition items have ended up in the marine environment from war actions and army excercises. From artillary weapons on shore or on ships, the laying of sea mines along the coast, to ships sinking with munition still on board and aircrafts dropping their bombs over sea, bombs can easily end up unexploded and submerged on the seabed. These unexploded ordnances (UXO's) can still be dangerous when encountered. However, the largest contributor of munition left at sea is through the intentional dumping of munition material (Barbosa, Asselman, & Janssen, 2023).

The idea behind this dumping seemed logical at the time; munition that contains explosive material has an expiration date. Over time, the detonators and fuses could become unreliable or the energetic chemical components might degrade to the point of becoming inert or unstable (Pfeiffer, 2012). Munition like this is unfit to be used for military actions and needs to be disposed of in some way. Especially after wartime operations, when the production of munition was high, the amount of leftover and confiscated munition would be high as well. Militaries across the world have had to deal with the issue of disposing of these large amounts of munition unfit for use. For a long time, sea-dumping was seen as a more environmentally friendly option compared to land-based disposal (Bergmann et al., 2022). The first sea-dumping reportedly took place in 1919 by the USA as a result of World War I, but many countries around the world would soon follow (Barbosa et al., 2023). Over 40 countries have admitted to munition dumping operations at sea, with main contributors being the USA, France, the UK, Japan and Russia (Carton & Jagusiewicz, 2009). In Europe, both World Wars contributed to a large amount of dumped material, consisting of WWI era chemical weapons like mustardgas, Adamsite, Lewisite and Tabun, and mostly conventional weapons from WWII (fig. 4).

At the hight of the dumping of munition material and military waste, this process was still completely legal. In 1958, the Geneva Convention of the High Seas only prohibited pollution through radioactive waste in all parts of the sea that are not territorial or internal waters (UN Convention on the High Seas, 1958). It wasn't until 1972 that the "Convention On the Prevention of Marine Pollution by Dumping of Wastes and Other Matter" came into existence, also known as the "London Convention". This convention is a treaty from the International Maritime Organization (IMO) and was one of the first global agreements that aimed to prevent marine pollution in the marine environment, currently with 87 contracting parties (IMO, 2019). The focus of this convention is to limit the amount of dumped material in the ocean. Article 1 of this convention states that the contracting parties should "prevent pollution through the dumping of waste and other matters that is liable to create hazards to human health, harm to living resources and marine life, damage amenities and interfere with other legitimate uses of the sea" (IMO Convention On the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972). While not explicitely stated, this includes the dumping of legacy munition in the ocean.

In 1980, the issue of conventional weapons was expanded on in the Convention on Certain Conventional Weapons (ICRC Convention on Certain Conventional Weapons, 1980). This treaty was established by the International Committee of the Red Cross (ICRC), a neutral and humanitarian organization, and currently has 126 contracting parties. Most of the content in this convention focusses on the prohibition and restriction of conventional weapons that are indiscriminate and/or cause unnecessary suffering, and is not focussed on the dumping of said weapons. However, Protocol V of this convention does cover the effects of explosive remnants of war (ERW) in the form of unexploded ordnance and abandoned ordnance. This protocol requires parties to reduce the dangers of ERW as much as possible. It specifically states that these rules only apply to conflicts that occur after the creation of the Protocol. This means that these agreements do not apply to any explosive remnants from WWI and WWII, and there is no responsibility to clear these munitions. There is however an addendum that states that “any party can seek assistance from others, and each party (in a position to do so) should provide help as far as necessary and feasable.” In practice, many European countries deal with the explosive remnants from WWI and WWII individually, or in small partnerships.

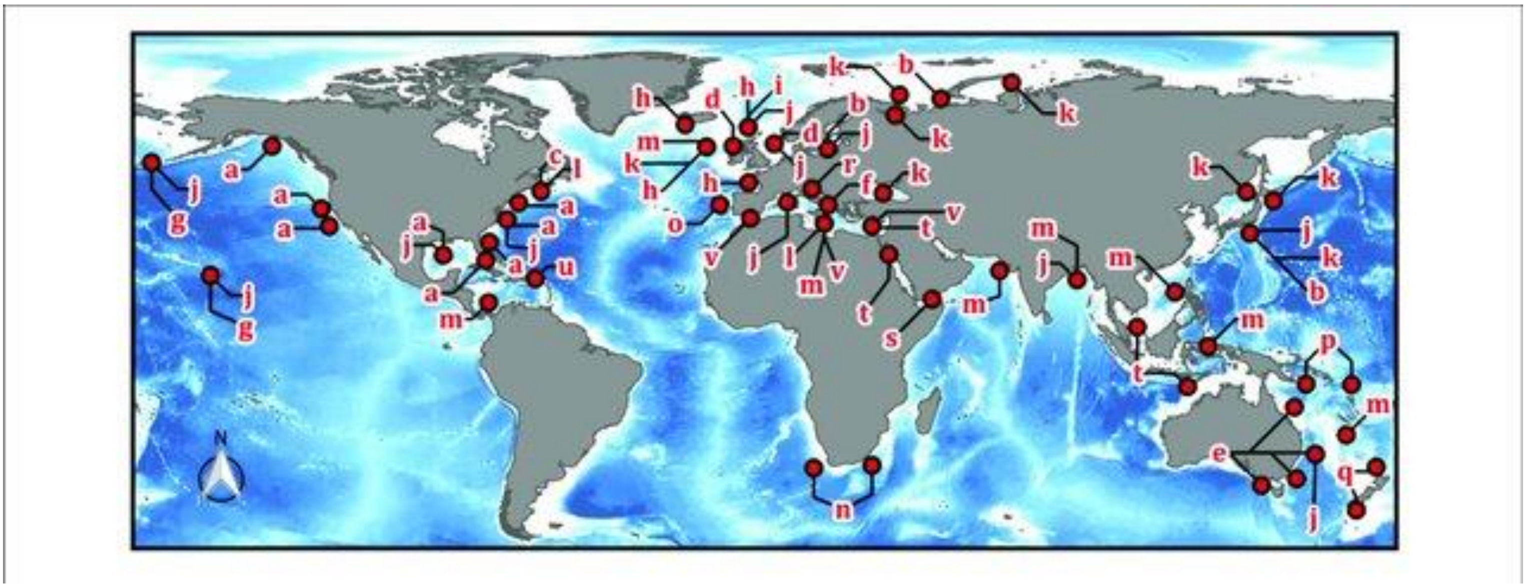


Figure 4. Global distribution of documented marine sites with munitions present (includes conventional weapons, chemical weapons, and UXO). Map created by Beck et al., 2022. Letters refer to literature references: a, MEDEA (1997) and Bohaty (2009); b, MEDEA (1997); c, Ampleman et al. (2004); d, Missiaen and Henriet (2002); e, Plunkett (2003); f, Amato et al. (2006a,b); g, Bearden (2007); h, Nixon (2009); I, HELCOM (1995); j, Brankowitz (1989); k, James Martin Center for Nonproliferation Studies (2017); l, Bull (2005a,b); m, US ARMY (2001); n, Godschalk and Ferreira (1998); o, Thiel (2003); p, Francis and Alama (2011); q, Royal New Zealand Navy (2015); r, Obhodas et al. (2010) and Valkovic et al. (2009); s, Nadim et al. (2008) and National Geospatial-Intelligence Agency (2017); t, Landmine Action (2005); u, Porter et al. (2011); v, UNEP/MAP (2009). Note that the map resolution is coarser than the number of actual munitions dumps; for example, the OSPAR report by Nixon (2009) (letter h) contains 148 individual munitions dumpsites. (Image drawn using QGIS, with data from: The GEBCO_2014 Grid, version 20150318, Wessel and Smith, 2017). Image source: Beck et. al., 2018.

2.2 A variety of explosive remnants of war

All explosive munition that ends up left behind after military actions – by accident or by design – can be classified as 'explosive remnants of war', or ERW. However, there are different risks associated with different types of ERW. This report will focus on discarded military munition (DMM) and on unexploded ordnance (UXO) of the conventional kind.

Discarded military munition is a category of ERW that includes all munition that has been intentionally left behind after military practices, or intentionally dumped in the environment. These include the marine munition dumpsites. Intentionally dumped munition was often dumped after the end of war, and consisted of leftover material and confiscated material. This results in a mix of many different types of munition, often dumped without active fuses and sometimes still within full storage boxes. These dumpsites usually have a large amount of munition located in one spot. This makes it easier to restrict access to this location. Countries can enact fishing bans, anchor bans and even restrictions for shipping for these locations. The lack of active fuses and the the ability to restrict activity near these locations reduces the possibility of accidentaly encountering any of the dumped munition and setting of an accidental explosion. However, there are worries for the water quality if such a large concentration of munition material starts to leak chemical content in the environment.

For unexploded ordnances (UXO), the risks are different. UXO are munition items that have been deployed during wartime activities, often dropped with active fuses, but for some reason did not explode on impact. This leaves many UXO scattered on the seabed. If these items start leaking, the chemicals will be less concentrated due to the scattered and isolated nature of these items. However, the risk of an accidental explosion is present, especially in area's with bottom trawl fishing and dredging activities.

A final type of ERW are sunken ship- or planewrecks that still have munition items on board. For this report, these wrecks are not included as a separate type of ERW. When it comes to risks, these are largely dependent on the type of wreck and the amount of munition on board. A wreck with a large amount of munition still on board could start leaking higher concentrations, similar to a small dumpsite. The explosive danger of a wreck can be dependent on many different factors, like the amount of munition on board, whether the wreck is off-limits for activities such as diving, the shock-sensitivity of the munition and the stability of the wreck itself. Therefore, these wrecks should be assessed on a case-by-case basis and are excluded from this report.

2.3 Leaking of toxic content

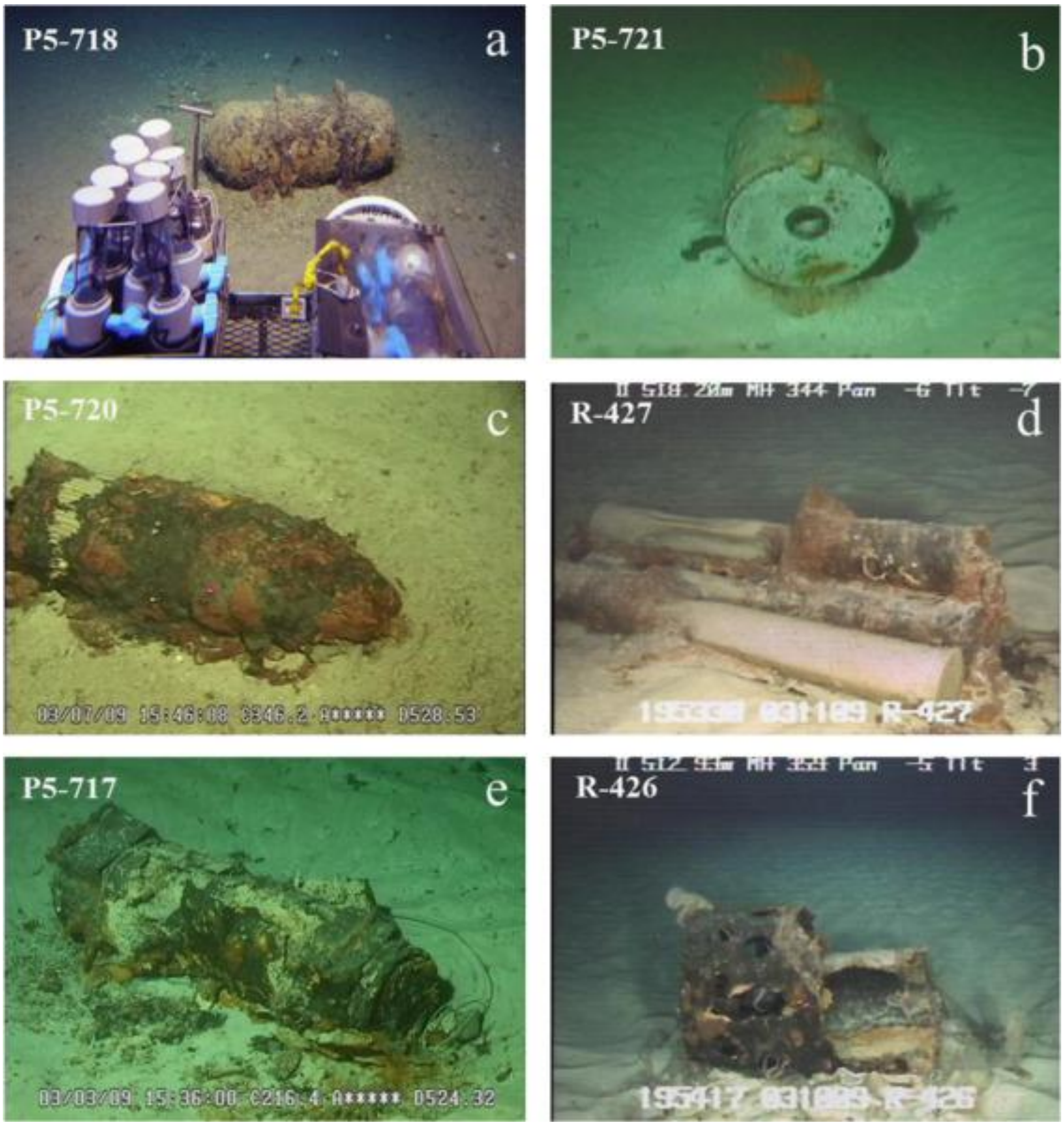
Corrosion of metal hulls

The leaking of munition material starts with the corrosion of the protective hull after longterm exposure to seawater. Most of the munition located in the North Sea originates from World War II, meaning by now it has been exposed to seawater for over 70 years. For World War I munition, this has already been well over a 100 years. The actual speed of corrosion can vary depending on the abiotic factors at play. Increased temperature, pressure and salinity can influence the rate at wich different metals deteriorate, while the steel quality and varied thickness of the shells means different estimated times for the total degradation (Pfeiffer, 2012). For instance, the type of bombs that are more likely to end up as offshore UXO's like aircraftbombs, seamines and torpedo's are thin-walled items with aluminum hulls (Kustwacht, 2020). It takes much less time for these items to degrade compared to thickwalled munition like heavy artilliry and projectiles. Aditionally, oxygen availability is also needed for corrosion to take place. Biological growth on top of munition items could increase the oxygen flux and thus the corrosion (Macleod, 2016), while sediment cover can create anoxic conditions and slow down the corrosion significantly (George et al., 2015; Wang, Liao, George, & Wild, 2011). In general, corrosion rates of steel are higher in seawater compared to fresh water and a rough estimated value ranges from 0.01-0.575 mm per year for the corrosion rate of steel in saline water (Voie & Mariussen, 2017).

In situ measurements of WWI and WWII era munition and shipwrecks over the past 20 years show that much of the material is currently corroded. In the 90's, reports from chemical dumpsites in the Baltic Sea revealed that 70 to 100% of the munition had been corroded (Beck et al., 2018). A 2006 study in the Adriatic sea revealed that the corrosion of chemical munition was extensive enough to expose the contents and leak chemical warfare agents into the sediment (Amato et al., 2006).

HUMMA, the Hawaii Undersea Military Munitions Assessment, was a deep-water investigation into the state of conventional DMM near the Hawaiian islands Oahu and Molokai, with investigations taking place from 2007 to 2012. In this study, visual images were captured by 6 ROV's and 16 human-operated vehicles of 1842 DMM items, dumped by the US military between 1919 and 1970 (Edwards et al., 2016). The majority of these items, 66% or 1222 objects, were severely corroded but still visually intact (fig. 5). Aditionally, 29% of items were breached with their contents exposed. The remaining 5% was classified with mild to moderate degrees of corrosion (Silva & Chock, 2016).

A 2015 report from Denmark indicated 'completely corroded' munitions in the Bornholm munition dumpsite, and included reports from fishermen who caught lumps of hard gas ranging from the size of tennisballs to lumps of 50 kg (Sanderson & Fauser, 2015). Additional corrosion studies on chemical weapon hulls determined that while one of the best constructed containers could last another 200 years, the leaking of material could happen much earlier. Non-alloy steel, which was used often for pre-war containers, has a lower corrosion resistance. Uneven corrosion can lead to the creation of leakpaths in these types of barrels between the time of writing and 2040 (Jurczak & Fabisiak, 2017).



Figuur 5: Examples of DMM observed in the Hawaii Undersea Military Munition Assessment. Description of items: (a) moderately corroded aerial bomb, (b) depth charge exhibiting mild corrosion, (c) significantly corroded artillery projectile, (d) bundle of brass artillery cartridges with significantly corroded projectiles, (e) severely corroded cluster bomb, and (f) severely corroded depth charge. Dive designations are provided in the upper lefthand corner of each image. P5 refers to the Pisces 5 Human Operated Vehicle and R refers to the RCV-150 Remotely Operated Vehicle. Numbers following vehicle designation refer to a particular assigned dive number. Source: Silva & Chock, 2016.

Dissolution speed of chemicals

After the corrosion of the metal hulls has created pathways for seawater to come in contact with the explosive load, the chemicals can start to enter the marine environment. The most common explosive compound that is released from conventional muntion is TNT. To a lesser extent, explosives RDX – also known as hexogen or cyclotrimethylenetrinitramine – and HMX – also called octogen – were used in WWII as well. These are the main three explosive compounds that are regularly included in studies towards toxicity of conventional munition related compounds.

TNT, RDX and HMX are all soluable in seawater, but the speed at which it dissolves increases exponentionally with temperature (fig. 6). At 20C, TNT has a dissolution rate of roughly 70 – 100 mg/L, with the dissolution of RDX at 40 mg/L and HMX only >10 mg/L (Beck et al, 2018).

Several environmental conditions present in dumpsites can chemically transform TNT into different degradation products. Bacteria and fungi are able to transform the nitro-group into an amino-group, transforming TNT into ADNT and DANT. TNT can also mineralize into ADNT without the help of microbes, through photo-reactions and Fenton reactions, which are reactions influenced by the presence of naturally occuring Fe(II) and hydrogen peroxide (Beck et al., 2018). In 2010, mineralization rates of TNT in North Sea seawater had been established to have a half-life of 5 years. In sediment, this process is much faster and the halflife of TNT in coastal zones can be only a few days or weeks (Harrison and Vane 2010, Montgomery 2014).

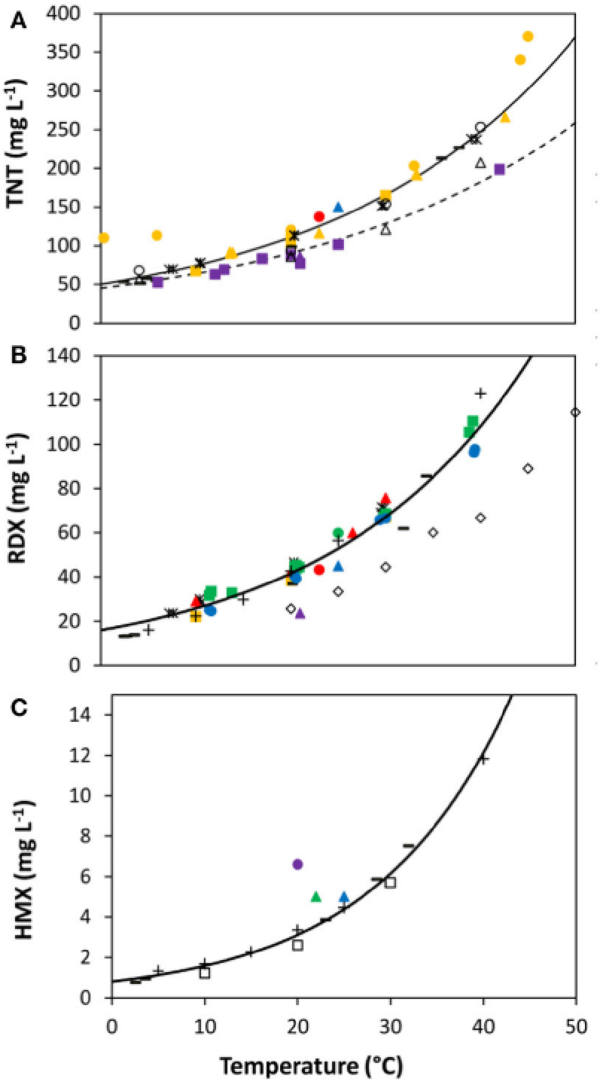


Figure 6. Soluability of munition compounds (A: TNT, B: RDX, C: HMX) as a function of temperature. The various different icons refer to the wide range of different studies that have been compiled for this graph. Data compiled and graph sourced from Beck et.al., 2018.

The release of these chemicals (TNT, RDX, HMX and the degradation products of TNT) affect the quality of the surrounding seawater. A US study (Lotufo et al., 2017) compiled data from different dumpsites around the world to create an overview of the concentrations of munition compounds (MC) in the marine environment (Table 2). These include 2 locations near Puerto Rican Isla de Vieques, a 2001 value from the Eastern Scheldt, Point Armour in Canada, Swiss lakes Thun and Brienz, Lake Mjøsa in Sweden and coastal sites in Norway. The values in the table represent the highest measurement at each of these locations. Most detected concentrations of munition compounds are quite low, ranging from an RDX measurement of 12.7 µg/L in Norway to measurements of 0.0003 µg/L in the Swiss lakes. However, two measurements are much higher, for TNT and DNT measured at the Isla de Vieques Bombing Range. Important context is that these measurements were taken at 10 cm distance from a bomb with visible damage (Porter et al., 2011). In this study, the concentration of TNT was also measured 1 meter from the breached bomb, which resulted in a mean concentration of 13 µg/L. This shows that the concentrations released from leaking munition can rapidly dilute with distance.

Table 2: Locations of munition dumpsites around the world, the detected compounds at those locations and a measurement of the highest measured concentration. Source: Lotufo, 2017.

