Cent. Eur. J. Energ. Mater. 2025, *22*(4): 540-551; DOI 10.22211/cejem/216306

Article is available in PDF-format, in colour, at:
https://ipo.lukasiewicz.gov.pl/wydawnictwa/cejem-woluminy/vol-22-nr-4/

Review

Dumped Ammunition – Never Ending Story?

Tomasz Sałaciński*), Mateusz Szala, Barbara Wiaderek, Klaudia Rzadkowska
Military University of Technology, 2 gen. S. Kaliskiego Street, 00-908 Warsaw, Poland
* *E-mail:* tomasz.salacinski@wat.edu.pl

ORCID Information

Tomasz Sałaciński: https://orcid.org/0000-0002-4376-4081
Mateusz Szala: https://orcid.org/0000-0002-6928-2689
Barbara Wiaderek: https://orcid.org/0009-0005-4737-2690
Klaudia Rzadkowska: https://orcid.org/0009-0001-2690-090X

Abstract: Since the 1990s, the issue of the accumulation of ammunition, deliberately dumped in the 20th century, has been raised on a global scale. The main reason is the economic interest in the areas where these ammunition are located. There are also other reasons, such as the fact that ammunition in the aquatic environment is a source of many elements and chemicals, including those that have a negative effect on aquatic fauna and flora. In addition, ammunition that is intentionally sunk still poses a risk of explosion.
So far, the removal of dumped ammunition has not been started on the full scale. There are many reasons raised by many researchers around the world, among others, the unsolved concerns on technical executing of the removal processes and the fear that as a result of starting disposal, it may lead to even greater problems. Moreover, due to the constant changes of the seabed, full restoring of dumped sites may be regarded as mission impossible. The presented paper focuses on arguments that are not often raised, however, it seems that they should be taken into account by researchers dealing with explosives and dumped ammunition, *i.e.* the general pollution of water reservoirs, the lack of sufficient methods for managing and analyzing large databases, as well as, the danger of terrorist threats.

Keywords: dumped ammunition, disposal, aquatic systems, data analysis, terrorism

1 Introduction

It has long been known that huge amounts of explosives are lying at the bottom of the seas and oceans. Explosives were placed in the aquatic environment not only as a result of random events, conducting combat operations, military exercises, including at coastal training grounds [1], but also as a result of their deliberate sinking. The range of these products is practically unlimited, both in terms of the time of sinking, construction or country of origin. It includes both sunken warships and merchant ships transporting ammunition, downed military aircraft, as well as pistol ammunition, bombs, torpedoes, and naval mines that failed to work properly during military operations. Explosives are still introduced into the aquatic environment, *e.g.* as a result of laying underwater minefields or destroying unexploded ordnance.

Until the 1970s, all over the word dumped in seas and oceans of all kinds of wastes, among them ammunition, was regarded as a cheap, fast, safe and effective form of disposal. Nowadays, it is estimated that due to the contamination of aquatic and coastal ecosystems it was a very harmful procedure. From today's point of view, the sinking of ammunition was not only a postponement – for the next generations – of the need to dispose of this ammunition, but also an unimaginable multiplication of the costs of disposal. Many actions are being taken to contribute to solving the problem of disposal of sunken ammunition. These are both basic research and implementation projects, usually carried out as part of large international research projects, *e.g.* [2-6], including the currently implemented [7]. You can easily find information about many other projects. From the point of view of the presented work, the common denominator of these projects is that they are certainly insufficient to comprehensively solve the problem of sunken munitions. In other words, more projects will be needed. Paintings depicting