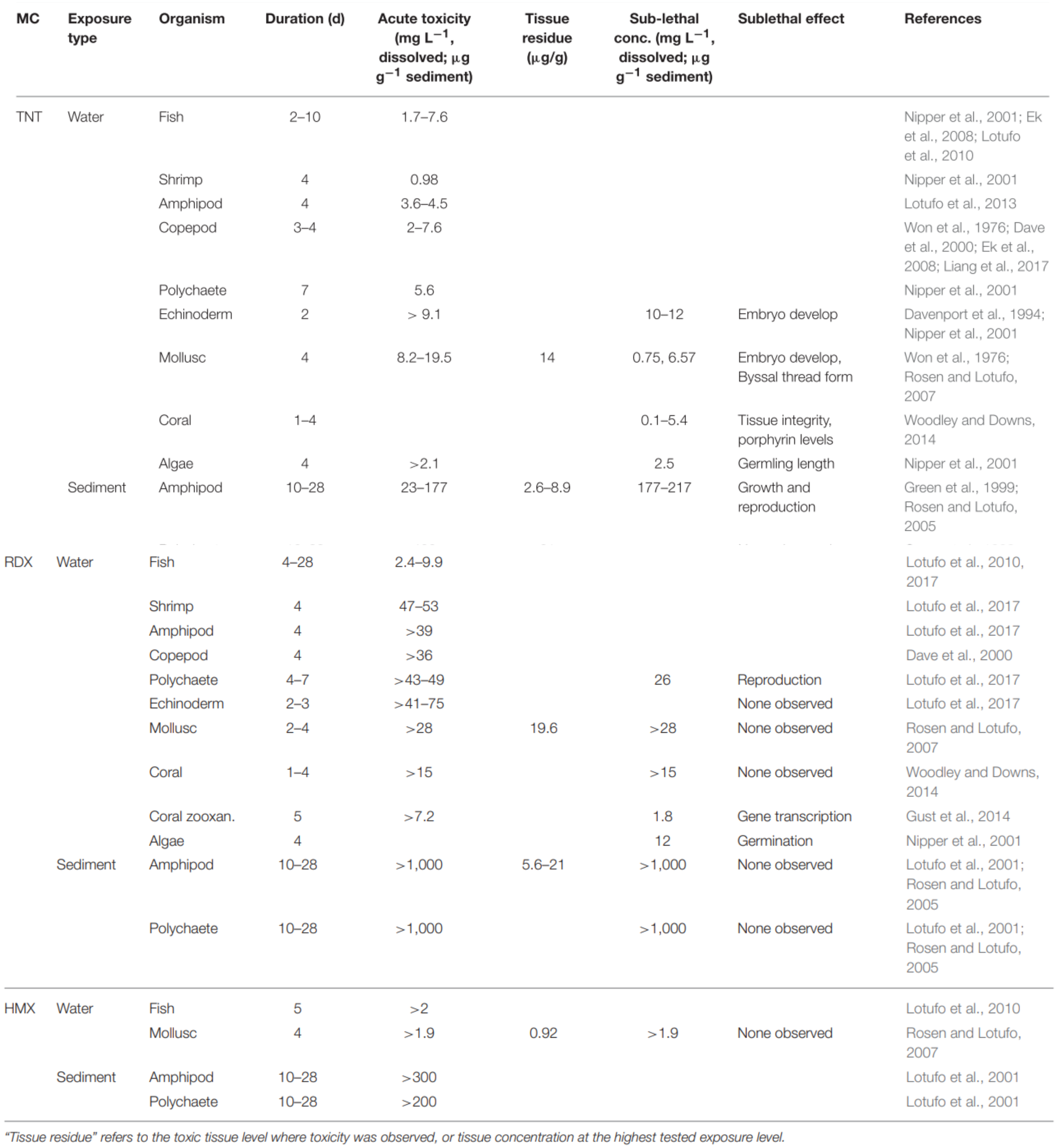
Location	**Munition Compound (MC)**	**Max. Conc. (µg/L) in collected water samples**
Isla de Vieques Bombing Range (Porter et al, 2011)	2,4,6-TNT	105
	2,4 + 2,6-DNT	107
	RDX	4.96
Isla de Vieques (ESTCP Project)	2,4,6-TNT	7.5
	2-A-4,6-DNT	0.09
	2-A-2,6-DNT	0.32
	2,4-DNT	0.07
	RDX	0.011
Eastern Scheldt (Lotufo, 2017; den Otter et al., 2023)*	2,4,6-TNT	< 0.5 (below detection limit)
Point Armour (Ampleman et al. 2004)	2,4,6-TNT	0.002
Lakes Thun and Brienz (Ochsenbein et al, 2008)	HMX	0.0003
	RDX	0.0004
Coastal sites Norway (Rossland et al. 2010)	2,4,6-TNT	0.03
	HMX	0.62
	RDX	12.7

*) data originally from Van Ham et al. 2007, which is not openly accessable.

Toxic effect on species

Dissolved muntion compounds in seawater can be taken up by a wide range of species. These compounds can be toxic. The following table (table 3) gives an overview of both the concentration of MC in seawater and sediment which leads to acute toxicity, and the concentration that could lead to sublethal effects in various taxonomic groups (Beck et al., 2018). Out of the three main munition compounds, TNT is the most toxic, with lethal concentrations TNT in seawater ranging from 0.98 mg/L for shrimp up to 19.5 mg/L for molluscs. In comparison, the lowest toxic concentration for RDX is measured at 2.4 mg/L for fish, while the rest of the RDX measurements sit generally in the 10 to 100 mg/L range. Both TNT and RDX can alos lead to sublethal effects in certain groups. Exposure to these concentrations do not lead to death, but to other negative health effects, like a slower growth, reproduction and embryo development for TNT, and gentoxic effects for RDX. For HMX, no sublethal effects have been measured so far.

Table 3. An overview of the concentrations of acute and sublethal toxicity for TNT, RDX and HMX, across a range of species. Source: Beck, 2018.



MC	Exposure type	Organism	Duration (d)	Acute toxicity (mg L^{-1}, dissolved; µg g^{-1} sediment)	Tissue residue (µg/g)	Sub-lethal conc. (mg L^{-1}, dissolved; µg g^{-1} sediment)	Sublethal effect	References
TNT	Water	Fish	2–10	1.7–7.6				Nipper et al., 2001; Ek et al., 2008; Lotufo et al., 2010
		Shrimp	4	0.98				Nipper et al., 2001
		Amphipod	4	3.6–4.5				Lotufo et al., 2013
		Copepod	3–4	2–7.6				Won et al., 1976; Dave et al., 2000; Ek et al., 2008; Liang et al., 2017
		Polychaete	7	5.6				Nipper et al., 2001
		Echinoderm	2	> 9.1		10–12	Embryo develop	Davenport et al., 1994; Nipper et al., 2001
		Mollusc	4	8.2–19.5	14	0.75, 6.57	Embryo develop, Byssal thread form	Won et al., 1976; Rosen and Lotufo, 2007
		Coral	1–4			0.1–5.4	Tissue integrity, porphyrin levels	Woodley and Downs, 2014
		Algae	4	>2.1		2.5	Germling length	Nipper et al., 2001
	Sediment	Amphipod	10–28	23–177	2.6–8.9	177–217	Growth and reproduction	Green et al., 1999; Rosen and Lotufo, 2005
RDX	Water	Fish	4–28	2.4–9.9				Lotufo et al., 2010, 2017
		Shrimp	4	47–53				Lotufo et al., 2017
		Amphipod	4	>39				Lotufo et al., 2017
		Copepod	4	>36				Dave et al., 2000
		Polychaete	4–7	>43–49		26	Reproduction	Lotufo et al., 2017
		Echinoderm	2–3	>41–75			None observed	Lotufo et al., 2017
		Mollusc	2–4	>28	19.6	>28	None observed	Rosen and Lotufo, 2007
		Coral	1–4	>15		>15	None observed	Woodley and Downs, 2014
		Coral zooxan.	5	>7.2		1.8	Gene transcription	Gust et al., 2014
		Algae	4			12	Germination	Nipper et al., 2001
	Sediment	Amphipod	10–28	>1,000	5.6–21	>1,000	None observed	Lotufo et al., 2001; Rosen and Lotufo, 2005
		Polychaete	10–28	>1,000		>1,000	None observed	Lotufo et al., 2001; Rosen and Lotufo, 2005
HMX	Water	Fish	5	>2				Lotufo et al., 2010
		Mollusc	4	>1.9	0.92	>1.9	None observed	Rosen and Lotufo, 2007
	Sediment	Amphipod	10–28	>300				Lotufo et al., 2001
		Polychaete	10–28	>200				Lotufo et al., 2001

"Tissue residue" refers to the toxic tissue level where toxicity was observed, or tissue concentration at the highest tested exposure level.

These results all stem from labstudies where organisms have been exposed to these concentrations for a relatively short time, with most of the exposure duration between 2 to 10 days. The resulting toxic concentrations all sit in the 0.1 to > 100 mg/L range. This is in line with later findings as well. Barbosa et al., (2023) compiled even more lab studies on the toxicity of munition compounds on a wide range of species and taxonomic groups. Here, the LC50 – the lowest concentration at which 50% of a population does not survive – of fish and copepods ranges between 1.2 to 50 mg/L after 4 to 15 days of exposure (table 4). The full table, including the sublethal effects of munition compounds can be found in the Appendix A.

Table 4. A selection of LC50 concentrations of various munition compounds for fish and copepods. Source: Barbosa, 2023.

Chemical	Taxonomic group	Species	LC50 (mg/L)	Exposure duration
TNB	fish	Cyprinodon variegatus	1.20 mg/L	4 days
DNB	fish	Oncorhynchus mykiss	1.7 mg/L	4 days
TNT	fish	Danio rerio	4.5 mg/L	5 days
	copepods	Nitocra spinipes	7.6 mg/L	4 days
		Tigriopus japonicus	4.8 mg/L	4 days
2,4-DNT	Fish	Oncorhynchus mykiss	16.3 mg/L	4 days
		Gasterosteus aculeatus	2.2 mg/L	35 days
	copepods	Nitocra spinipes	17.0 mg/L	4 days
2,6-DNT	copepods	Schizopera knabeni	65 mg/L	4 days
2-ADNT	fish	Cyprinodon variegatus	8.6 mg/L	5 days
		Danio rerio	13.4 mg/L	4 days
2-NT	fish	Pimephales promelas	38 mg/L	4 days
4-ADNT	fish	Pimephales promelas	6.9 mg/L	4 days
		Danio rerio	14.4 mg/L	4 days
4-NT	Fish	poecilia reticulata	36.9 mg/L	14 days
		Pimephales promelas	49.9 mg/L	4 days
RDX	fish	Cyprinodon variegatus	9.9 mg/L	5 days
NG	fish	Oncorhynchus mykiss	1.9 mg/L	4 days
HMX	fish	Pimephales promelas	15 mg/L	4 days

Long-term in situ toxicity studies

Despite the amount of laboratory studies to the toxicity of munition compounds, in situ studies are still lacking. This could be an important knowledge gap, since many of the lab-studies expose organisms to a relatively high concentration of munition compounds (in the mg/L range) for a short period of time (4 to 8 days). However, this does not necessarily relect the natural situation. In the area of dumped munition, organisms are likely to be exposed to much lower concentrations but for a much longer period of time, possibly their whole lifetime. Research in this area is still lacking. In a recent study to the munition aboard WWII wrecks, one aspect of the sampling efforts included fishing on dab (*Limanda limanda*), a non-migrating flatfish, as close to the wrecksite as possible (Bergmann et al., 2022; Pers. corr.). While this research is still ongoing and not fully published yet, they established the presence of dissolved munition compounds in the water and also a higher instance of liver disease in the dab caugt at the wrecksite compared to organisms caught in reference area's. This suggests that sublethal health effects can still arise, even if the concentrations of munition compounds in situ are not nearly as high as the LC50 established in various lab studies.

Biological uptake of munition compounds

Munition compounds can accumulate in the bodies of marine species as well. One model species that is often used for studies towards biological uptake is the mussel. These immobile species can be placed near a leaking munition object to monitor the biological effects at that specific location. Aditionally, these filter feeders can process many liters of water a day and tend to accumulate contaminants from that water in their bodies (Fisher et al., 1993; Rosen & Lotufo, 2007). They are slow to metabolize those contaminants, making it possible to dissect and extract these compounds after exposure, to study the amount of contaminants that have been taken up. Mussels are also a common prey animal. Persistant contaminants in mussels could possible make their way up in the food chain, which means the detection of chemicals in mussels can act as an early warning for species higher up the foodchain (Farrington et al., 1983).

One of the first studies towards the biological uptake of munition compounds in mussels exposed the Mediterranean mussel, *Mytilus galloprovincialis*, to three different munition compounds, TNT, RDX and HMX, dissolved in water (Rosen & Lotufo, 2007). Samples of the mussels were taken at different time intervals, starting with intervals of ten minutes and ending with samples taken after 1, 2, 3, and 4 hours of exposure to the compounds in the water. The results showed a low uptake for RDX and HMX, but the TNT uptake showed interesting results. The body burden of TNT, 2-ADNT and 4-ADNT were respectively measured at 20.4±6.4%, 54.4±3.1%, and 25.2±6.1% of the total sum molar body residue. These measurements stayed relatively similar across the entire timespan of the experiment (figure 7). This showes that mussels metabolize TNT very quickly into ADNT, as early as 10 minutes after exposure.

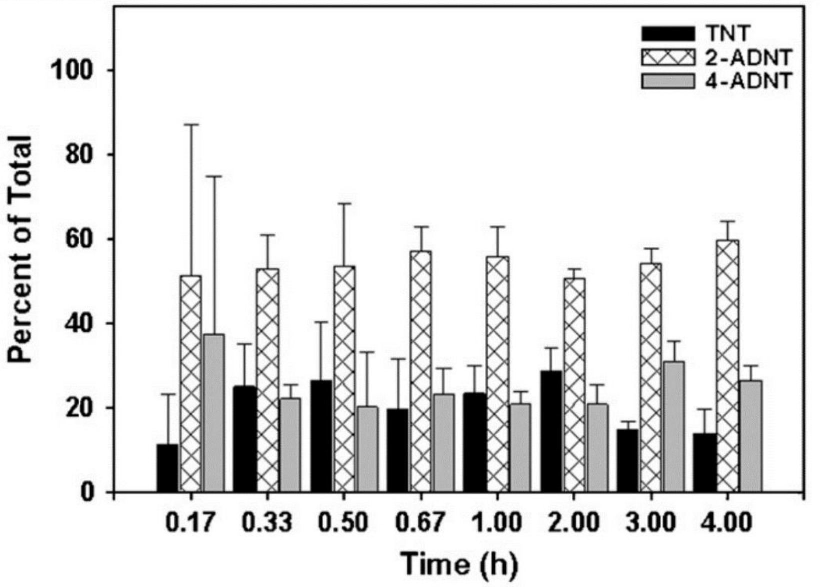
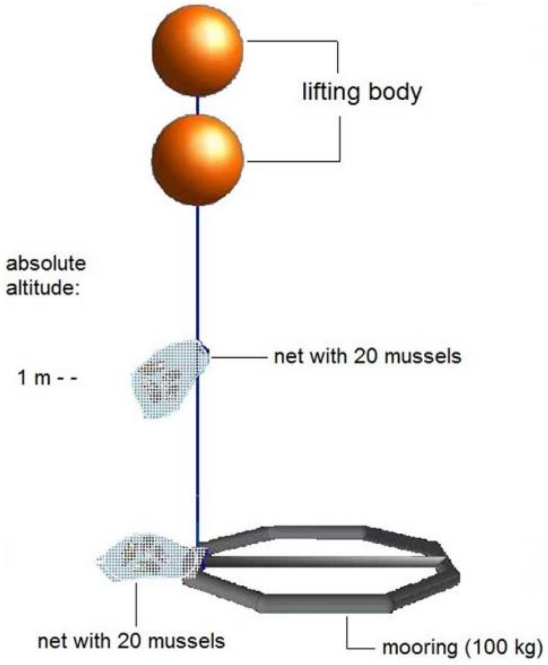


Figure 7. The body burden of TNT, 2-ADNT and 4-ADNT in mussels after exposure to TNT dissolved in water. The TNT very quickly metabolizes into ADNT, which then appears to stay stable.

Later studies focussed on placing mussels in situ near corroding munition items in the Baltic Sea. Blue mussels, *Mytilus edulis*, were placed near blast craters with visual remnants of explosive material in the German Kolberger Heide, a large munition dumpsite in the Baltic Sea near Kiel (Strehse, Appel, Geist, Martin, & Maser, 2017). A net of 20 mussels were placed directly at the seafloor, and a second net of 20 mussels was suspended with a bouy at 1 meter distance (figure 8). After 93 days, the mussels were retrieved and analysed for the presence of TNT, 2-ADNT and 4-ADNT in the tissue of the mussels. For the first group at the ground, body burdens of 2-ADNT and 4-ADNT were much higher than the body burden of TNT, while TNT and 2-ADNT not even detected in mussels at 1 meter distance. The higher levels of ADNT are in line with the laboratory studies that showed that TNT is quickly metabolized in the mussel. It also showes that the uptake of munition compounds drastically decreases with just 1 meter distance, indicating that the toxicological impact of leaking munition compounds is limited to a small range.



Distance from blast crater	**MC**	**Body burden (ng/g mussel wet weight)**
1 meter distance	TNT	None detected
	2-ADNT	None detected
	4-ADNT	8.71 ± 2.88
At ground level	TNT	31.04 ± 3.26
	2-ADNT	103.75 ± 12.77
	4-ADNT	131.31 ± 9.53

Figure 8. The experimental setup of mussels suspended over a blast crater

A follow up study measured once again mussels placed in this configuration near a mine mound in the Kolberger Heide, this time measuring the body burden of TNT, 2-ADNT and 4-ADNT after 92 days of exposure, 106 days of exposure and 146 days of exposure. Another relevant difference is that this time, the mines seemed relatively intact still, with no visually exposed explosive material (Appel, Strehse, Martin, & Maser, 2018). This time, no TNT or 2-ADNT could be detected in any of the samples. 4-ADNT was present in all samples, with the highest measurement of 7.76 ng/g mussel wet weight sampled in mussels at 1 meter heigth. This is much lower than the measurements in 2017, which can be explained due to the fact that the 2017 samples were exposed to free-laying munition material, while the 2018 samples were placed near mines that were still mostly intact.

Food safety concerns

With munition compounds present in mussels, the question arises whether these could pose a threat to food safety. After all, exposure to TNT is not healthy for humans either. The United States

Environmental Protection Agency (US-EPA) has classified TNT as a possible human carcinogen after studies in rats and mice showed an increase in carcinoma, lymphoma and leukemia after they had been exposed to TNT in their diet (US-EPA, 2014). The reference dose set by the US-EPA for TNT is 0.5 µg/kg bodyweight per day. By taking these guidelines and assuming the risk of consumption of ADNT is the same as TNT, Maser & Strehse compared this to the average daily intake of seafood of 39 g in Germany (Maser & Strehse, 2021). They concluded that in the worst case scenario – that is, a person consuming 39 grams of contaminated mussels from the immediate vicinity of corroded mines every day for 70 years – might have an increased risk of cancer. In other words, the food safety concerns are very unrealistic, especially taking into account the fact that many dumpsites are off limits for fisheries.

Accumulation in the foodweb

The final gap in knowledge is whether the munition compounds taken up by mussels are persistant enough to possibly accumulate in the foodchain, for instance when these contaminated mussels are eaten by predators. The potential for bioaccumulation is assumed to be low, due to the fact that TNT gets quickly metabolized in ADNT. So far, one study attempted to test this assumption by examining the Common Eider (Somateria mollissama), a predatory seabird. 25 Common Eiders that had been accidentaly drowen as bycatch were collected from Øresund, an area that connects the Baltic Sea to the Kattegat (Schick, Strehse, Bünning, Maser, & Siebert, 2022). Both the Baltic Sea and Kattegat contain chemical and conventional munition dumpsites. The organs and bile were collected and analyzed for the presence of TNT, its metabolites 2-ADNT and 4-ADNT and the byproduct dinitrobenzene (1,3-DNT and 2,4-DNT). However, these compounds were below the limit of detection in all samples, which ranged from 0.1 to 1.6 ng/g dry weight. So far, there is no evidence of munition compounds entering the trophic chain and accumulating in top predators. However, the authors of this study emphasize the importance of further study, as this was just a pilot study at a non-ideal sample site and a limited sample size.

2.4 Explosive danger

Aside from the toxic danger, another main concern of DMM is the potential for explosions. Many munition items were fused and activated, but did not go off when they were originally deployed. These items are still at risk of exploding when subjected to shock, pressure, or sudden temperature changes. This is particularly a problem when relic bombs are accidentally encountered by fishermen, dredging ships, or when they wash up on shore. Munition in dumpsites was often unfused when dumped, but long-term exposure to seawater can make the explosive load more sensitive to external pressure as well, possibly resulting in an explosion.

Movement of UXO

Unexploded Ordnances (UXO's) are the bombs that were actively deployed during the war, but for one reason or another did not go off. These items now rest wherever they were released, scattered on the North Sea seabed. Over the years, there have been reports of munition washing up on beaches to be found by unsuspecting beach-goers. Just a few examples include a German woman who accidentally pocketed a piece of white phosphorous, mistaking it for an amber stone. She luckily was not wearing her jacket when the phosphor ignited in her pocket (Staudenmaier, R, 2017). In 2012, a Dutch tourist found a WWII era aerial bomb on an Irish beach, while in 2022 several munition encounters were reported on a Scottish beach (AD, 2012; Sheperd, J, 2022). In august 2022, a beach in Baltimore, USA had to be partially closed after finding several fragments of WWII ammunition on the beach, presumably from an old testing range on a nearby island (CBS Baltimore, 2022).

The movement of UXO on the seabed can lead to encounters on beaches such as this, but can also lead to re-contamination of previously cleared area's, or can be the reason for distrust in historical records when examining an area for potential UXO-risk. In 2022, researchers developed a model to predict the circumstances in which a munition item might move from its place on the seabed, by examining the hydrodynamics and sediment dynamics of the German North Sea (Menzel, Drews, Mehring, Otto, & Erbs-Hansen, 2022). The North Sea consists of a sandy seafloor and waves and currents can influence and move the seabed to form ripples and sandwaves. Figure 9 shows the possible migration and burial processes that might occur on such a seabed.

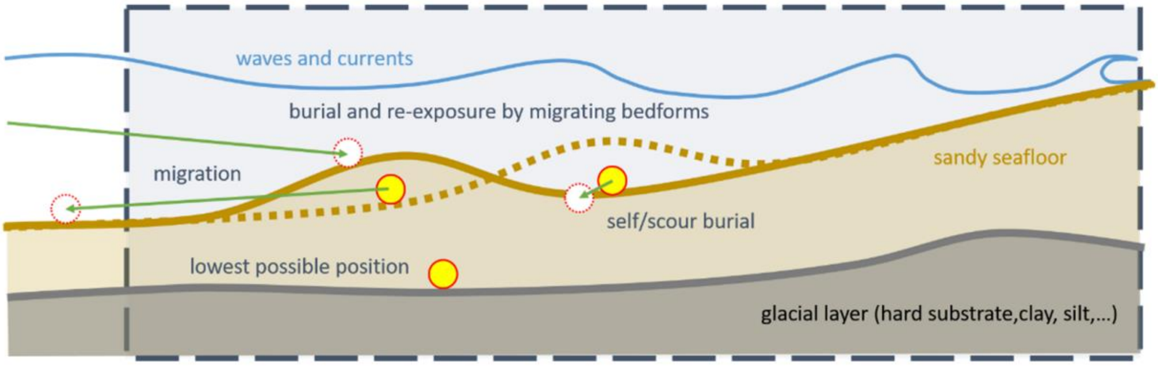


Figure 9. Conceptual drawing of possible processes of burial, re-exposure, and migration of UXO in the area of interest. Yellow circles with red outline represent the original position of the UXO, white circles with dashed red outline represent the position after migration, with the direction indicated by a green arrow. (Menzel et. al, 2022).

The model was based on the hydrodynamics – the waves and currents – of the German North Sea, and the physical properties of a 250 pound General Purpose Bomb. The model indicated the likelyhood for complete burial, in which case mobilization would be unlikely. The model then followed this up by calculating the return time of both wave-induced mobilization and current-induced mobilization. Wave-induced mobilization refers to the movement of items due to the influence of surface waves, particularly in shallow water, while current-induced mobilization is the movement of unburied items due to the ocean currents. For the German North Sea, the result showed that currents are not strong enough to mobilize the object, while wave-induced mobilization only occurs in very shallow water. However, this model is based on a 250-pound bomb. It is very likely that smaller items, or fragments of munition material are much more mobile.

Causes of explosions

The average bomb consist of several explosive parts. The first part is the fuse. This part is very sensitive to shock or heat and contains a small, explosive load. This is for all intents and purposes the 'trigger' and is designed to go off when a bomb is dropped on or disturbed by a target. This small detonation sets off the main charge, the main explosive load of the bomb. If these fuses are still active, the bomb is still primed and ready detonate when disturbed. It is however possible for the fuse to corrode and degrade after a long time submerged at sea. But this does not make a bomb safe. In fact, the main explosive load may also become more sensitive over time, depending on the filling (Pfeiffer, 2012). Munition with additives like Shellite or Lyddite could start a chemical reaction with the TNT and the metal from the hull, forming picric acid or picrates, which are very shock-sensitive compounds (Hopper, 1938).

This makes it possible for munition to spontaneously explode. In a British Geological survey, 47 seismic readings from 1992 to 2004 could point to spontaneous explosions in Beaufort's dyke, a large munition dumpsite located between Northern Ireland and Scotland (British Geological Survey, 2005).

In 2013 in the Netherlands, fishermen were disturbed by two sudden explosions in the waddensea, near the location of dumped munition (de Graaf, J, 2013). In 2019, an article in Trouw posed the question if a spontaneous explosion could lead to a chain reaction within a munition dumpsite (Bos, I, 2019). A british literature review on the dangers of munition dumpsites stated however that chain reactions are quite unlikely, especially if there is a buffer of water or sediment between different munition items (Beddington & Kinloch, 2005). Historically, there has never been a chain reaction of explosions in dumping sites, the main risk of explosion has always been through contact. Either due to the accidental contact, or due to clearing practices.

Environmental effects of underwater explosions

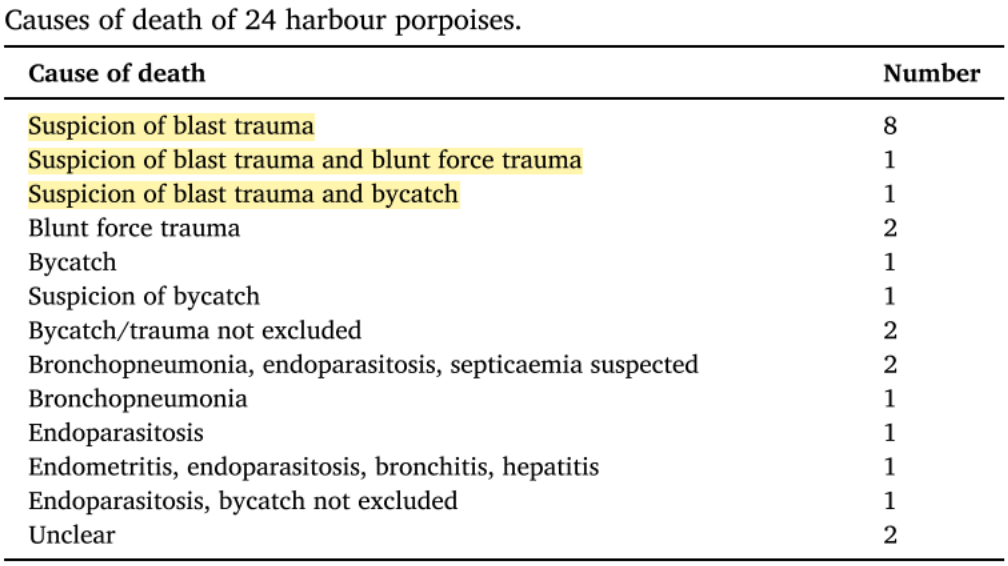
Coming into contact with an UXO can be dangerous. Therefore, it is usually cleared when it is encountered by accident, or to make way for shipping lanes, windparks or pipelines. The standard practice for years used to be to detonate the item wherever it was found, as long as it is safe to do so. This could be done by placing a small secondary charge on top of the munition item. Detonating this small charge sets off the rest of the bomb, clearing the item (). With this controlled detonation comes a large pressure wave, which can damage, wound or kill species hit by the blast impact. The resulting sound wave can very negatively affect species sensitive to sound, in particular the harbour porpoise.

The harbour porpoise (*Phocoena phocoena*) is a small cetacean that can commonly be found in coastal waters (NIOZ, 2023). It is the most abundant marine mammal in the North Sea, with current estimates ranging between 300,000 and 450,000 individuals (Noordzeeloket, 2020). It is also a protected species that is very sensitive to noise (NOAA, 2022). They rely on sonar to help orient themselves, forage and communicate. To assess the impact of underwater noise on marine life, they are often used as a model species due to their protected status and sensitivity to noise. When it comes to underwater explosions, the danger for harbour porpoises is two-fold. First, the intial blast radius can lead to injury or death. But the sound from an explosion travels far in water, potentially causing temporary hearing damage or permanent deafness.

Blast injury

Blast injuries are the injuries an organisms sustains from the direct pressure of an explosion. The severity of the injury is very dependent on the weight of the explosion and the distance of the target. In 1995, estimates were calculated for the zone in which different types of blast trauma might occur. This model looked at the theoretical effects that marine mammals could encounter within a 15 km radius of an explosion of a 544 kg bomb and a 4535 kg TNT-bomb. The lethal zone in which mammals and fish would not survive the direct blast was estimated within 300 meter of the 544 kg bomb and 800 meter for the 4535 kg bomb (Ketten, 1995). It wasn't until 2019 that the impact of explosion-related blast-trauma was observed on a large scale in Germany (Siebert et al., 2022). In august of 2019, 42 WWII mines were cleared by way of underwater detonation in the Fehmarn Belt, a protected area in the German Baltic Sea. This was also during the mating and birth period of harbour porpoises (Hasselmeier, Abt, Adelung, & Siebert, 2023; Kesselring et al., 2019). In the following two months, 24 dead harbour porpoises were found on the coast. Only six of these were adults, meaning that 75% of the group consisted of juveniles and neonates. The animals were examined for their injuries, and for 8 individuals the cause of death was determined to be due to blast injuries, like bleeding and haemorrhages in the melon and acoustic fat. For 2 more individuals, blast injuries were found in combination with other possible injuries (see table 5). Some of the neonates and juveniles still had milk or fish in their stomach, which could indicate an immediate death.

Table 5. Causes of death of 24 Harbour porpoises.



Causes of death of 24 harbour porpoises.

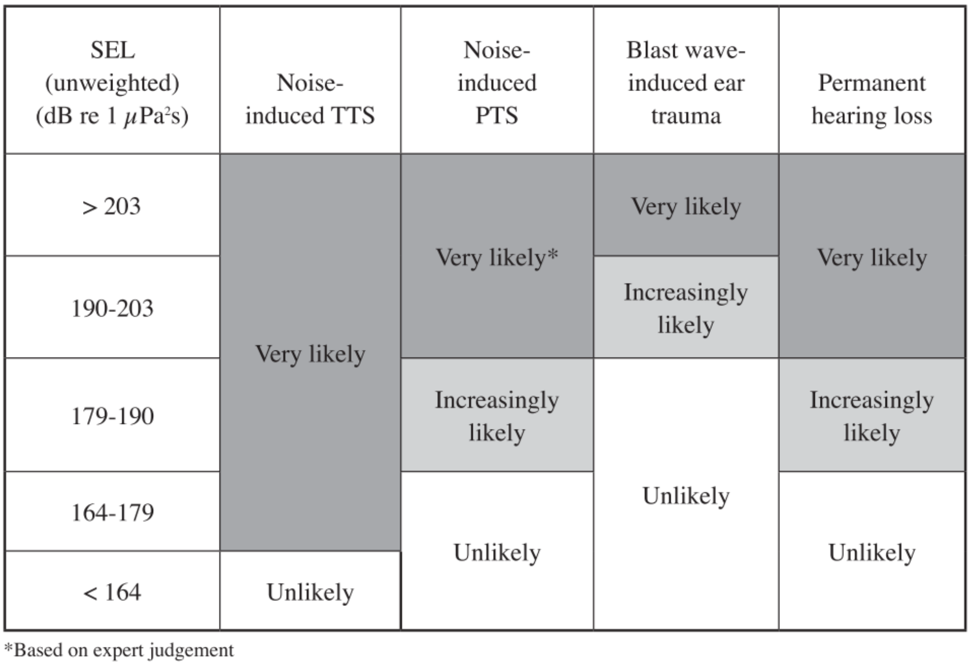
Cause of death	Number
Suspicion of blast trauma	8
Suspicion of blast trauma and blunt force trauma	1
Suspicion of blast trauma and bycatch	1
Blunt force trauma	2
Bycatch	1
Suspicion of bycatch	1
Bycatch/trauma not excluded	2
Bronchopneumonia, endoparasitosis, septicaemia suspected	2
Bronchopneumonia	1
Endoparasitosis	1
Endometritis, endoparasitosis, bronchitis, hepatitis	1
Endoparasitosis, bycatch not excluded	1
Unclear	2

Noise impact

At further distances, harbour porpoises might survive the blast inpact, but still experience negative effects from the acoustic impact. Out of all of the human noise-producing-activities, underwater detonations are the cause of the highest peak sound pressures (von Benda-Beckmann et al., 2015). Not only that, but sound travels much farther in water than it does in air, possibly creating a large affected area with each detonation (dosits.org, 2018).

Over the course of one year, 88 UXO´s were detonated in the Dutch North Sea, prompting a study towards the impact of sound exposure from underwater detonations on harbour porpoises (von Benda-Beckmann et al., 2015). In this study, the risk thresholds for hearing loss were established for both temporary hearing loss and permanent hearing loss (table 6).

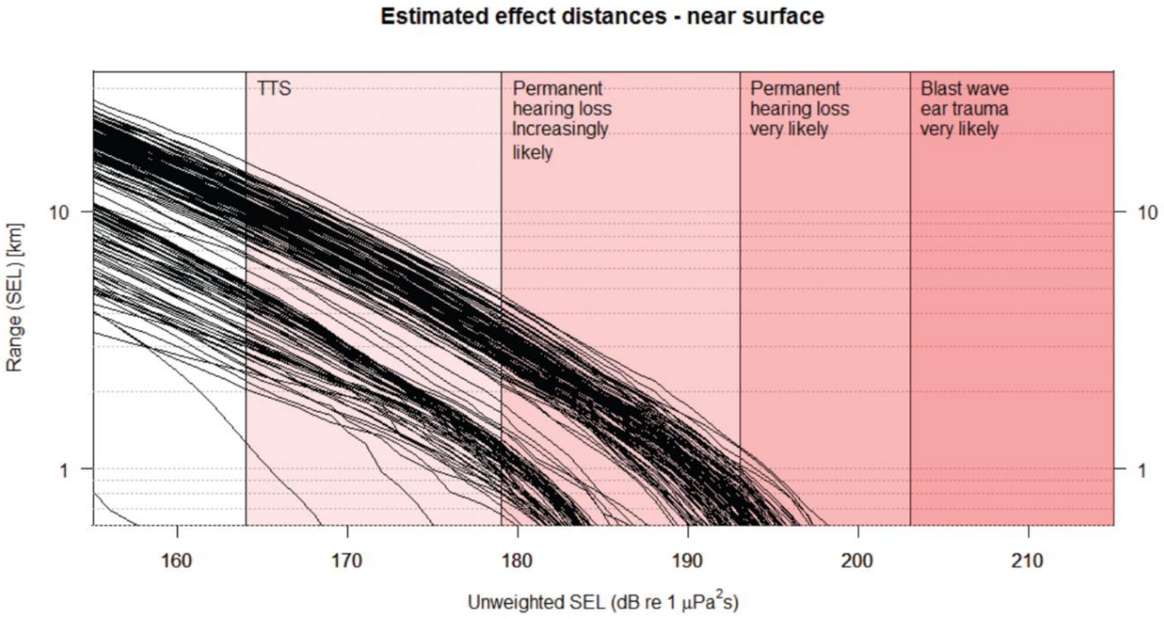
Table 6. An overview of the suspected type of hearing loss after exposure to various amounts of acoustic pressure.



SEL (unweighted) (dB re 1 $\mu Pa^2 s$)	Noise-induced TTS	Noise-induced PTS	Blast wave-induced ear trauma	Permanent hearing loss
> 203	Very likely	Very likely*	Very likely	Very likely
190-203			Increasingly likely	
179-190		Increasingly likely	Unlikely	Increasingly likely
164-179		Unlikely		Unlikely
< 164	Unlikely			

*Based on expert judgement

The acoustic impact can lead to a shift in the hearing threshold, like the loss of hearing certain frequencies. This might be a Temporary Treshold Shift (TTS) where the hearing eventually can return to normal, or a Permanent Threshold Shift (PTS), where the hearing does not return. Based on these levels and the data from the explosions of that year, a model could be developed to assess the impact from the explosions. The outcome can be seen in the figure below (fig. 10). Each black curve represents a detonated bomb. The figure shows the acoustic pressure it produced and the range (in km) at which TTS, PTS and blast wave ear trauma are likely to occur. The sound travels slightly less far in items detonated near the surface, but in both situations TTS can still occur up to 10 km away, with the heavier detonations possibly leading to permanent hearing loss in a range up to up to 5 km.



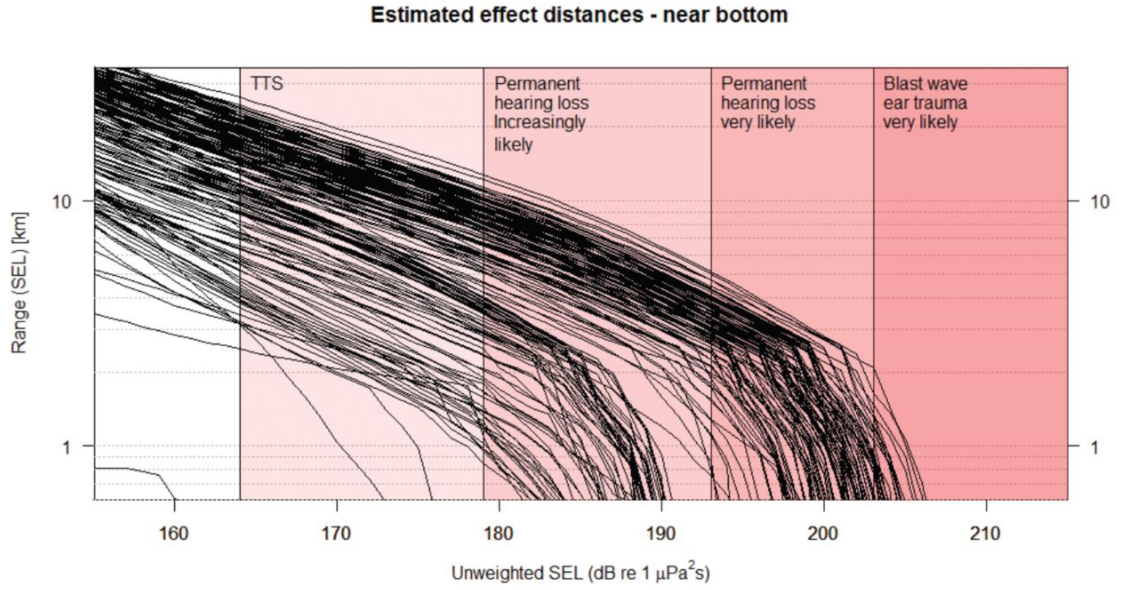


Figure 10. The range at which a certain type of hearing loss occurs for different acoustic pressures. Each black curve represents a detonation. Detonations near the surface seem to be less harmful than detonations near the bottom.

Chapter 3 – The Dutch marine muntion dumpsites

Keynotes

- *There are 4 Dutch munition dumpsites, with the dumpsite in the Eastern Scheldt being most openly monitored.*
- *The corrosion is extensive enough that munition compounds are leaking.*
- *The concentration of munition compounds is detected in the ng/L range, far below the legal REACH guideline of 0.1 mug/L and below the toxicity data from chapter 2, which was mostly in the mg/L range.*
- *The sampling techniques could be slightly updated, but right now the concentrations are still so low that there is no urgency.*

Munition item recovered by EOD divers in 2020 from the Dutch munition dumpsite in the Eastern Scheldt. The item was located under a layer of sediment and in fairly good condition, with the year of production on the hull still visible. Source: Van Elk, September 2020

3.1 Locations of Dutch marine dumpsites

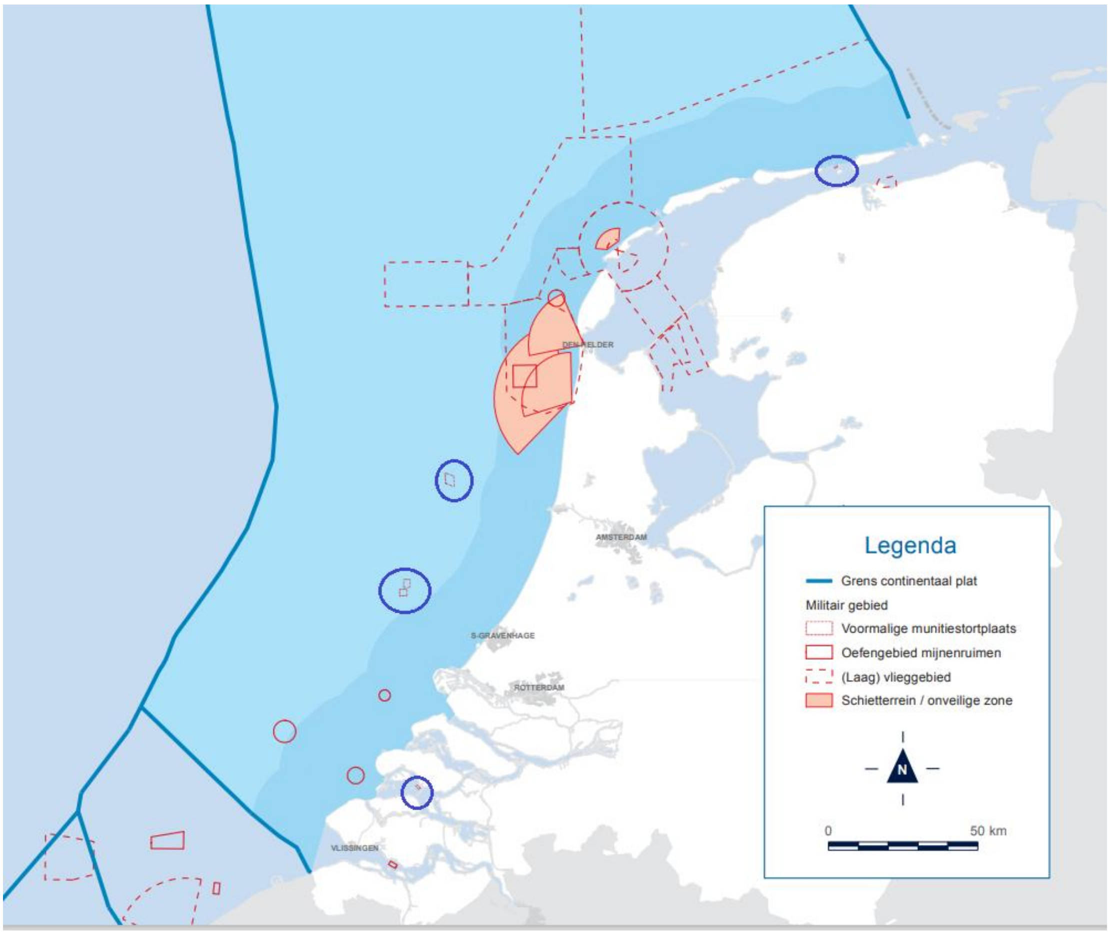


Figure 11. Map of military areas in the Dutch EEZ. The former munition dumpsites are cirkeld in dark blue. (Informatiehuis Marien, 2023).

The Netherlands has four documented dumpsites of DMM. One located in the Eastern Scheldt near the harbour of Zierikzee, one in the Waddensea under sandbar Het Rif ('The Reef') and 2 sites roughly 30 km off the coast of IJmuiden and off the coast of Hoek van Holland (fig. 11). These munition dumps are annotated on nautical maps as 'military areas' (Informatiehuis Marien, 2023). The sites off the coast have been deemed as 'areas to be avoided' in May of 2013. This term is recognized by the International Maritime Organization (IMO) to annotate areas that are extremely dangerous for shipping. In August of that same year, the Dutch Coast guard enacted a sailing ban on the IJmuiden and Hoek van Holland area's (figure 12).

Information about the material that has been dumped at these sites is limited, however all dumpsites were established as a result of World War II and contain mainly confiscated conventional munition from Germany, and leftover ammunition from the allied forces. While the locations are publically known, the amount of available information varies for the different dumpsites. This chapter will start with an overview of all four dumpsites, but the analysis on the current status of the Dutch dumpsites is mostly derived from the Eastern Scheldt location.

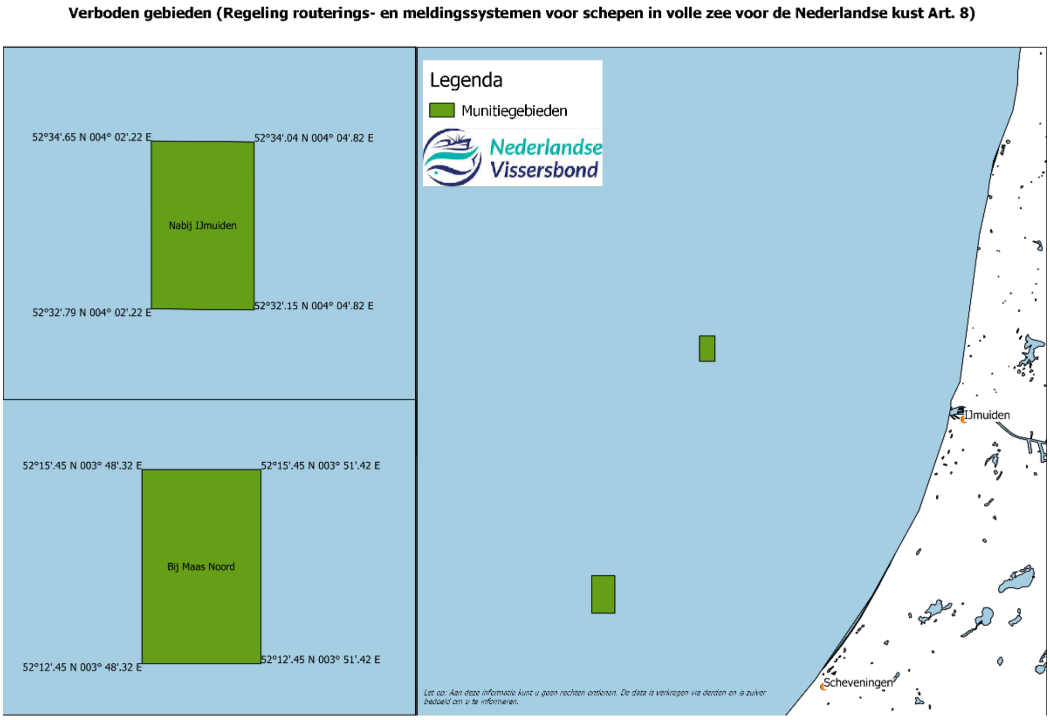


Figure 12. Notice of "area's-to-be-avoided" from the Dutch fishermen's union, including the coordinates. (Nederlandse Vissersbond, 2017)

Eastern Scheldt

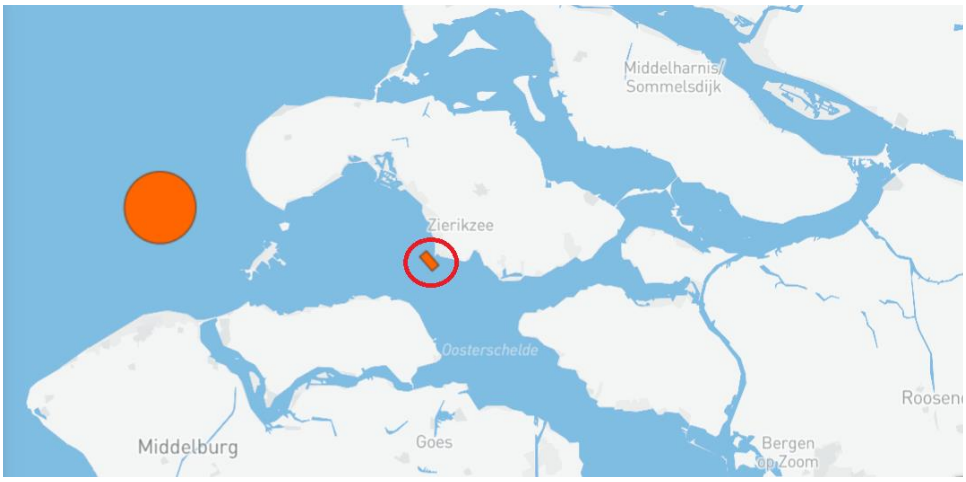
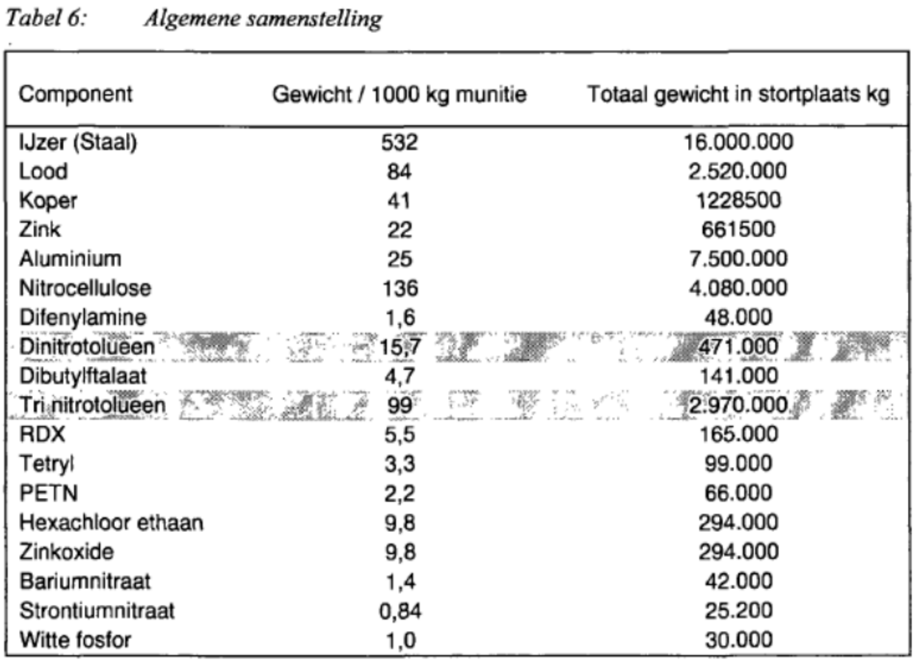


Figure 13. Munition depot in the Eastern Scheldt, just outside the Zierikzee harbour. Marked by red circle to separate from other military areas. (Informatiehuis Marien, 2023)

This dumpsite is located in the Eastern Scheldt, near the harbour of Zierikzee. The Eastern Scheldt was a former estuary, but closed off from the sea by storm surge barriers in 1986. The storm surge barriers still allow for high and low tide conditions, making the Eastern Scheld a dynamic and rich natural area (Ministerie LNV, 2023a). It is a Natura2000 area, dedicated to protect several habitattypes and species, including but not limited to top-predators like the harbour porpoise (Phocoena phocoena), the grey seal (Halichoerus grypus) and the harbour seal (Phoca vitulina).

Aside from the Zierikzee harbour, in the Eastern Scheldt is also a fishery and mussel farm located at 200m north and 100m west of the dumpsite (den Otter et al., 2023). Of all Dutch marine munition dumpsite, the Eastern Scheldt is the best documented. A historical desk study in 2000 estimated that this site held roughly 30.000 metric ton of dumped material, including TNT, RDX and white fosfor (Berbee & de Boer, 2015). This site is monitored by Rijkswaterstaat every 5 years, to test the water quality and the release of chemicals.

Table 7. Table: inventarisation of dumped material in the Eastern Scheldt dumpsite. (Source: Berbee & de Boer, 2015. Originally from TNO rapport PML 2000 A68.)



Tabel 6: *Algemene samenstelling*

Component	Gewicht / 1000 kg munitie	Totaal gewicht in stortplaats kg
IJzer (Staal)	532	16.000.000
Lood	84	2.520.000
Koper	41	1228500
Zink	22	661500
Aluminium	25	7.500.000
Nitrocellulose	136	4.080.000
Difenylamine	1,6	48.000
Dinitrotolueen	15,7	471.000
Dibutylftalaat	4,7	141.000
Tri nitrotolueen	99	2.970.000
RDX	5,5	165.000
Tetryl	3,3	99.000
PETN	2,2	66.000
Hexachloor ethaan	9,8	294.000
Zinkoxide	9,8	294.000
Bariumnitraat	1,4	42.000
Strontiumnitraat	0,84	25.200
Witte fosfor	1,0	30.000

Wadden Sea (Het Rif)

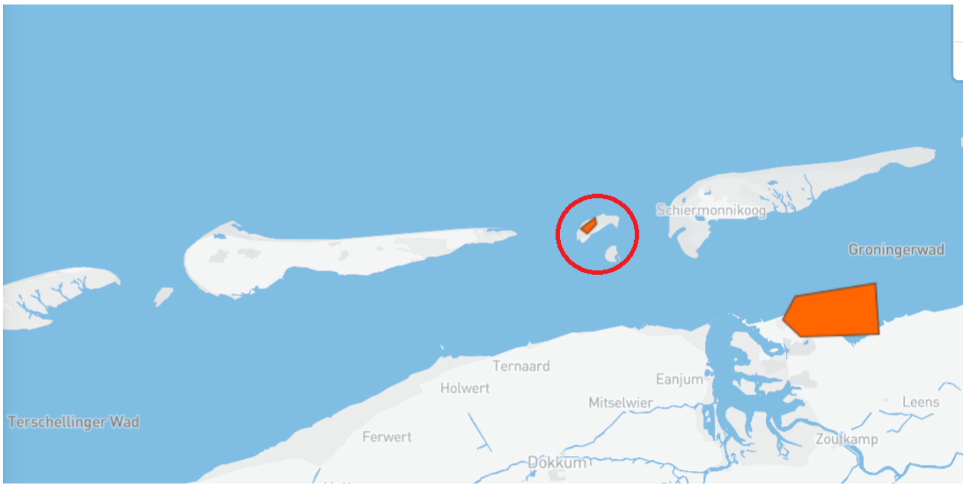


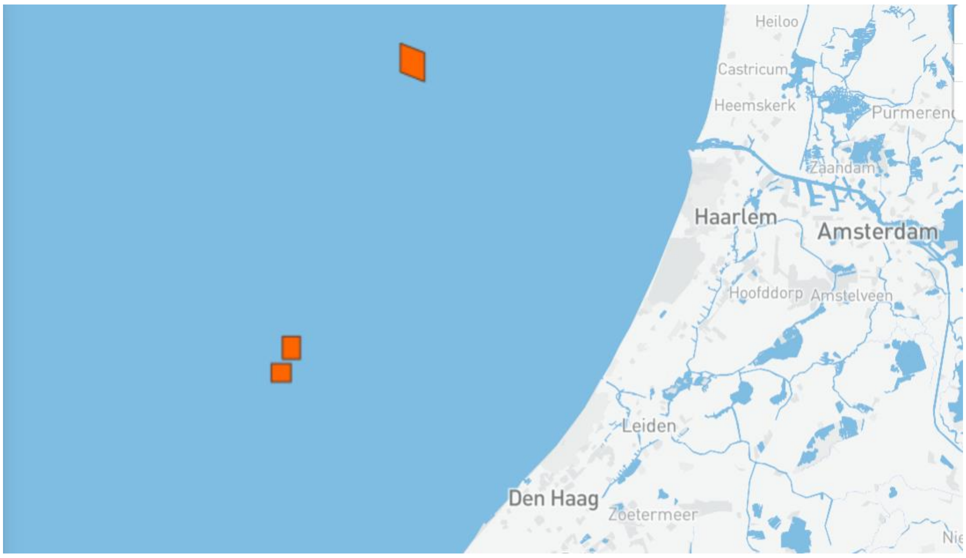
Figure 14. Munition depot in the Wadden Sea, located on Het Rif, a sandbar inbetween Ameland and Schiermonnikoog. Marked by red circle to separate from other military areas. (Informatiehuis Marien)

In the Wadden Sea, between the islands Ameland and Schiermonnikoog is a small munition dumpsite located under a sandbar. The Wadden Sea is both a Natura2000 area and a world heritage site (Ministerie LNV, 2023b; UNESCO, 2023). The international Wadden Sea (ranging from the

Netherlands all the way up to Denmark) is the largest intertidal system in the world. The Wadden Sea is part of the East-Atlantic Flyway, making it a key stop-over site for migratory birds. It is also a biodiversity hotspot, with many specially adapted species surviving the many varied habitats in the intertidal zones.

Information about the dumpsite is limited, but in 2013 the Dutch newsprogramme EenVandaag investigated the location in an episode that is only available on a belgian website (Beobom, 2013). In the episode it is established that roughly 500 tons of German grenades were dumped on the sandbar Het Rif. These grenades were collected from an abandoned german anti-aircraft station that was located on Schiermonnikoog. The location of the dumpsite used to be known as the 'ijzerbult' (iron-hill), but has been forgotten by most people on the islands. It has been annotated on hydrographical maps from the Dutch Navy, and is also visible on the online map from Noordzeeloket. According to the report, the dumpsite has been investigated by TNO in 2001 and they concluded that the munition is covered by a sediment layer of 10m thick, and therefore declared it to be safe, although regular monitoring is recommended every 5 years. This episode prompted parlementairy questions about the safety and monitoring of this location, which is done by Rijkswaterstaat (Hennis-Plasschaert, J. A., 2014).

North Sea munition dumps (IJmuiden and Hoek van Holland)



The final munition dumps are located at two locations in the North Sea, roughly 30 km off the coast of IJmuiden and 30 km off the coast of Hook of Holland. Information about these locations is even more limited. The same parlementairy questions about the waddensea also referred to the munition dumpsites in the North Sea. When asked in cabinet questions about the monitoring of these sites, RWS said that "for the sites in the North Sea, RWS conducts regular measurements to the bottom developments and the water quality." (Hennis-Plasschaert, J. A., 2014).

3.2 Current regulations and monitoring of Dutch dumpsites

Responsible parties

When asked who is responsible for the munition dumpsites in the netherlands, two parties point fingers at eachother. On one hand there is the ministry of Defence. In the original creation of the dumpsites, the ministery of defence was responsible for the actual dumping of material. After ww2, the dumping of munition material was proposed by the ministry of Defence. According to anecdotal information (pers. corr. Appendix RWS), there might have been some parlementairy opposition to this plan at the time, but the prime minister at the time greenlit the plan and the legal dumping of munition could proceed. The dumping of ammunition material was executed by the Dutch military under the responsibility of the Ministry of Defence. Dumping activities started in the Eastern Scheldt. Once this dumpsite was deemed to be filled to capacity, different sites in the North Sea were allocated as dumpsites – the IJmuiden and Hook of Holland dumpsites. The Waddensea dumpsite is a separate case, this dumpsite only holds material recovered from a German military bunker located on the island Schiermonnikoog. The location was chosen based on proximity and depth.

Nowadays, Rijkswaterstaat carries the responsibility of guarding the quality of surface water. This includes the monitoring of pollution sources like the munition dumpsites. They do this once every five years. If Rijkswaterstaat deems it necessary – based on their own measurements or based on worries from the public – sometimes TNO is hired to do an extended survey. This is usually funded by the Ministry of Defence and aided with personell from the military, for example divers trained in the dismanteling and safely handeling of bombs. So far, this monitoring by TNO has happened in 2001 and in 2020.

National policy water quality

The main policy protecting the marine water quality is the Kader Richtlijn Marien (KRM) (Ministerie IenW, 2018). The KRM is a European incentive, aiming for each member state to develop a strategy to protect and conserve the marine environment of their own marine area's. The KRM names several descriptors that deserve attention when aiming to better the marine environment. Two of these descriptors are relevant for the monitoring of munition dumps, namely Descriptor 8, Contaminants in the Environment, and Descriptor 9, Contaminants in Seafood. Interestingly, no munition compounds are included for D8 or D9 in the Dutch marine strategy.

However, this doesn't mean that a guideline does not exist. For dangerous chemicals, the European Chemicals Agency has set up a database called REACH, which stands for the Registration, Evaluation, Authorisation and restriction of Chemicals, which provides guidelines for the production, use and toxicity of registered compounds. TNT is a registered substance in the REACH database, with a PNEC value for marine water. PNEC stands for the Predicted No Effect Concentration, and is currently set at 0.1 µg/L (REACH, 2022). This is the guideline that RWS upholds for the water quality at the Dutch marine dumpsites.

Monitoring technique

The only information available about the monitoring of munition dumpsites are the monitoring reports from the Eastern Scheldt. Monitoring of the Dutch dumpsites is exclusively done through active sampling. This is simply collecting a vial of water at the location of the dumpsite, which can then be analyzed for the presence of munition compounds. Sampling by Rijkswaterstaat is schematically shown in figure 15. Four different types of samples are taken, one sample taken 1 meter above the seabed at the deepest point of the dumpsite, one sample taken 1 meter below the surface at low tide, one sample in the middle of the water column, and a reference point at Wissekerk further away from the munition site (Berbee & de Boer, 2015).

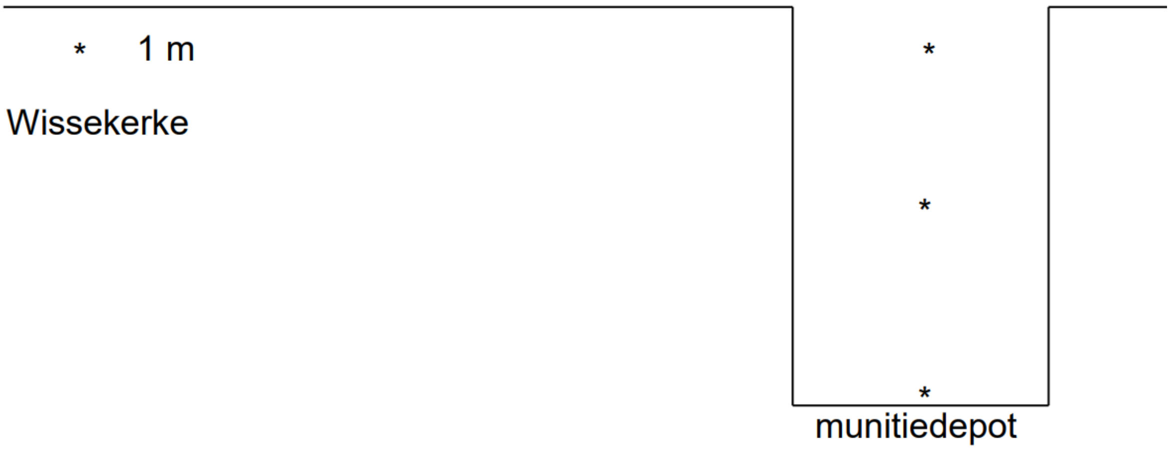


Figure 15. Schematic of the monitoring of the Eastern Scheldt munition dumpsite

When TNO does a survey, they are also able to retrieve muniton items from the dumpsite to examine the state of the corrosion, and to take a water sample directly above the seabed and sediment samples (den Otter et al., 2023).

3.3 Current status of Dutch dumpsites

During the writing of this report, a new TNO report on the munition dumpsite of the Eastern Scheldt has been published (den Otter et al., 2023). This gives a good overview of the current status of the munition that has been dumped here.

Corrosion

In the Eastern Scheldt, the corrosion rate of munition has been estimated in 2001 to be 0,01 – 0,03 mm/year. Ammunition items that were completely corroded have been surfaced during the 2020 survey , to examine the current state of the items. Thinwalled munition, like the aluminium casing around mines has been largely corroded to the point where the explosive load can be exposed. While the hull of thickwalled munition looks to be largely intact, upon closer inspection many of those items have developed leak-paths as well. These mostly develop near the fuses and screwthreads, where it is easier for water to slowly seep between the crevices. Aditionally, galvanic corrosion is observed in several items. This is a type of accelerated corrosion that occurs when two different types of metal are in contact with eachother while submerged in seawater. This has created leak-paths in some of the thicker-walled items. However, despite the presence of leak-paths, the explosive load is still present in many of the items. This shows that the explosive load is still slowly dissolving in the water and not creating a sudden spike in the concentration of dissolved munition compounds.

Figure 16. An almost completely corroded landmine

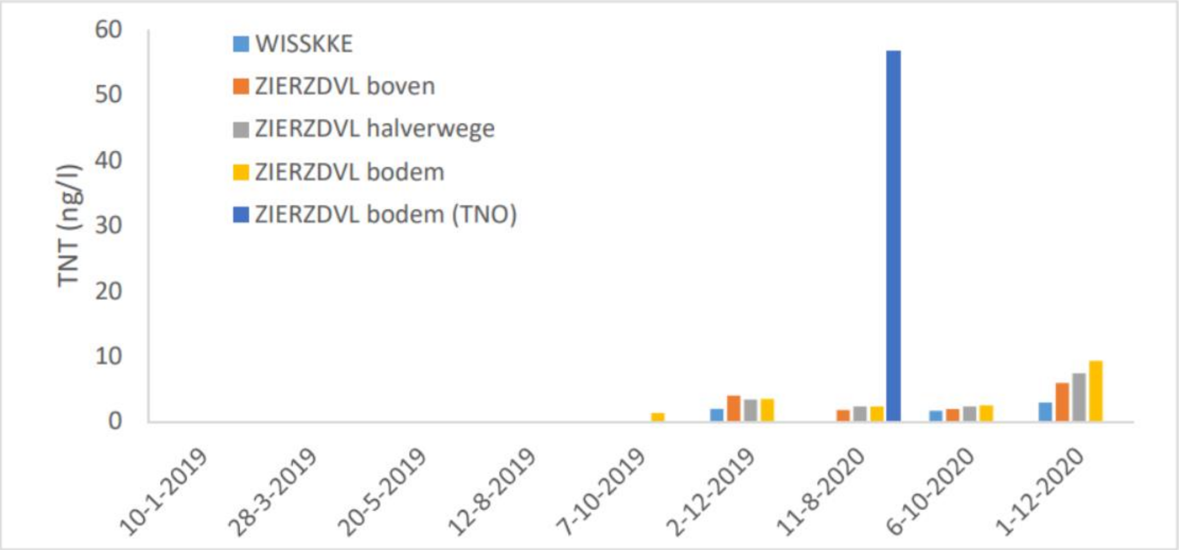
Figure 17 Thickwalled munition with leakpaths due to galvanic corrosion of the driving bands

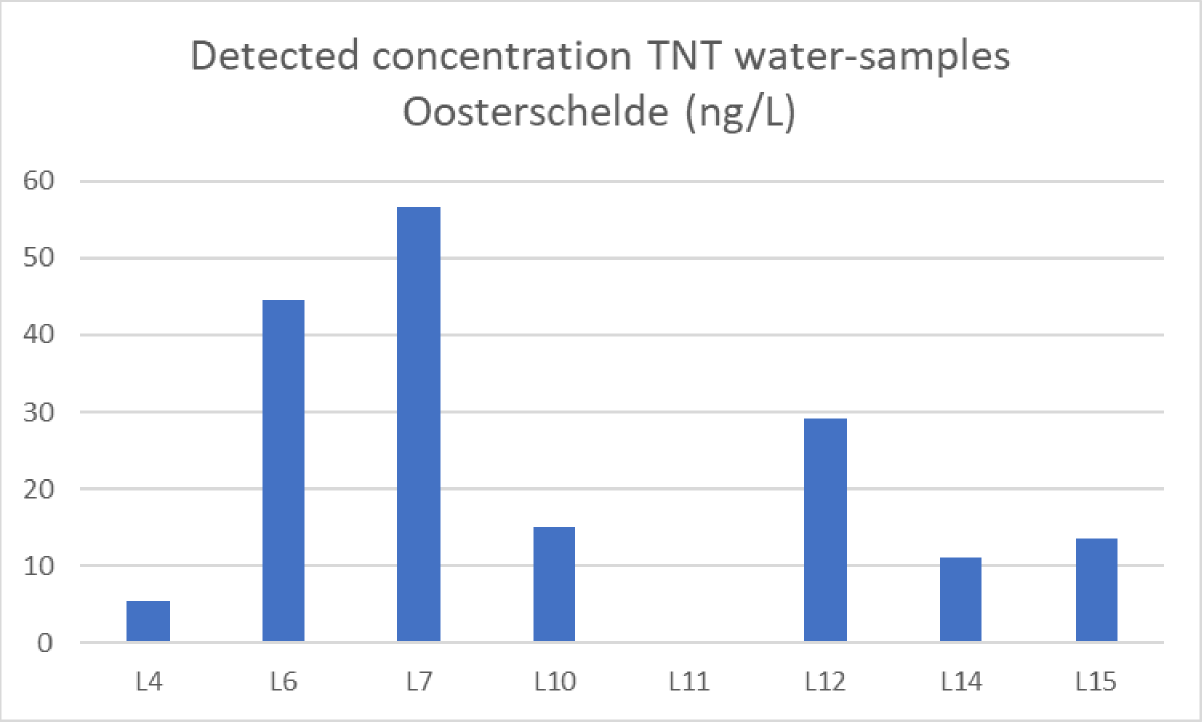
Detected compounds in the Eastern Scheldt

The concentrations of TNT measured by the RWS monitoring can be found in figure dsaf. These were the concentrations measured at 1 meter above the seafloor (yellow), 1 meter below the sea surface (orange), in the middle of the water column (grey) and the reference site (light blue). Added to this figure is also the highest measured concentration from the TNO study, measured 10 cm centimeters above the seafloor (dark blue).

The first thing to notice is the drastic difference between the concentration 10 cm above the sediment and 1 meter above the sediment. In such a small distance, the concentration of TNT decreases from 56 ng/L at the seabed to < 5 ng/L a meter away. This is in line with the Baltic Sea mussel studies discussed in chapter 2.3, where a meter distance from the source of the pollution rapidly decreases the uptake of MC in the body of the mussel.

Another important observation is the order of magnitude in which these measurements are taken. All fall below 60 ng/L, which is 0.06 µg/L. The closest legal guideline for TNT in the marine environment is the PNEC value determined by REACH at 0.1, so the measured concentrations are still in the safe zone.





3.4 Overview of possible improvements

According to personal correspondence with TNO researchers, the risks of clearing a munition dumpsite far outweigh the benefits. Corroded munition can leak more of their contents when moved and contact with munition increases the risk of explosions. For the Netherlands, all munition dumps are sectioned off as areas where dropping anchors or fishing nets is prohibited or even to be avoided completely. This greatly decreases the risk of accidental contact. Because the munition dumps are largely covered in sediment, the possibility of cleanup would only lead to more contact. Therefore, cleanup of these sites would only be possible if the risks of leaving the munition where it is outweighing the risks of cleanup. Right now, this seems to not be the case. The concentrations of leaking munition compounds are incredibly low, far below the legal REACH limit of 0.1 µg/L. Any LC50 data from toxicology studies put the limit even higher, in the mg/L range.

While the concentrations are currently very low, it is important to keep monitoring in case this might change. There are however three suggestions to make about the way this monitoring can be improved in the future.

First, the measurements of the water quality itself. Currently, a single water sample is actively taken from a location to be measured in the lab. This way of measuring gives only a single datapoint, which could have been influenced by many abiotic factors. The measured concentration could seem lower or higher due to incoming or outgoing currents or the changing of the tides, especially in a dynamic environment like the Eastern Scheldt. This makes comparing data from different days or across the years tricky. Instead, the use of passive samplers can give a more accurate reading (Barbosa, 2023; Rosen, G. et al, 2017; pers. corresp. Maser, NSW). These samplers can be placed in a certain location for a few days or weeks and continuously monitor the environment. They consist of a medium that accumulate munition compounds from the environment and calculates the average chemical concentration over time. By looking at the average, this can correct for sampling inconsistencies due to tides or currents, giving a more accurate reading.

Secondly, only measuring the abiotic factors like water and sediment concentrations provide us with a limited picture. By increasing the use of biomonitoring, for instance by placing mussels or examining fish, we could gain a better understanding of the impact of exposure to munition compounds on organisms. The in-situ study of species that are exposed to low concentrations of munition compounds for a long period of time is just starting to emerge, and there is a lot we do not know yet. This could be an opportunity to better understand how munition compounds enter and leave the trophic chain and whether they are persistent in the foodweb.

The final suggestion has less to do with monitoring and more to do with the sharing of information. Munition dumpsites are not a pretty subject, and many people are not even aware of the existence of these sites. So, when munition dumpsites garner attention, the news tends to take a sensationalist tone, focussing on the explosive risk and the dangers of contaminated seafood, which often leads to the reaction of people demanding the items be cleaned up immediately. A more open and clear communication takes away the air of mystery and sensationalism from this explosive topic. Additionally, this topic is garnering more and more attention in the scientific community for the past 10 á 20 years. By sharing the monitoring data, not just from the Eastern Scheldt, but from all the Dutch dumpsites, we can contribute to this international learning process, and collaborate in the development of solutions.

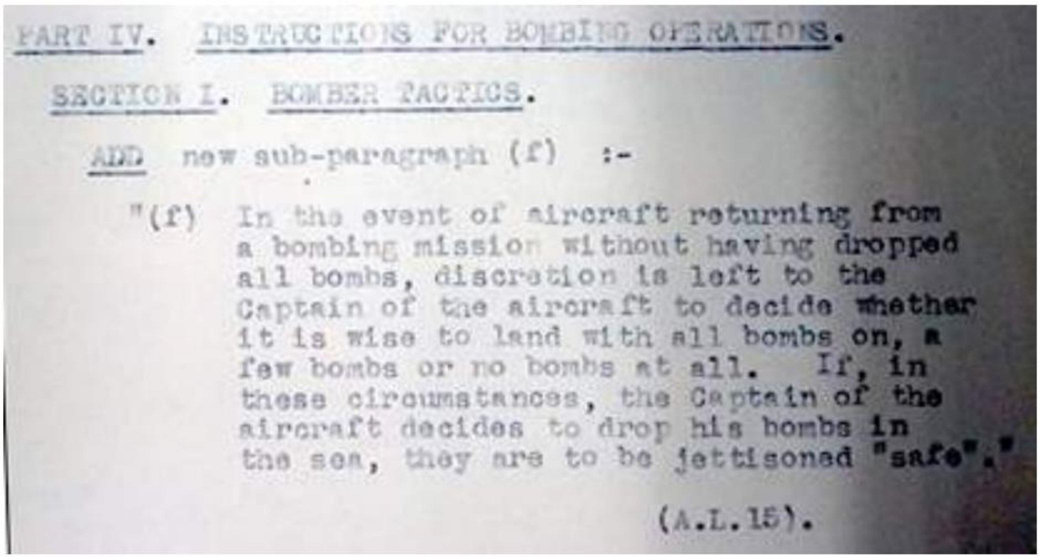
Chapter 4 – Unexploded ordnance in the North Sea

Keynotes

- *The main mechanism of clearing munition is by explosion*
- *The main sound mitigation the Dutch military has in place is the use of ADD's*
- *More effective ways to mitigate noise effects are through bubble screens, or by avoiding explosions as much as possible*

4.1 UXO in the Dutch North Sea

Unexploded ordnances in the Dutch North Sea primarily originate from World War II. Particularly aircraft bombs are found in abundance (fig 18). This could be explained by the large amount of British planes flying over the North Sea during WWII. On their way back to England, they would often jettison any munition they had left. This was partly to save on fual cost, but also because it was safer to get rid of the excess munition instead of landing with the primed and fuzed munition items still on board (see fig 17). In addition, German seamines are still found along the entire Dutch coast. These were placed as part of the 'Atlantik-wall', which were lines of German defence during their occupation of the Netherlands. The bulk of UXO found in the Dutch EEZ is typically thin-walled, conventional munition. Coming into contact with these munition items can still be dangerous, so when UXO's are encountered the military disposes of the items.



PART IV. INSTRUCTIONS FOR BOMBING OPERATIONS.

SECTION I. BOMBER TACTICS.

ADD new sub-paragraph (f) :-

"(f) In the event of aircraft returning from a bombing mission without having dropped all bombs, discretion is left to the Captain of the aircraft to decide whether it is wise to land with all bombs on, a few bombs or no bombs at all. If, in these circumstances, the Captain of the aircraft decides to drop his bombs in the sea, they are to be jettisoned "safe"."

(A.L.15).

Figure 17 Historical note detailing the jettison of british munition above sea. (Tennet & rijkswaterstaat 2017)

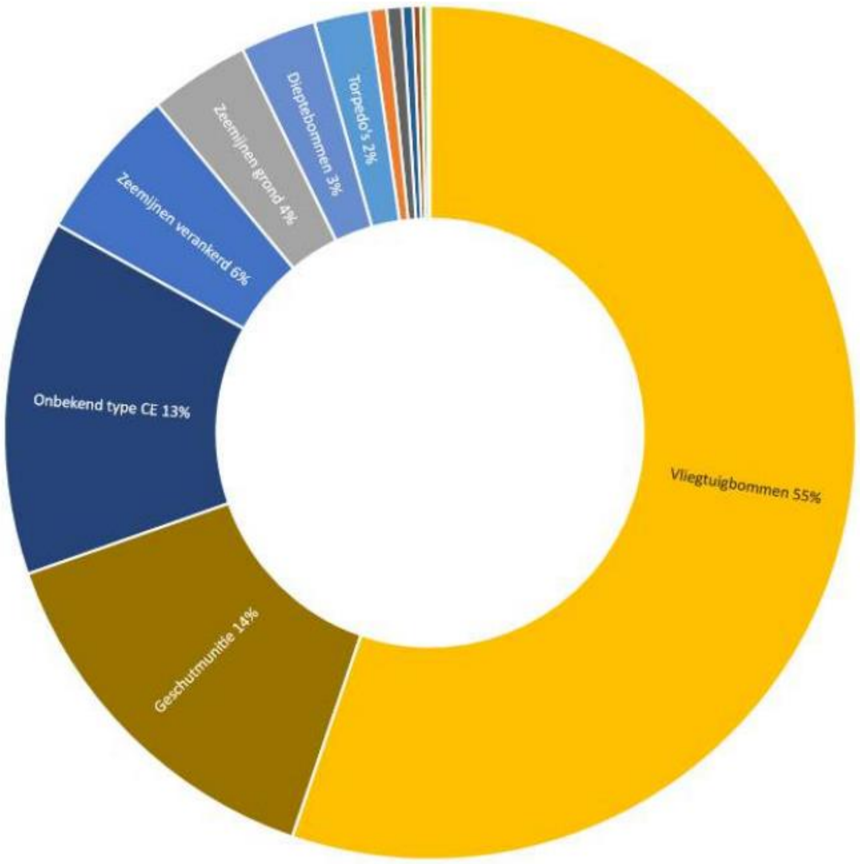


Figure 18. The distribution of different types of munition encounterd in the North sea according to Tennet & Rijkswaterstaat, 2017.

The OSPAR commission

The OSPAR Commision is an organisation that started in 1972 with the Oslo Convention against dumping. Later this merged with the Paris Convention of 1974 against and-based sources of marine pollution. The two conventions combined in 1992, and aims to protect the marine environment of the North-East Atlantic against pollution and promote biodiversity (OSPAR, 1998). Fifteen governments are involved in the OSPAR agreement, including the Netherlands, Belgium, Germany and England.

In the case of marine munition, OSPAR collects data from the contracting countries on locations of munition dumpsites and the amount of munition encounters have occurred in the OSPAR area (see fig). Based on the OSPAR Quality status report of 2010, dumped munitions at sea are a significant risk to fishermen and other users. In 2010, the OSPAR commision came with a set of recommendations to their contracting parties for the reporting of munition encounters (OSPAR Commission, 2010). These recommendations are legally binding for the contracting parties.

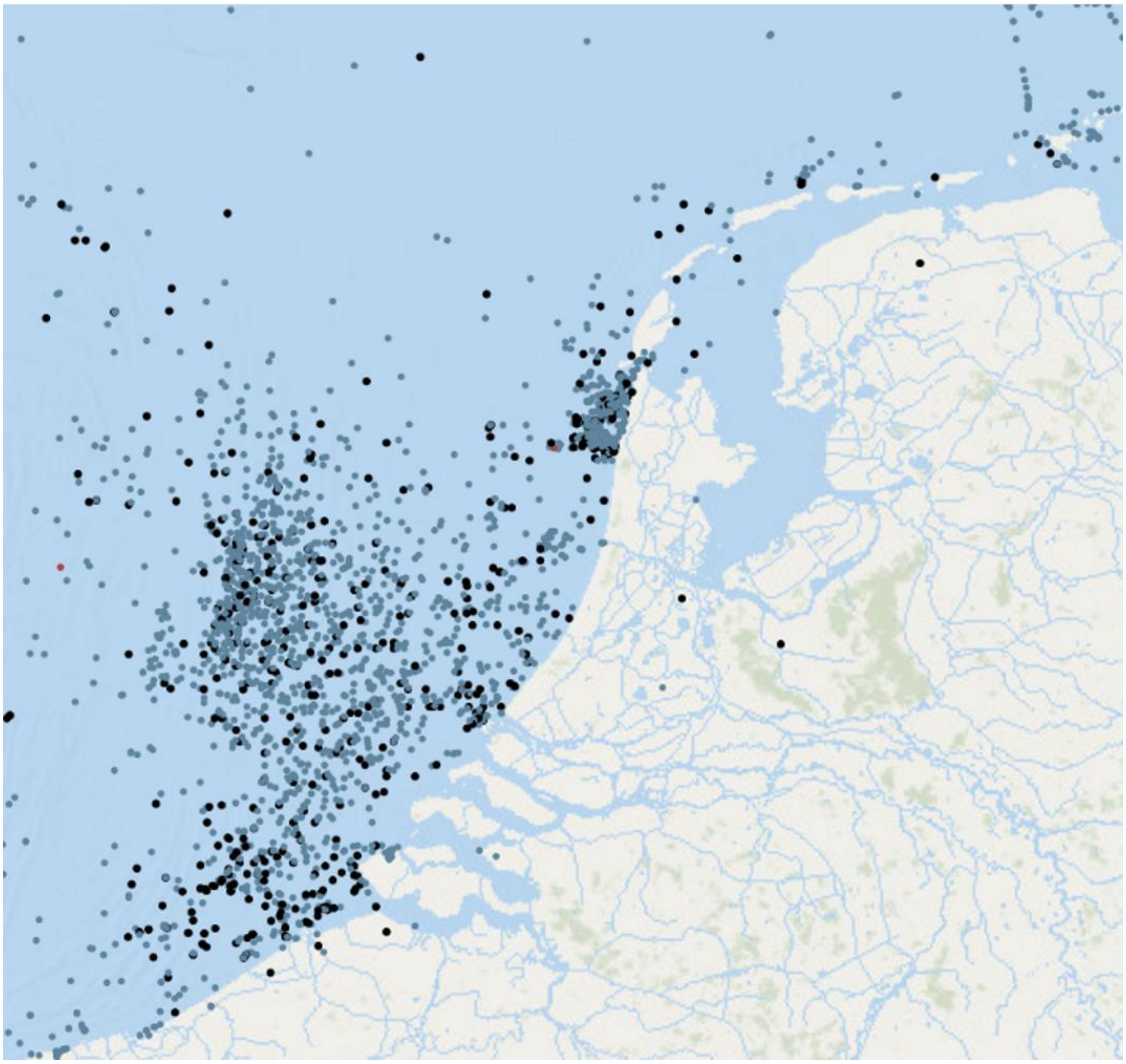


Figure19. Munition encounters in the North Sea, 1999-2020. Red dots: chemical munition, blue dots: conventional munition, black dots: unknown. Source: OSPAR, dataset: Munition Encounters.

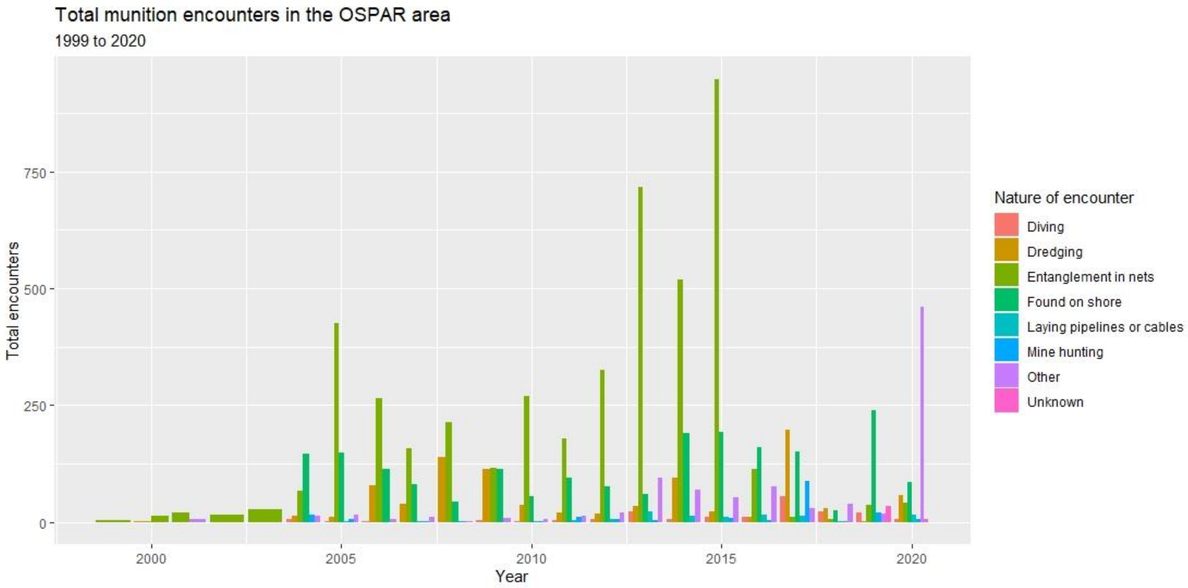
The recommendation states that contracting parties are obliged to maintain systems in which reporting an encounter is easy for fishermen and other users and are encouraged to do so; that these reports include additional information of the encounter. Each contracting party keeps track of the munition encounters of their own jurisdiction area, and yearly submitted to OSPAR in a format that OSPAR provides.

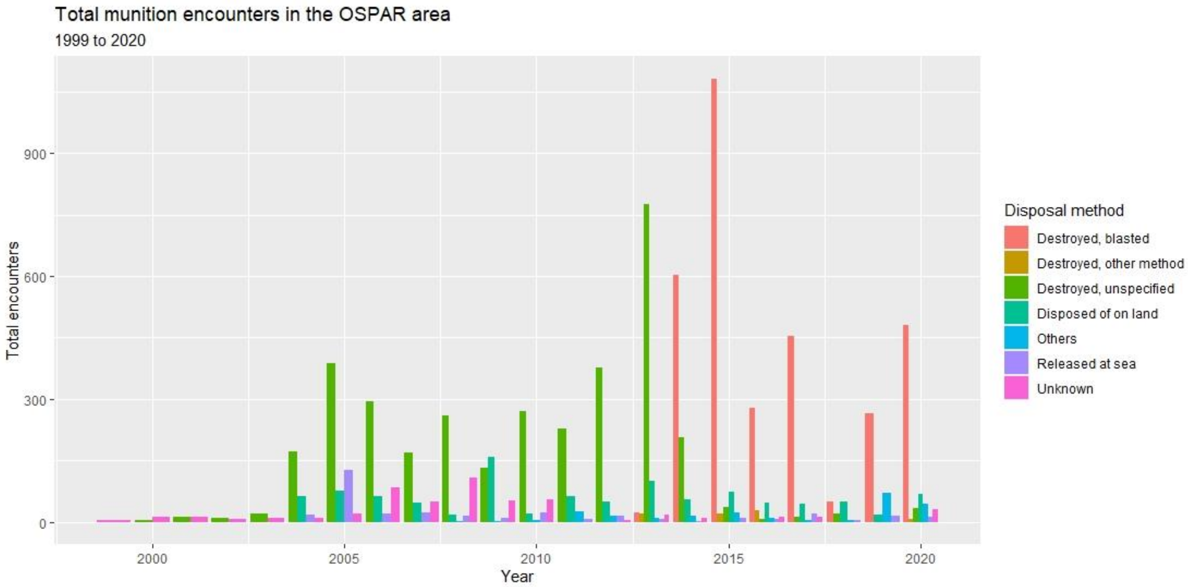
This format is needed to ensure all data is in the same format and can be put into one database. This format includes basic information, like the date, location and contracting party, but also additional data such as:

- the nature of the encounter (through dredging, diving, fishing nets, etc)
- the type of munition found (chemical, conventional, unknown)
- the action that was taken (blasted, released at sea, disposed on land or other), and
- the state of munition (heavily or partly corroded, in good condition, or unknown).

There is also room for remarks. It is encouraged to use the remarks section especially to provide further details if the nature of the encounter was determined ‘other’, or the taken action was described as ‘destroyed, other method’.

Universal datasets like this make it possible to visualise trends within these encounters, identify which users might be most at risk of encountering something, and which methods are primarily used to deal with the encountered munition.



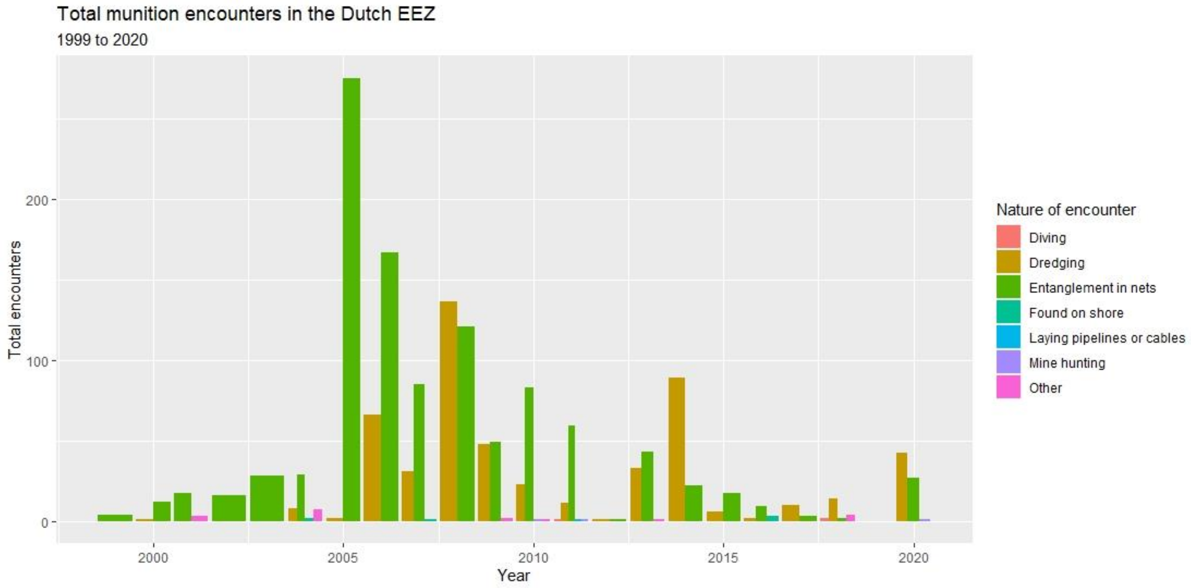


For example, graph 1 shows that in the entire OSPAR area, most of the encounters with munition is due to items being entangled in nets, with encounters on shore as a second and dredging as a third cause for encounters. Graph 2 shows that destruction of the munition is still the most popular disposal method by far. Once we started distinguishing between blasting and other forms of destruction, it is clear that the blasting of munition items remains at the top.

4.2 National uxo-clearing practice

In the Netherlands, munition disposal is a task carried out by the military, specifically the EOD branch of the military. For offshore munition encounters, the Dutch EOD and the Belgium Navy have started working together in a collaboration called the Beneficial Cooperation (Ministerie van

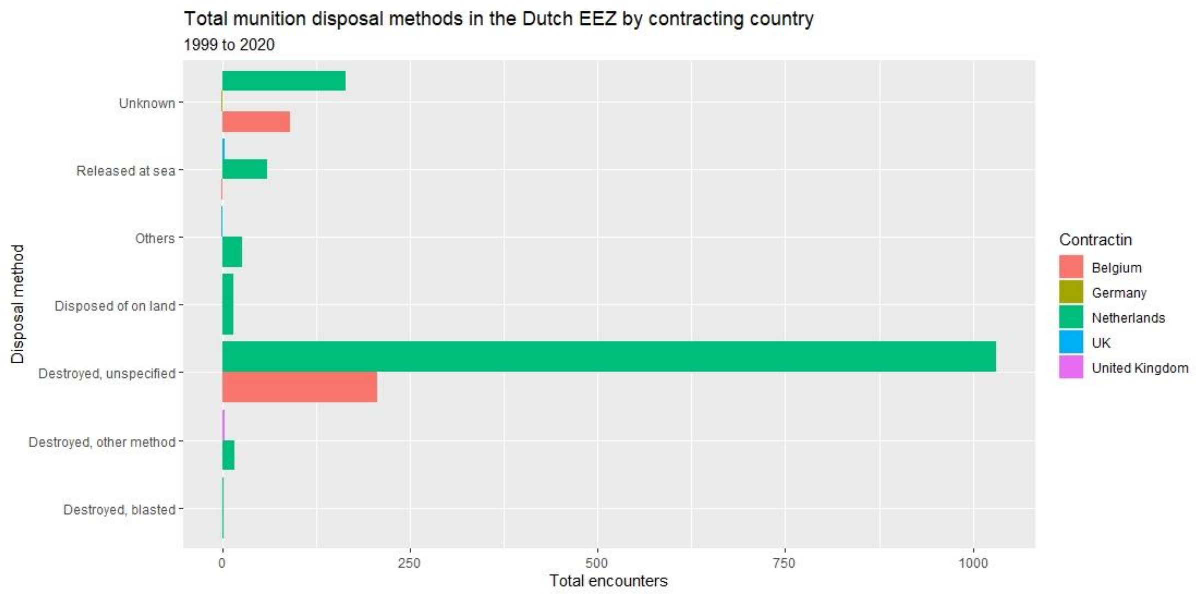
Defensie, 2014). This was set in motion after three Dutch fishermen lost their lives after an accident in which a WWII bomb landed in their nets and exploded on the deck (ANP, 2005). According to them, between 2005 and 2021 they received 2000 calls about munition encounters and cleared roughly 1500 bombs. When looking at the data collected by OSPAR, you can see that the 2005 incident led to a rise in reported encounters (fig). The exact reason might be difficult to trace back, but it is probably a combination of a rise in awareness among fishermen of the risks of munition and the active approach of the Beneficial Cooperation in mine-clearing practices.



Whenever a munition item is found, the unlucky finder should not just throw it back, this could possibly set the item off. Instead, they should call the Coast Guard, who will give them instructions on what to do over the phone, while also alerting the Beneficial Cooperation. They will come to collect the item and dispose of it safely (Kustwacht Nederland, 2022). There is financial compensation for people who encounterd munition items, as long as the individual properly followed the instructions from the Coast Guard and from the military (Rijksoverheid, 2019).

Dutch disposal methods

Once a munition item is identified and safely in the hands of the bomb squad, they have the responsibility to dispose of it. For a long time, the easiest and cheapest way to get rid of munition is to detonate it at sea, also known as Blast-In-Place (BIP). When it comes to the Dutch clearing methods, there is some uncertainty of the exact clearing method. Personal correspondence from a different colleage in NSF with a member of the military led us to believe that they will often try to recover an object and dispose of it on land. However, looking at the official OSPAR data, most of the encounters are labelled simply as ‘Destroyed’, without disclosing the method. OSPAR does provide the option to label an encounter as ‘Disposed of on land’, but this option is not submitted for encounters in the Dutch EEZ. (fig. 6). Therefore, for the purposes of this report, I will assume the OSPAR data is correct in that most of the munition encounterd by the Netherlands, on the Dutch Continental Shelf is destroyed at sea. If this assumption is incorrect, then I advise the members of the Beneficial Cooperation to use the ‘Disposed of on land’ label for these encounters in the future.



Sound mitigation

After the previously mentioned 2015 study showed that on a yearly basis, potentially thousands of harbour porpoises were at risk of permanent hearing damage, the Ministry of Defence was provided with a shortlist of possible sound mitigation strategies (von Benda-Beckmann et al., 2015; Defensie Expertise Centrum EODD, 2020).

The following table includes this shortlist, whether it increases risk for human personell and the implementation of the shortlist option, according to the 2020 Handbook . The final column are suggestions and notes on where the implementation could be improved or falls short.

	Shortlist suggestions	**Increase human risk?**	**Current implementation**	**Commentary**
1	Detonation in undeep water (leading to a smaller peak-impact)	No	Only if an item already has to be moved due to safety concerns, then we will look for possibilities of moving it to undeeper water. If this is not the case, it will not be unneccesarily moved.	If it is safe to move the item, why not include it as a standard practice to see if there are nearby undeeper zones or sandbanks?
2	Deflagration instead of detonation	Yes	Not implemented due to increased human risk	
3	Do not stack multiple explosive to detonate at once	No	When multiple items are encountered, it is recommended to do the clearing in sequential order.	
4	Lifting munition to detonate closer to surface	Yes	Not implemented due to increased human risk	This technique is being applied by commercial UXO companies, therefore the possibility exists in a safe manner.

5	Wait with detonation until low tide	No	When practical, detonations are preferably executed during low tide instead of high tide.	
6	Use of Acoustic Deterrent devices to scare animals away from blast site	No	Started with the use of 10 ADD’s. Harbour porpoises can hear the sound up to 1 km distance and flee the area. The ADD is preferably activated half an hour before detonation to give animals enough time to move away.	ADD’s with a 1 km range might suffice for preventing blast injury, but temporary hearing loss in harbour porpoise can still occur up to 5-10 km away, depending on the intensity of the explosion.
7	Limit explosions during mating/birthing season of marine mammals	No	At time of writing, the Ministery of Defence was not provided a seasonal chart of marine mammals, but is open to move munition before detonation if it is safe and neccesary.	In general, the number of Harbour porpoises in the North Sea is higher in spring/summer and lower in fall/winter, with the mating season somewhere around July.
8	Visual, infrared or acoustic monitoring to spot nearby individuals	No	Visual monitoring, including night goggles when necessary. When spotting a marine mammal, detonation is delayed until the animal is gone.	
9	Extraordinairy situation (explosive >1000kg)	No	MAREODD is in charge of the clearing, possibly including stronger ADD’s or lifting devices.	

Based on the information in this table, there are a few options that have more potential.

First, the use of ADD’s. The ADD’s that are currently being used have a range of 1 km. In a previous section of this report it has been established that permanent and temporary hearing damage can still occur in harbor porpoises far beyond the 1 km range. A different solution is possible that actually inhibits the sound of the explosion and the affected range, instead of scaring the animals away from the loud noise. A technique that is frequently used in Germany and Scandinavia is to place a bubble screen around the area where the detonation will take place. A bubble screen is effectively a hose with small holes where air is pumped through. As the air escapes, a curtain of bubbles rises up to act as a sound barrier between the source of the noise and the surrounding area. The way this works is because sound travels differently through air than it does through water. Air can be compressed, meaning that a sound wave travelling through air slows down and loses energy, it attenuates. Water however can not be compressed, so sound waves travel much faster and further in water compared to air. Creating a layer of bubbly water for the sound wave to move through makes the sound wave lose some of that energy and range (Koschinski & Kock, 2015). A 2008 study examined the effectiveness of bubble screens used for underwater detonations. They tested three options, a single, double and triple bubble screen against a 1 kg detonation charge. The best option turned out to be the use of a double bubble screen, which reduced the sound wave with 15.4 dB and shrunk the dangerous range with 98% (Nützel, 2008).

A second area of improvement is the use of specialized equipment to move, de-fuse or lift a munition item. From the 2020 Handbook, the Ministery of Defence seems to only move an item away if it is necessary for the safety, but not for environmental concerns. The reason is that it would be too dangerous. However, new techniques are constantly being developed that make manouvers like this possible in a safe way. These innovations are usually made by commercial uxo-clearing companies (pers. corresp.). These type of companies tend to have a wide range of cababilities. Starting with desk-research, companies like this can be hired for historical research to determine the risk-factor of a certain area. In fact, it is mandatory for any construction in the Dutch North Sea – like the laying of pipelines and cables or the construction of windparks – that the area is assessed for the risk of encountering UXO first. If an area is deemed as a potential UXO hotspot, these companies often also offer imaging scans, for example by sonar, to investigate the area and identify any potential UXO. Ideally, many of these companies would then like to clear the identified items. They have the expertise and the equipment to safely move UXO or lift them towards the surface. New techniques are continually being developed, like using high pressure water with a slight abrasive to cut through the hulls or fuses, or remotely operated vehicles that can grab munition items and move them, while the human crew is at a safe distance. In many countries in Europe, these companies are allowed to do these practices, provided they have the right certification. But in the Netherlands, Belgium and Luxembourgh, munition clearing is only allowed to be performed by members of the military.

4.3 Overview of possible improvements

While there are mixed messages about the exact method of munition disposal by the military, this report bases itself on assumptions made based on the available OSPAR data and the 2020 Handbook of Orndance Disposal. According to those assumptions, underwater detonations are the main method in which munition is removed. Even if these assumptions are wrong, you could still argue that limiting the amount of explosions, or limiting the impact of an explosion as much as possible, would still be benificial to sensitive species like the harbor porpoise.

To limit the noise impact of explosions on harbor porpoise, there are two main points that could be introduced.

First, the quickest and easiest option to reduce the noise impact of underwater explosions is to introduce the use of bubble screens. The dangers of explosions lie not just in the direct blast injury for animals in close range, but the possible hearing loss that can occur up to 10 km away from the initial explosion. Studies have shown that a double bubble screen can greatly reduce the range of the sound impact of an explosion. Bubble screens are already being used for the pile driving of windpark construction and are used for UXO detonation in Scandinavia. The Ministery of Defence could either invest in their own bubble curtains, which can be re-used, or hiring the services of companies that manufacture and maintain bubble curtains.

The second suggestion will probably take a bit more work and convincing. Right now, we have companies in the Netherlands with top-of-the-line equipment and expertise when it comes to clearing munition in an environmentally friendly fashion, which makes less of a noise impact than the methods of the military. However, they are not allowed to use those skills and equipment in the Netherlands. This is because the Netherlands is a lot more strict about munition clearing than other European countries. In the Netherlands, Belgium and Luxembourgh, the EOD is part of the military and falls under the jurisdiction of the Ministry of Defence. They are the only group with the legal competancy to clear munition. In many other European countries, the EOD is part of the state-funded police. Their methods can vary state to state and are often more flexible. If they deem it necessary, they might hire the services of a commercial UXO-clearing company. But since theyare not allowed to operate in the Netherlands, a lot of that expertise is going to waste.

Chapter 5 – Conclusions

Insert keynotes

Figure 8 A harbour porpoise in Denmark. Photo by Erik Christensen. Source: Anstett, A, 2017

5.1 Summary of improvements

This report has given a wide overview of munition-related research, policies and problems.

Munition dumpsites have reached the point where they have started leaking toxic substances in the environment. However, in the Dutch munition dumps, these substances are leaking in incredibly small amounts that dilute very quickly. There is no reason yet to clear the dumpsites, since disturbing the munition could pose more risks than it solves. However, it is important to keep monitoring and to keep up to date with research that is being done in different area's of the world. The monitoring of our dumpsites could be slightly improved by introducing the use of passive samplers. There are still gaps in our understanding of how munition compounds might enter and leave the trophic chain, so bio-measurements of mussels, fish or even predator-species could be very interesting. In general, being open about the existance and status of the marine dumpsites, and informing people about the lack of risk might make the subject less sensational.

UXO-clearing is an important task as it makes the marine environment safer for all its users. However, the use of explosions can have a harmful effect on sensitive species like the harbour porpoise. The use of an ADD that can scare individuals away up to 1 km distance is not enough when the range in which harbour porpoises can lose part of their hearing is up to 10 km. It is much more effective to dampen the sound of the explosion with a bubble screen or a double bubble screen. Even better would be to avoid a deep-water explosion altogether, by using advanced equipement to relocate munition to shallow water, lift it to the surface, or defusing a munition item by cutting through the fuses with a waterjet. This could be done by military personell, but there is also a fairly big group of experts in UXO-clearing companies already familiar with this equipment. Giving them the authorization to to actually clear the munition that they find might speed up the process.

5.2 Focus for NSF

Out of all these findings, some are more interesting for NSF to dedicate their time to then others. This report aimed to answer the question:

What are the environmental and human risks of leaking ammunition dumps and the clearing of ammunition in the Dutch North Sea and what steps can the North Sea Foundation take to reduce future harm?

This report has given a broad overview of the risks, or the lack thereof. Now we focus on the last part of the question; what NSF can do to reduce future harm.

Given the fact that the environmental risks of leaking munition are relatively small, especially in the Dutch dumpsites, I would argue that NSF's attention is best directed towards limiting the amount and the impact of explosions in the North Sea.

The introduction of bubble screens

According to the Ospar data, explosions are still quite abundant in the Dutch EEZ. After 2015, when the TNO report showed that 88 explosions in one year could have contributed to a large amount of harbour porpoises suffering from hearing loss, many people were shocked. A shortlist of solutions was proposed to the Ministry of Defence. From those options, the use of Acoustic Deterrent Devices was quickly adopted, the discision proudly displayed in the revised Harbour Porpoise Protection plan. However, these ADD's only have a range of 1 km, and do not reach the harbour porpoises that are still within range of possible hearing loss. The use of bubble curtains however, is much more effective by dampening the sound itself.

There are a few ways in which NSF could introduce the idea of bubble screens. Firstly, the fact that the use of ADD's to limit the impact of explosions is already included in the Harbour Porpoise Protection plan is a great introduction to the topic. It shows that the policy-makers already acknowledge that these explosions are harmful and the effects need to be mitigated. However, the chosen mitigation strategy (the use of ADD's) is not sufficient, and the use of bubble screens is a more effective strategy. As a partner in the Harbour Porpoise Protection Plan, NSF is already a respected voice within the debate, which will hopefully help in making changes. This way, by influencing an already existing policy plan, we might change how Defence operates.

A different strategy can be seen in Germany. There, three environmental NGO's (The Nature and Biodiversity Conservation Union (NABU), The Society for the Conservation of Marine Mammals (GSM) and The Society for Dolphin Conservation (GRD)) worked together on an intiative to ban underwater detonations altogether. Their campaigning led to the Department of Disaster management to direct more study towards alternate strategies. It did not lead to an altogether ban, but this initiative led to the 2008 study towards the effectiveness of bubble curtains. A more science based approach fits with the attitude of NSF, and a science based approach was effective in 2015 with the introduction of ADD's. NSF could reach out to the German NGO's NABU, GSM and GRD to share information about the strategy they used. NSF could also reach out to their network of scientist to see if there is a possibility to set up a pilot project with scientists and EOD marines to investigate the effectiveness of bubble screens for themselves.

A switch to new technology

New technologies to limit explosions even more are constantly being developed. The military however, seemes reluctant to change and the uxo-companies that develop and use these techniques are not allowed to do so in the Netherlands.

Since I have not been able to speak to a representative of Defence during my internship, a good first step would be to reach out again to them, to clear up some assumptions. Based on interviews with other parties, the military sounds like it is unwilling to change and is stuck in its their ways. Also, a possible reason that people have given for the reluctance to change is that the detonations are a good way to practice their skills and train for war-like scenarios. It is important to clear up these rumors and assumptions first.

It would be very nice if NSF could reach out to the Commandant Zeestrijdkrachten, René Tas. This is the person in charge of the Royal Marine and is very involved in the protocols that the marines have to follow. The Commandant Zeestrijdkrachten also has the function of Admiraal Benelux, working closely together with the Belgian Marine. This means he has to be involved with the running of the Beneficial Cooperation, the Belgian/Dutch team in charge of many of the UXO-clearances in the North Sea.

Whether or not it is possible for NSF to get in contact with this person, it would be a nice first step to possibly organise a roundtable of EOD personell, UXO-clearing companies and scientists specialized in underwater noise and harbour porpoises, to fully talk about the possibilities of the current technology, the reasons why Defence is slow to adopt them, the legal capabilities of these UXO-clearing companies and the best-cast scenario for the harbour porpoise. Based on the outcome of these talks, the wishes and attitude of the stakeholders involved and the potential that NSF might see in the topic, a further strategy can be developed. This might be aimed at increasing the legal capabilities of UXO-clearing companies, or the adoption of new technology be the Ministry of Defence.

Bibliography

AD. (2012, May 8). *Nederlander vindt bom op Iers strand*. AD Nieuws. https://www.ad.nl/buitenland/nederlander-vindt-bom-op-iers-strand~a98c72e1/

Amato, E., Alcaro, L., Corsi, I., Della Torre, C., Farchi, C., Focardi, S., … Tursi, A. (2006). An integrated ecotoxicological approach to assess the effects of pollutants released by unexploded chemical ordnance dumped in the southern Adriatic (Mediterranean Sea). *Marine Biology*, *149*(1), 17–23. https://doi.org/10.1007/S00227-005-0216-X

Ampleman, G., D. Faucher, S. Thiboutot, J. Hawari, and F. Monteil-Rivera. 2004. Evaluation of underwater contamination by explosives and metals at Point Amour Labrador and in the Halifax Harbour Area. Technical Report DRDC Valcartier TR 2004-125. Valcartier, Quebec, Canada: Defense Research and Development Canada.

ANP. (2005, April 6). *Drie zeemannen komen om door explosie op schip*. Algemeen | NU.nl. Retrieved January 23, 2023, from https://www.nu.nl/algemeen/507641/drie-zeemannen-komen-om-door-explosie-op-schip.html

Anstett, A. (2017, April 28). *A.anstett*. Shark Research & Conservation Program (SRC) | University of Miami. https://sharkresearch.earth.miami.edu/a-simple-tool-to-predict-bycatch-in-harbour-porpoises/

Appel, D., Strehse, J. S., Martin, H. J., & Maser, E. (2018). Bioaccumulation of 2,4,6-trinitrotoluene (TNT) and its metabolites leaking from corroded munition in transplanted blue mussels (M. edulis). *Marine Pollution Bulletin*, *135*, 1072–1078. https://doi.org/10.1016/J.MARPOLBUL.2018.08.028

Barbosa, J., Asselman, J., & Janssen, C. R. (2023). Synthesizing the impact of sea-dumped munition and related chemicals on humans and the environment. *Marine Pollution Bulletin*, *187*, 114601. https://doi.org/10.1016/j.marpolbul.2023.114601

Beck, A. J., Gledhill, M., Schlosser, C., Stamer, B., Böttcher, C., Sternheim, J., … Achterberg, E. P. (2018). Spread, behavior, and ecosystem consequences of conventional munitions compounds in Coastal marine waters. *Frontiers in Marine Science*, *5*(APR), 141. https://doi.org/10.3389/FMARS.2018.00141/BIBTEX

Beddington J, Kinloch A.J. (2005, June). *Munitions dumped at sea: a literature review*. Imperial College LondonConsultants, London

Beobom. (2013, December 5). *EénVandaag: Munitiestort met 500 ton Duitse Granaten in Waddenzee*. BeoBOM. https://www.beobom.nl/nieuws/eenvandaag-munitiestort-met-500-ton-duitse-granaten-in-waddenzee/

Berbee, R. P. M., & de Boer, R. (2015, April 17). Munitiestort Eastern Scheldt - metingen waterkwaliteit 2014. RWS WVL. Digital file access: https://www.helpdeskwater.nl/onderwerpen/emissiebeheer/onderzoeken/munitiestort/

Bergmann, S., Brenner, M., Strehse, J. S., Bünning, T. H., Maser, E., Grassel, P., … Wichert, U. (2022). *North Sea Wrecks - An interdisciplinary approach towards understanding the risks posed by wrecks containing munitions in the North Sea*. https://doi.org/10.5281/ZENODO.7149216

Bos, I. (2019, June 17). *De Bodem van de Noordzee Ligt Vol met Tikkende Tijdbommen*. Trouw. Retrieved February 2, 2023, from https://www.trouw.nl/duurzaamheid-economie/de-bodem-van-de-noordzee-ligt-vol-met-tikkende-tijdbommen~bb16fe39/

Böttcher, C., Knobloch, T., Rühl, N.-P., Sternheim, J., Wichert, U., & Wöhler, J. (2011). Munitionsbelastung der deutschen Meeresgewässer – Bestandsaufnahme und Empfehlungen. *Technical Report, Bund/Länder-*

Messprogramm Für Die Meeresumwelt von Nord Und Ostsee: Expertenkreis Munition Im Meer, 174. Retrieved from www.munition-im-meer.de

British Geological Survey. 2005. Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992–2004. Seismology & Geomagnetism Programme, Commissioned Report CR/05/064

Carton, G., & Jagusiewicz, A. (2009). *Historic Disposal of Munitions in U.S. and European Coastal Waters, How Historic Information Can be Used in Characterizing and Managing Risk*.

CBS Baltimore Staff. (2022, August 1). *WWII-era bomb debris washes up on Assateague Island Beach, prompting partial closure*. CBS News. https://www.cbsnews.com/baltimore/news/wwii-era-bomb-debris-washes-up-on-assateague-island-beach-prompting-partial-closure/

DAIMON. (2019). *Decision Aid for Marine Munitions*. DAIMON Project. http://www.daimonproject.com/

de Graaf, J. (2013, December 12). *Zeilers opgeschrikt door Ontploffingen bij munitiedump*. EenVandaag. https://eenvandaag.avrotros.nl/item/zeilers-opgeschrikt-door-ontploffingen-bij-munitiedump/

Defensie Expertise Centrum EODD. (2020, June 12). Handboek Explosive Ordnance Disposal Support to National Operations. Den Haag; Ministerie van Defensie.

den Otter, J. H., Pröfrock, D., Bünning, T. H., Strehse, J. S., van der Heijden, A. E. D. M., & Maser, E. (2023). Release of Ammunition-Related Compounds from a Dutch Marine Dump Site. *Toxics*, *11*(3), 238. https://doi.org/10.3390/toxics11030238

Derycke, M. (2019, May 2). *Mosterdgas Lekt voor Kust van Knokke-Heist: "pilootproject nodig om munitie op te Bergen"*. vrtnws.be. Retrieved January 24, 2023, from https://www.vrt.be/vrtnws/nl/2019/05/02/er-lekt-mosterdgas-voor-kust-van-knokke-heist/#:~:text=Uit%20de%20oorlogsmunitie%20voor%20de,munitie%20veilig%20op%20te%20bergen.

dosits.org. (2018, December 18). *How does sound in air differ from sound in water?*. Discovery of Sound in the Sea. https://dosits.org/science/sounds-in-the-sea/how-does-sound-in-air-differ-from-sound-in-water/

Edwards, M. H., Shjegstad, S. M., Wilkens, R., King, J. C., Carton, G., Bala, D., … Woerkom, M. Van. (2016). The Hawaii Undersea Military Munitions Assessment. *Deep-Sea Research Part II: Topical Studies in Oceanography*, *128*, 4–13. https://doi.org/10.1016/J.DSR2.2016.04.011

Farrington, J.W., Goldberg, E.D., Risebrough, R.W., Martin, J.H., Bowen, V.T., 1983. U.S. Mussel Watch 1976–1978. An overview of the trace metal, DDE, PCB, hydrocarbon and artificial radionuclide. Environ. Sci. Technol. 17, 490–496.

Fisher, S.W., Gossiaux, D.C., Bruner, K.A., Landrum, P.F., 1993. Investigations of the toxicokinetics of hydrophobic contaminants in the zebra mussel (Dreissena polymorpha). In: Nalepa, T.F., Schloesser, D. (Eds.), Zebra Mussels: Biology, Impacts and Control. Lewis Publishers, Boca Raton, pp. 465–490.

George, R., Wild, B., Li, S., Srinivasan, R., Sugamoto, R., Carlson, C., … Hihara, L. (2015). *Recovery, Corrosion Analysis, and Characteristics of Military Munitions from Ordnance Reef (HI-06) Approved for Public Release*.

Hasselmeier, I., Abt, K. F., Adelung, D., & Siebert, U. (2023). Stranding patterns of harbour porpoises (Phocoena phocoena) in the German North and Baltic Seas: when does the birth period occur? *J. Cetacean Res. Manage.*, *6*(3), 259–263. https://doi.org/10.47536/jcrm.v6i3.768

Hennis-Plasschaert, J. A., & Schultz van Haegen-Maas Geesteranus, M. H. (2014, January 21). Antwoord op vragen van de leden Paulus Jansen en Van Gerven over munitiestortplaats Engelsmanplaat (Waddenzee). Den Haag; Tweede Kamer der Staten Generaal. Digital file access: https://www.tweedekamer.nl/kamerstukken/kamervragen/detail?id=2013Z24314&did=2014D01811

Hopper, J. D. (1938). Explosive characteristics of certain metallic picrates. *Journal of the Franklin Institute*, *225*(2), 219–225. https://doi.org/10.1016/S0016-0032(38)90327-8

ICRC Convention on Certain Conventional Weapons, 10 October, 1980. Digital file access: https://www.icrc.org/en/document/1980-convention-certain-conventional-weapons

IMO Convention On the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972. Digital file access: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/LC1972.pdf

IMO. (2019). *Convention on the prevention of marine pollution by dumping of wastes and other matter*. International Maritime Organization. https://www.imo.org/en/OurWork/Environment/Pages/London-Convention-Protocol.aspx

Informatiehuis Marien (IHM). (2022, November 1). *Open data viewer*. Open Data Viewer. Retrieved February 2, 2023, from https://www.informatiehuismarien.nl/open-data-viewer/

Interreg. (2017). *About North Sea Wrecks, Interreg North Sea Region Programme*. About, Interreg VB North Sea Region Programme. https://northsearegion.eu/nsw/about/

IWM, H 42208. *The dumping of surplus ammunition at sea*. Imperial War Museums. (n.d.). https://www.iwm.org.uk/collections/item/object/205208197

Jurczak, W., & Fabisiak, J. (2017). Corrosion of ammunition dumped in the Baltic Sea. *Journal of KONBiN*, *41*(1), 227–246. https://doi.org/10.1515/jok-2017-0012

Kesselring, T., Viquerat, S., IJsseldijk, L. L., Langeheine, M., Wohlsein, P., Gröne, A., … Brehm, R. (2019). Testicular morphology and spermatogenesis in harbour porpoises (Phocoena phocoena). *Theriogenology*, *126*, 177–186. https://doi.org/10.1016/J.THERIOGENOLOGY.2018.11.031

Ketten, D.R., 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In: Sensory Systems of Aquatic Mammals, R. A. Kastelein, J.A. Thomas and P.E. Nachtigall (editors) De Spil Publishers, Woerden, The Netherlands ISBN 90-72743-05-9.

Koschinski, S., & Kock, K.-H. (2015, August 28). *Underwater Unexploded Ordnance-Methods for a Cetacean-friendly Removal of Explosives as Alternatives to Blasting*.

Kustwacht Nederland. (2022, September 29). *Explosievenopruiming*. Kustwacht Nederland. Retrieved January 23, 2023, from https://kustwacht.nl/hulpverlening/explosievenopruiming/

Kustwacht. (2020). *Explosievenkaart*. Den Helder; Kustwachtcentrum. Digital file access: https://archief35.sitearchief.nl/archives/sitearchief/20220530125808/https:/www.kustwacht.nl/sites/default/files/Explosievenkaart%20%28Kustwacht%29.pdf

Lotufo, G. R., Chappell, M. A., Price, C. L., Ballentine, M. L., Fuentes, A. A., Bridges, T. S., … Carton, G. (2017). (PDF) Review and Synthesis of Evidence Regarding Environmental Risks Posed by Munitions Constituents (MC) in Aquatic Systems Review and Synthesis of Evidence Regarding Environmental Risks Posed by Munitions Constituents (MC) in Aquatic Systems. Retrieved January 27, 2023, from Engineer Research and Development Center - U.S. Army website: https://www.researchgate.net/publication/320776368_Review_and_Synthesis_of_Evidence_Regarding_Environmental_Risks_Posed_by_Munitions_Constituents_MC_in_Aquatic_Systems_Review_and_Synthesis_of_Evidence_Regarding_Environmental_Risks_Posed_by_Munitions_C

Macleod, I. D. (2016). In-situ Corrosion Measurements of WWII Shipwrecks in Chuuk Lagoon, Quantification of Decay Mechanisms and Rates of Deterioration. *Frontiers in Marine Science | Www.Frontiersin.Org*, *3*(38). https://doi.org/10.3389/fmars.2016.00038

Maser, E., & Strehse, J. S. (2021). Can seafood from marine sites of dumped World War relicts be eaten? *Archives of Toxicology*, *95*(7), 2255–2261. https://doi.org/10.1007/S00204-021-03045-9

Menzel, P., Drews, A., Mehring, T., Otto, C., & Erbs-Hansen, D. R. (2022). Mobilization of Unexploded Ordnance on the Seabed. *Toxics 2022, Vol. 10, Page 389*, *10*(7), 389. https://doi.org/10.3390/TOXICS10070389

Military Images (2018, March 20). *Aircraft*. A Military Photos & Video Website. https://www.militaryimages.net/media/aircraft.67173/

Ministerie LNV. (2023a). *Eastern Scheldt*. Eastern Scheldt | natura 2000. https://www.natura2000.nl/gebieden/zeeland/Eastern Scheldt

Ministerie LNV. (2023b). *Waddenzee*. Waddenzee | natura 2000. https://www.natura2000.nl/gebieden/friesland/waddenzee

Ministerie van Defensie. (2014, December 5). *Mijnenbestrijding Beneficial Cooperation*. Internationale samenwerking | Defensie.nl. Retrieved January 23, 2023, from https://www.defensie.nl/onderwerpen/internationale-samenwerking/maritiem-en-amfibisch/belgisch-nederlandse-mijnenbestrijding

Ministerie van Defensie. (2021, September 9). *Commandant Zeestrijdkrachten*. Koninklijke Marine | Defensie.nl. https://www.defensie.nl/organisatie/marine/cszk

Ministerie van IenW. (2018, June). Kaderrichtlijn Mariene strategie. Rijksoverheid. Digital file access: https://www.noordzeeloket.nl/beleid/mariene-strategie-krm/

NABU Schleswig-Holstein. (2010). *Munition im Meer*. NABU. https://schleswig-holstein.nabu.de/natur-und-landschaft/aktionen-und-projekte/munition-im-meer/index.html

NIOZ. (2023). Harbour porpoises. https://www.nioz.nl/en/expertise/wadden-delta-research-centre/expertise-wadden/marine-mammals/harbour-porpoises

NOAA. (2022, September 15). *Harbor Porpoise*. NOAA Fisheries. https://www.fisheries.noaa.gov/species/harbor-porpoise

Noordzeeloket. (2020). *Harbour Porpoise*. Noordzeeloket UK. https://www.noordzeeloket.nl/en/policy/noordzee-natura-2000/gebieden/klaverbank/cleaver-bank/beschermde-soorten/mammals/bruinvis/#:~:text=The%20harbour%20porpoise%20is%20included,Conventions%20of%20Bonn%20and%20Bern.

Noordzeeloket. (2021). *Voorbereiding Windparken*. Noordzeeloket. https://www.noordzeeloket.nl/functies-gebruik/windenergie/voorbereiding-windparken/

Nützel, B. 2008. Untersuchungen zum Schutz von Schweinswalen vor Schockwellen. Technischer Bericht TB 2008-7. Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik (FWG). Kiel. 18 pp.

Ochsenbein, U., M. Zeh, and J. D. Berset. 2008. Comparing solid phase extraction and direct injection for the analysis of ultra-trace levels of relevant explosives in lake water and tributaries using liquid chromatography-electrospray tandem mass spectrometry. Chemosphere 72(6): 974–980.

OSPAR Commission. (2010). *OSPAR Recommendation 2010/20 on an OSPAR framework for reporting encounters with conventional and chemical munitions in the OSPAR Maritime Area*.

OSPAR. (1998, March 25). *Convention for the Protection of the Marine Environment of the North-East Atlantic*. Convention text. https://www.ospar.org/convention/text

Pfeiffer, F. (2012). Changes in Properties of Explosives Due to Prolonged Seawater Exposure. *Marine Technology Society Journal*, *46*(1), 102–110. https://doi.org/10.4031/MTSJ.46.1.5

Porter, J. W., J. V. Barton, and C. Torres. 2011. Ecological, radiological, and toxicological effects of naval bombardment on the coral reefs of Ilsa de Vieques, Puerto Rico. In Warfare ecology: A new synthesis for peace and security, ed. G. E. Machlis, T. Hanson, Z. Spiric, and J. E. McKendry, 65–122. NATO Science for Peace and Security Series C: Environmental Security. Dordrecht, The Netherlands: Springer

REACH. (2022, November 23). *Registration dossier TNT*. ECHA. https://echa.europa.eu/nl/registration-dossier/-/registered-dossier/16165/6/1

Rijksoverheid. (2019). *Bijdrageregeling opgeviste explosieven 1992*. wetten.nl - Regeling - Bijdrageregeling opgeviste explosieven 1992 - BWBR0005727. https://wetten.overheid.nl/BWBR0005727/2019-07-01

Rosen, G., & Lotufo, G. R. (2007). Bioaccumulation of explosive compounds in the marine mussel, Mytilus galloprovincialis. *Ecotoxicology and Environmental Safety*, *68*(2), 237–245. https://doi.org/10.1016/j.ecoenv.2007.04.009

Rosen, G., Colvin, M., George, R., Lotufo, G., Woodley, C., & Smith, D. (2017, September). Validation of Passive Sampling Devices for Monitoring of Munitions Constituents in Underwater Environments. San Diego; The United States Government. Digital file access: https://apps.dtic.mil/sti/pdfs/AD1042060.pdf

Rossland, H. K., A. Johnsen, T. E. Karsrud, M. P. Parmer, A. Larsen, A. Myran, and S. V. Nordas. 2010. Forurensning fra ammunisjon i akvatisk miljø og på kystfort: innledene undersøkelser (English Translation: Pollution from ammunition in the aquatic environment and the coastal forts - initial investigations). FFI report 2010/00239. Kjeller, Norway: Norwegian Defense Research Establishment.

Sanderson, H., & Fauser, P. (2015). *Scientifi c Report from DCE-Danish Centre for Environment and Energy ENVIRONMENTAL ASSESSMENTS OF SEA DUMPED CHEMICAL WARFARE AGENTS CWA report*.

Schick, L. A., Strehse, J. S., Bünning, T. H., Maser, E., & Siebert, U. (2022). Energetic Compounds in the Trophic Chain—A Pilot Study Examining the Exposure Risk of Common Eiders (Somateria mollissima) to TNT, Its Metabolites, and By-Products. *Toxics 2022, Vol. 10, Page 685*, *10*(11), 685. https://doi.org/10.3390/TOXICS10110685

Shepherd, J. (2022, March 25). *Coastguard issue warning as deadly WW2 ordnance washes up on Scots Beach*. scottishdailyexpress. https://www.scottishdailyexpress.co.uk/news/scottish-news/coastguard-issue-warning-deadly-ww2-26554762#google_vignette

Siebert, U., Stürznickel, J., Schaffeld, T., Oheim, R., Rolvien, T., Prenger-Berninghoff, E., … Morell, M. (2022). Blast injury on harbour porpoises (Phocoena phocoena) from the Baltic Sea after explosions of deposits of World War II ammunition. *Environment International*, *159*. https://doi.org/10.1016/J.ENVINT.2021.107014

Silva, J. A. K., & Chock, T. (2016). Munitions integrity and corrosion features observed during the HUMMA deep-sea munitions disposal site investigations. *Deep-Sea Research Part II: Topical Studies in Oceanography*, *128*, 14–24. https://doi.org/10.1016/J.DSR2.2015.09.001

Staudenmaier, R. (2017, August 7). *Woman plucks WWII munition from German Beach*. dw.com. https://www.dw.com/en/woman-mistakes-wwii-era-munition-for-precious-stone-on-german-beach/a-39977702

Stichting de Noordzee. (2022, May 19). *Over ons*. Stichting De Noordzee. https://www.noordzee.nl/over-ons/

Strehse, J. S., Appel, D., Geist, C., Martin, H.-J., & Maser, E. (2017). Biomonitoring of 2,4,6-trinitrotoluene and degradation products in the marine environment with transplanted blue mussels (M. edulis). *Toxicology*, *390*, 117–123. https://doi.org/10.1016/j.tox.2017.09.004

Tennet, & Rijkswaterstaat. (2019, February 28). *Noordzee pilotonderzoek conventionele explosieven*. Crisislab.nl. https://crisislab.nl/wordpress/wp-content/uploads/RAP01803005-Noordzee-CPL-gecomprimeerd.pdf

UNESCO, U. W. H. (2023). *Wadden Sea*. UNESCO World Heritage Centre. https://whc.unesco.org/en/list/1314/

United Nations Convention on the High Seas, 29 April 1958, https://treaties.un.org/doc/Treaties/1963/01/19630103%2002-00%20AM/Ch_XXI_01_2_3_4_5p.pdf

US-EPA. (2014, January). *Technical fact sheet – 2,4,6-trinitrotoluene (TNT) factsheet*. Technical Fact Sheet – 2,4,6-Trinitrotoluene (TNT). https://www.epa.gov/sites/default/files/2014-03/documents/ffrrofactsheet_contaminant_tnt_january2014_final.pdf

van Elk, B. (2020, September 16). *Munitieduiken in Eastern Scheldt*. 05 | Alle Hens. https://magazines.defensie.nl/allehens/2020/09/05_eod-Eastern Scheldt

Van Ham, N., A. Creemers, and D. Meuken. 2007. Risks of sea dumped ammunition. In proceedings, "Security Impact of Munition and Propellant Disposal," 12–14 September, Bulgaria.
Voie, Ø. A., & Mariussen, E. (2017). Risk Assessment of Sea Dumped Conventional Munitions. *Propellants, Explosives, Pyrotechnics*, *42*(1), 98–105. https://doi.org/10.1002/PREP.201600163

VOMES. (2023). *Certificaatregister CS-VROO*. VOMES. https://www.vomes.nl/certificatie/certificaatregister-cs-vroo-raadplegen/

von Benda-Beckmann, A. M., Aarts, G., Sertlek, H. Ö., Lucke, K., Verboom, W. C., Kastelein, R. A., … Ainslie, M. A. (2015). Assessing the Impact of Underwater Clearance of Unexploded Ordnance on Harbour Porpoises (Phocoena phocoena) in the Southern North Sea. *Aquatic Mammals*, *41*(4), 503–523. https://doi.org/10.1578/AM.41.4.2015.503

Wang, P. F., Liao, Q., George, R., & Wild, W. (2011). Release rate and transport of munitions constituents from breached shells in marine environment. *ACS Symposium Series*, *1069*, 317–340. https://doi.org/10.1021/BK-2011-1069.CH016

Wilbrand, J. (1863). Notiz über Trinitrotoluol. *Justus Liebigs Annalen Der Chemie*, *128*(2), 178–179. https://doi.org/10.1002/JLAC.18631280206

Wilkinson, I. (2018, September 20). *Chemical Weapon Munitions dumped at sea: An interactive map*. James Martin Center for Nonproliferation Studies. Retrieved March 21, 2023, from https://nonproliferation.org/chemical-weapon-munitions-dumped-at-sea/

Appendices

Appendix A, extended toxicity table

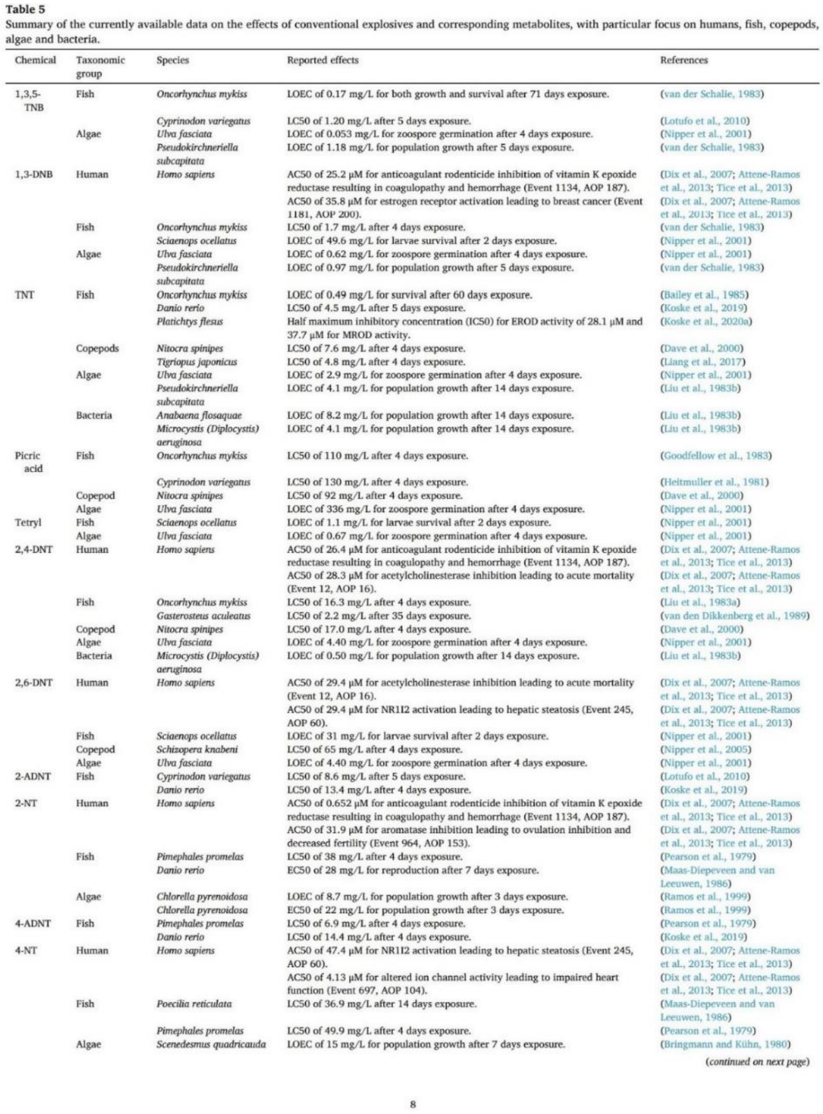


Table 5
Summary of the currently available data on the effects of conventional explosives and corresponding metabolites, with particular focus on humans, fish, copepods, algae and bacteria.

Chemical	Taxonomic group	Species	Reported effects	References
1,3,5-TNB	Fish	*Oncorhynchus mykiss*	LOEC of 0.17 mg/L for both growth and survival after 71 days exposure.	(van der Schalie, 1983)
		Cyprinodon variegatus	LC50 of 1.20 mg/L after 5 days exposure.	(Lotufo et al., 2010)
	Algae	*Ulva fasciata*	LOEC of 0.053 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
		Pseudokirchneriella subcapitata	LOEC of 1.18 mg/L for population growth after 5 days exposure.	(van der Schalie, 1983)
1,3-DNB	Human	*Homo sapiens*	AC50 of 25.2 μM for anticoagulant rodenticide inhibition of vitamin K epoxide reductase resulting in coagulopathy and hemorrhage (Event 1134, AOP 187).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
			AC50 of 35.8 μM for estrogen receptor activation leading to breast cancer (Event 1181, AOP 200).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
	Fish	*Oncorhynchus mykiss*	LC50 of 1.7 mg/L after 4 days exposure.	(van der Schalie, 1983)
		Sciaenops ocellatus	LOEC of 49.6 mg/L for larvae survival after 2 days exposure.	(Nipper et al., 2001)
	Algae	*Ulva fasciata*	LOEC of 0.62 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
		Pseudokirchneriella subcapitata	LOEC of 0.97 mg/L for population growth after 5 days exposure.	(van der Schalie, 1983)
TNT	Fish	*Oncorhynchus mykiss*	LOEC of 0.49 mg/L for survival after 60 days exposure.	(Bailey et al., 1985)
		Danio rerio	LC50 of 4.5 mg/L after 5 days exposure.	(Koske et al., 2019)
		Platichtys flesus	Half maximum inhibitory concentration (IC50) for EROD activity of 28.1 μM and 37.7 μM for MROD activity.	(Koske et al., 2020a)
	Copepods	*Nitocra spinipes*	LC50 of 7.6 mg/L after 4 days exposure.	(Dave et al., 2000)
		Tigriopus japonicus	LC50 of 4.8 mg/L after 4 days exposure.	(Liang et al., 2017)
	Algae	*Ulva fasciata*	LOEC of 2.9 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
		Pseudokirchneriella subcapitata	LOEC of 4.1 mg/L for population growth after 14 days exposure.	(Liu et al., 1983b)
	Bacteria	*Anabaena flosaquae*	LOEC of 8.2 mg/L for population growth after 14 days exposure.	(Liu et al., 1983b)
		Microcystis (Diplocystis) aeruginosa	LOEC of 4.1 mg/L for population growth after 14 days exposure.	(Liu et al., 1983b)
Picric acid	Fish	*Oncorhynchus mykiss*	LC50 of 110 mg/L after 4 days exposure.	(Goodfellow et al., 1983)
		Cyprinodon variegatus	LC50 of 130 mg/L after 4 days exposure.	(Heitmuller et al., 1981)
	Copepod	*Nitocra spinipes*	LC50 of 92 mg/L after 4 days exposure.	(Dave et al., 2000)
	Algae	*Ulva fasciata*	LOEC of 336 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
Tetryl	Fish	*Sciaenops ocellatus*	LOEC of 1.1 mg/L for larvae survival after 2 days exposure.	(Nipper et al., 2001)
	Algae	*Ulva fasciata*	LOEC of 0.67 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
2,4-DNT	Human	*Homo sapiens*	AC50 of 26.4 μM for anticoagulant rodenticide inhibition of vitamin K epoxide reductase resulting in coagulopathy and hemorrhage (Event 1134, AOP 187).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
			AC50 of 28.3 μM for acetylcholinesterase inhibition leading to acute mortality (Event 12, AOP 16).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
	Fish	*Oncorhynchus mykiss*	LC50 of 16.3 mg/L after 4 days exposure.	(Liu et al., 1983a)
		Gasterosteus aculeatus	LC50 of 2.2 mg/L after 35 days exposure.	(van den Dikkenberg et al., 1989)
	Copepod	*Nitocra spinipes*	LC50 of 17.0 mg/L after 4 days exposure.	(Dave et al., 2000)
	Algae	*Ulva fasciata*	LOEC of 4.40 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
	Bacteria	*Microcystis (Diplocystis) aeruginosa*	LOEC of 0.50 mg/L for population growth after 14 days exposure.	(Liu et al., 1983b)
2,6-DNT	Human	*Homo sapiens*	AC50 of 29.4 μM for acetylcholinesterase inhibition leading to acute mortality (Event 12, AOP 16).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
			AC50 of 29.4 μM for NR1I2 activation leading to hepatic steatosis (Event 245, AOP 60).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
	Fish	*Sciaenops ocellatus*	LOEC of 31 mg/L for larvae survival after 2 days exposure.	(Nipper et al., 2001)
	Copepod	*Schizopera knabeni*	LC50 of 65 mg/L after 4 days exposure.	(Nipper et al., 2005)
	Algae	*Ulva fasciata*	LOEC of 4.40 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
2-ADNT	Fish	*Cyprinodon variegatus*	LC50 of 8.6 mg/L after 5 days exposure.	(Lotufo et al., 2010)
		Danio rerio	LC50 of 13.4 mg/L after 4 days exposure.	(Koske et al., 2019)
2-NT	Human	*Homo sapiens*	AC50 of 0.652 μM for anticoagulant rodenticide inhibition of vitamin K epoxide reductase resulting in coagulopathy and hemorrhage (Event 1134, AOP 187).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
			AC50 of 31.9 μM for aromatase inhibition leading to ovulation inhibition and decreased fertility (Event 964, AOP 153).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
	Fish	*Pimephales promelas*	LC50 of 38 mg/L after 4 days exposure.	(Pearson et al., 1979)
		Danio rerio	EC50 of 28 mg/L for reproduction after 7 days exposure.	(Maas-Diepeveen and van Leeuwen, 1986)
	Algae	*Chlorella pyrenoidosa*	LOEC of 8.7 mg/L for population growth after 3 days exposure.	(Ramos et al., 1999)
		Chlorella pyrenoidosa	EC50 of 22 mg/L for population growth after 3 days exposure.	(Ramos et al., 1999)
4-ADNT	Fish	*Pimephales promelas*	LC50 of 6.9 mg/L after 4 days exposure.	(Pearson et al., 1979)
		Danio rerio	LC50 of 14.4 mg/L after 4 days exposure.	(Koske et al., 2019)
4-NT	Human	*Homo sapiens*	AC50 of 47.4 μM for NR1I2 activation leading to hepatic steatosis (Event 245, AOP 60).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
			AC50 of 4.13 μM for altered ion channel activity leading to impaired heart function (Event 697, AOP 104).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
	Fish	*Poecilia reticulata*	LC50 of 36.9 mg/L after 14 days exposure.	(Maas-Diepeveen and van Leeuwen, 1986)
		Pimephales promelas	LC50 of 49.9 mg/L after 4 days exposure.	(Pearson et al., 1979)
	Algae	*Scenedesmus quadricauda*	LOEC of 15 mg/L for population growth after 7 days exposure.	(Bringmann and Kühn, 1980)

(*continued on next page*)

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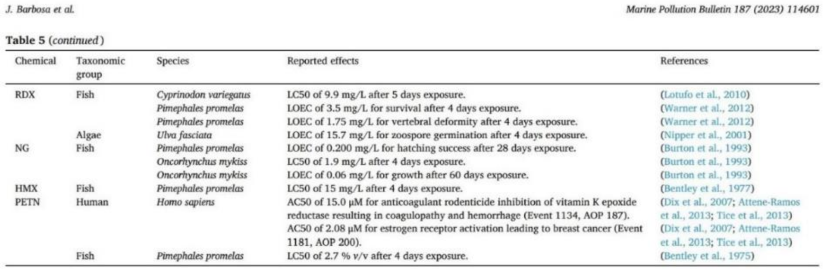


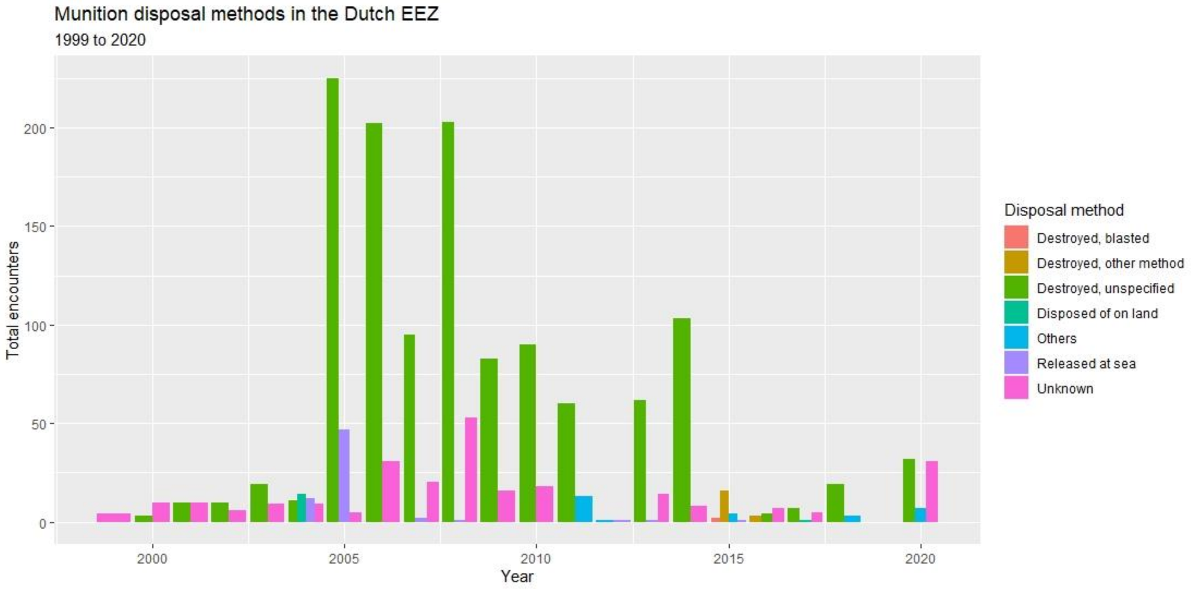
J. Barbosa et al. *Marine Pollution Bulletin 187 (2023) 114601*

Table 5 (*continued*)

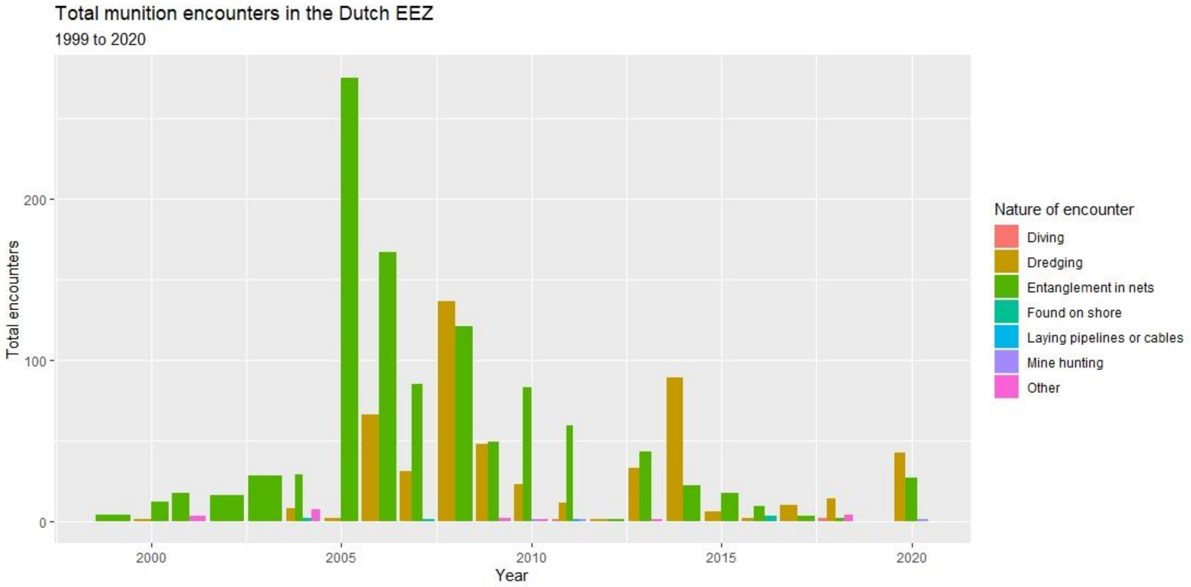
Chemical	Taxonomic group	Species	Reported effects	References
RDX	Fish	*Cyprinodon variegatus*	LC50 of 9.9 mg/L after 5 days exposure.	(Lotufo et al., 2010)
		Pimephales promelas	LOEC of 3.5 mg/L for survival after 4 days exposure.	(Warner et al., 2012)
		Pimephales promelas	LOEC of 1.75 mg/L for vertebral deformity after 4 days exposure.	(Warner et al., 2012)
	Algae	*Ulva fasciata*	LOEC of 15.7 mg/L for zoospore germination after 4 days exposure.	(Nipper et al., 2001)
NG	Fish	*Pimephales promelas*	LOEC of 0.200 mg/L for hatching success after 28 days exposure.	(Burton et al., 1993)
		Oncorhynchus mykiss	LC50 of 1.9 mg/L after 4 days exposure.	(Burton et al., 1993)
		Oncorhynchus mykiss	LOEC of 0.06 mg/L for growth after 60 days exposure.	(Burton et al., 1993)
HMX	Fish	*Pimephales promelas*	LC50 of 15 mg/L after 4 days exposure.	(Bentley et al., 1977)
PETN	Human	*Homo sapiens*	AC50 of 15.0 μM for anticoagulant rodenticide inhibition of vitamin K epoxide reductase resulting in coagulopathy and hemorrhage (Event 1134, AOP 187).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
			AC50 of 2.08 μM for estrogen receptor activation leading to breast cancer (Event 1181, AOP 200).	(Dix et al., 2007; Attene-Ramos et al., 2013; Tice et al., 2013)
	Fish	*Pimephales promelas*	LC50 of 2.7 % *v*/v after 4 days exposure.	(Bentley et al., 1975)

Appendix B- Rstudio

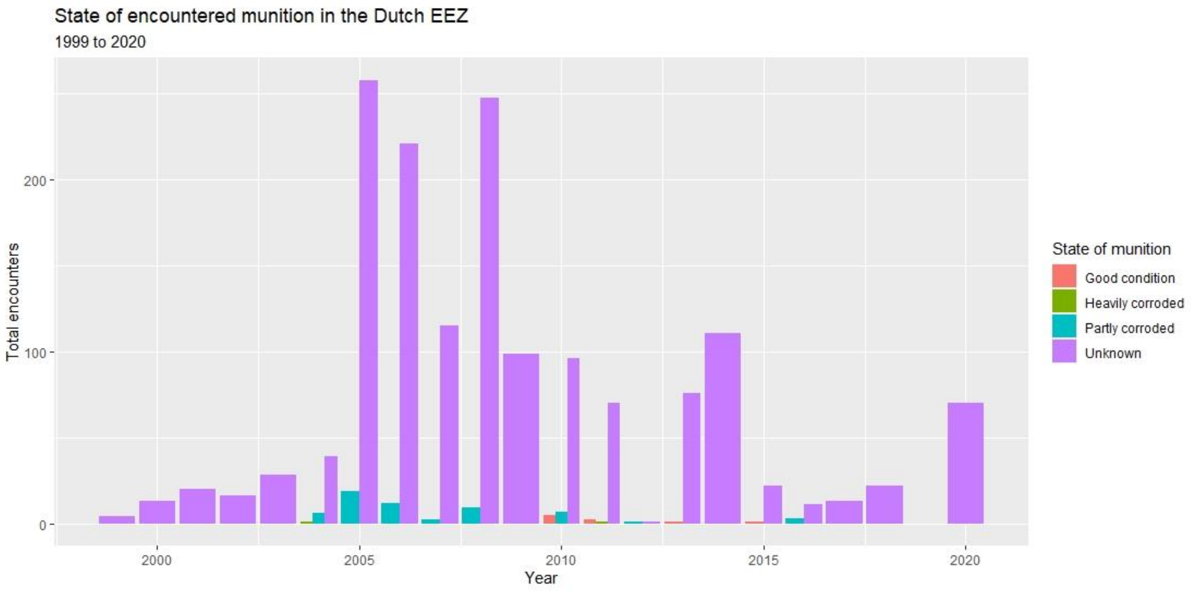
Figures


Munition disposal methods in the Dutch EEZ

1999 to 2020

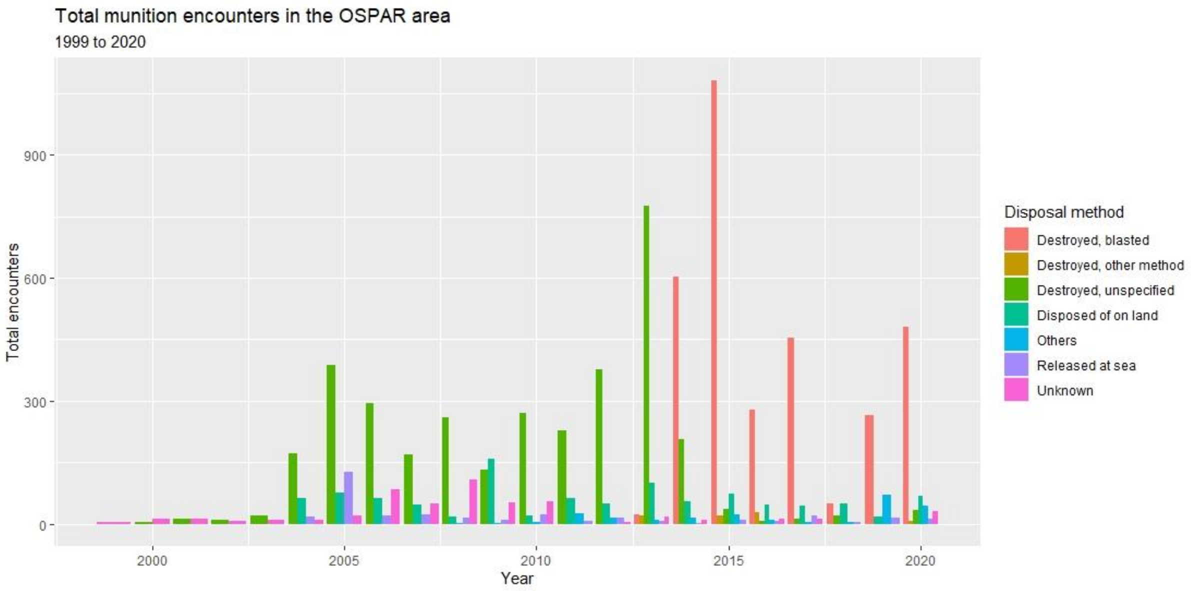

Total munition encounters in the Dutch EEZ

1999 to 2020



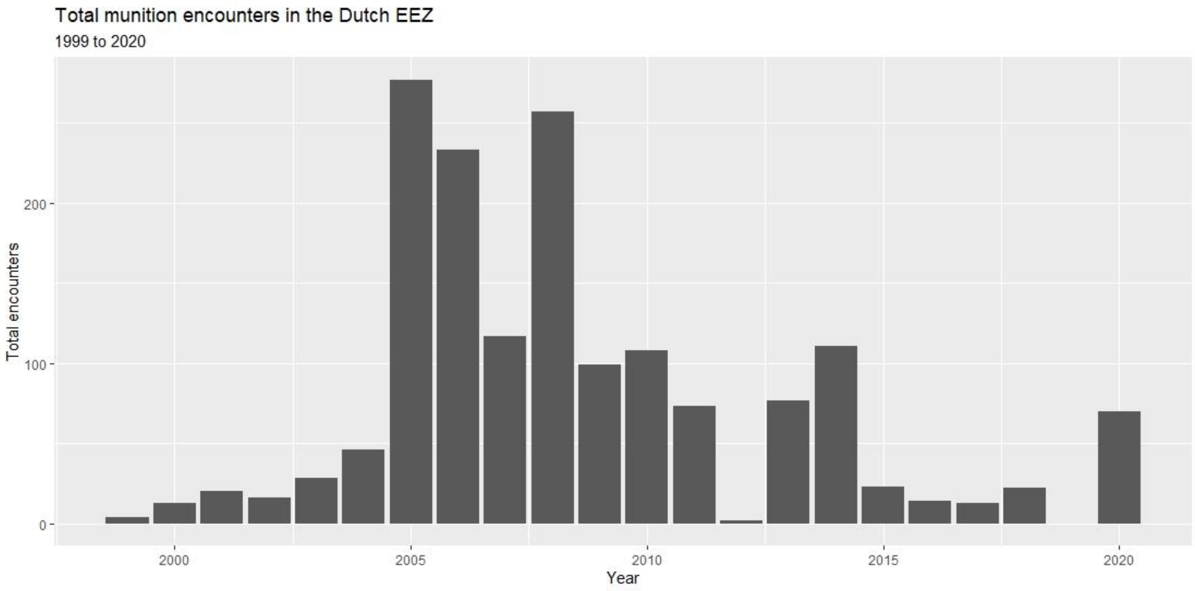
State of encountered munition in the Dutch EEZ

1999 to 2020



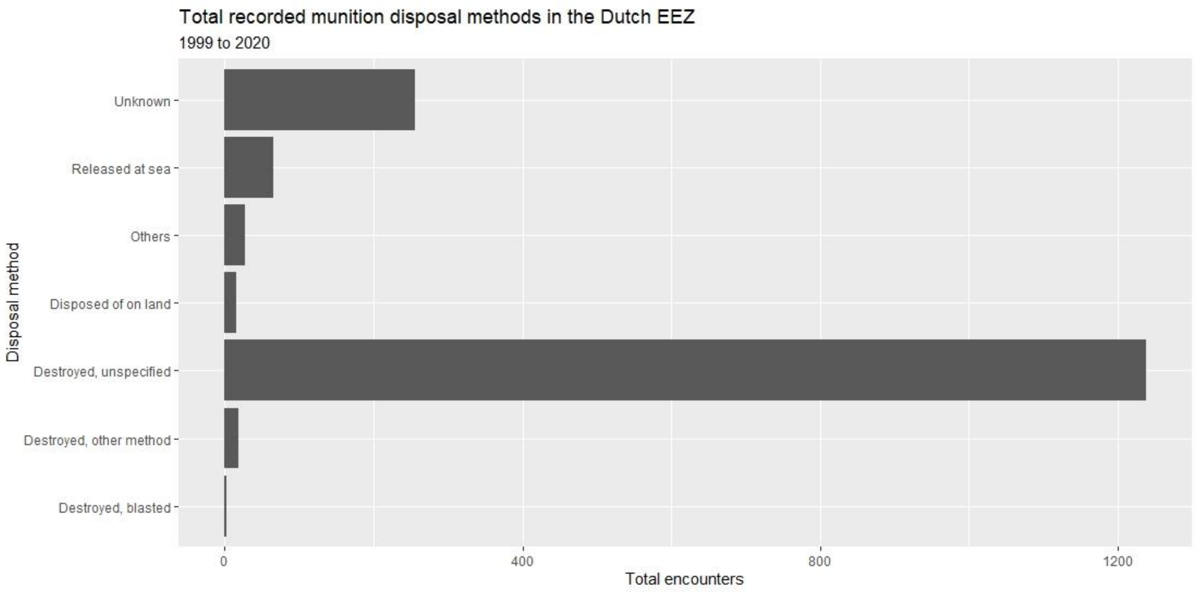
Total munition encounters in the OSPAR area

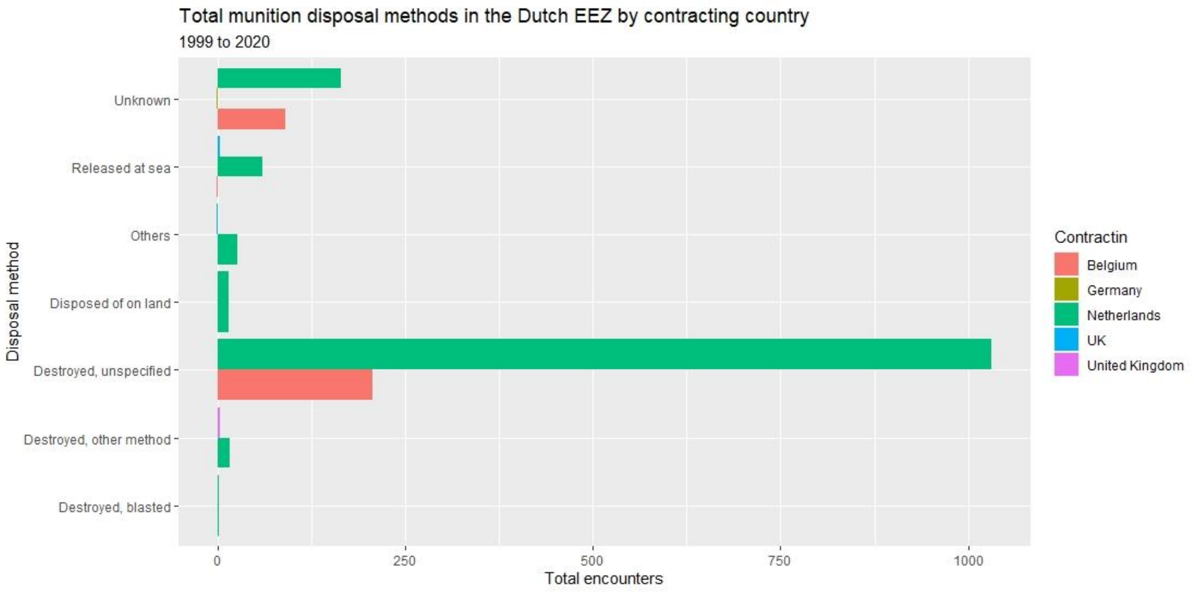
1999 to 2020

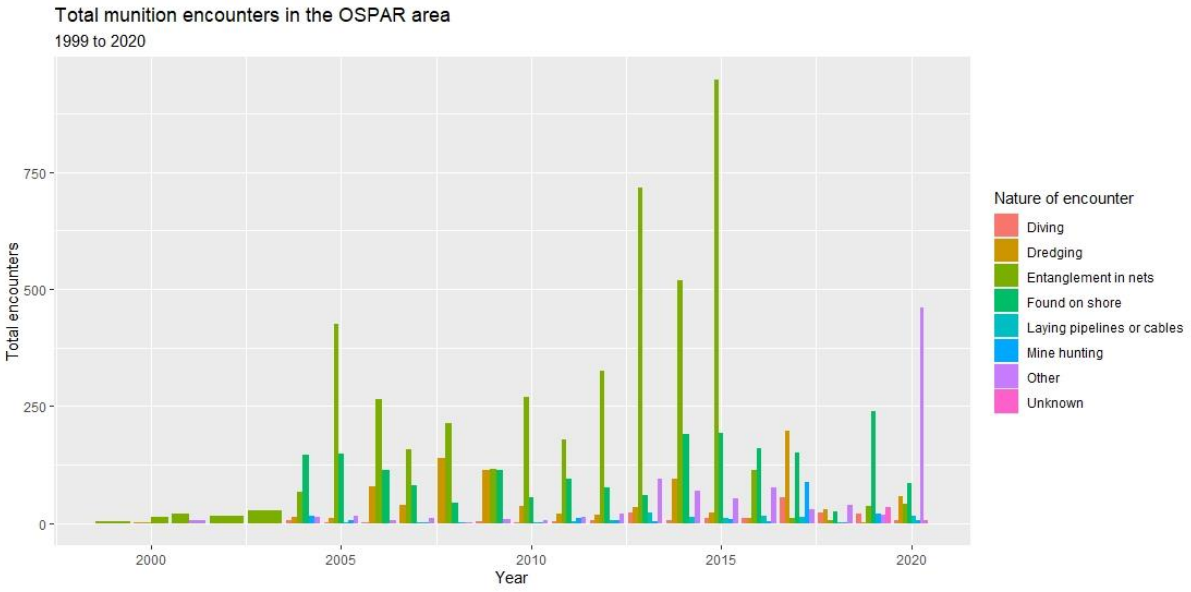


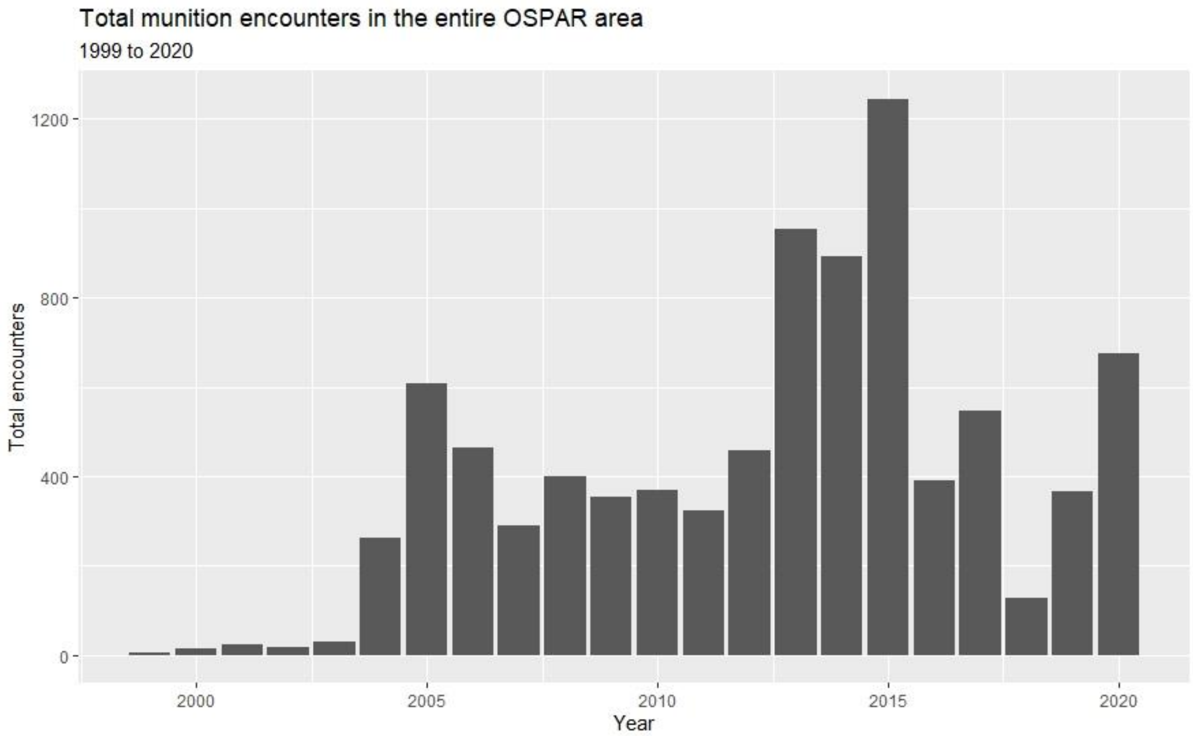
Total munition encounters in the Dutch EEZ

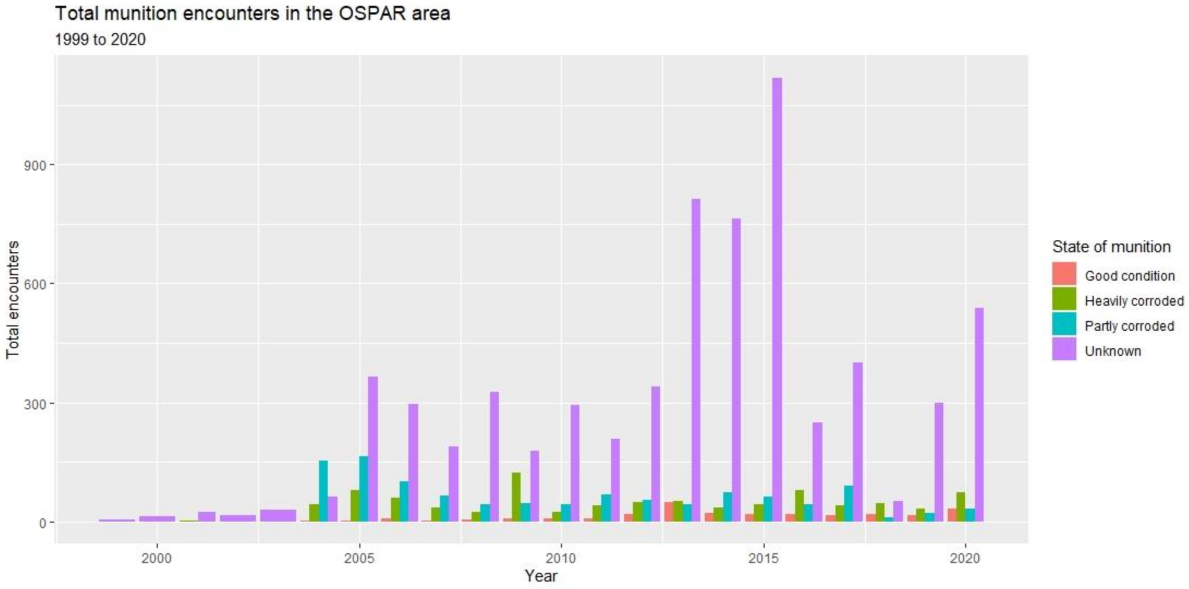
1999 to 2020


Total recorded munition disposal methods in the Dutch EEZ
1999 to 2020


Total munition disposal methods in the Dutch EEZ by contracting country
1999 to 2020


Total munition encounters in the OSPAR area
1999 to 2020


Total munition encounters in the entire OSPAR area
1999 to 2020
Total encounters
0
400
800
1200
2000
2005
2010
2015
2020
Year


Total munition encounters in the OSPAR area
1999 to 2020
Total encounters
0
300
600
900
2000
2005
2010
2015
2020
Year
State of munition
Good condition
Heavily corroded
Partly corroded
Unknown

Appendix C – Interview overview

Overview of personal correspondence with experts in the field

- North Sea Wrecks Team(7 feb)
- Terry Long, IDUM (7 mrt)
- Ad van Riel, REASeuro (8 mrt)
- Sander von Benda-Beckmann TNO (14 mrt)
- Aaron Beck, GEOMAR (15 mrt)
- Edmund Maser, Kiel University (16 mrt)
- Arjan den Otter, Antoine van der Heijden, TNO (24 mrt)
- Arthur Hollman, UXO offshore services (28 mrt)
- Carmen Hogenboom, Rijkswaterstaat (11 mei)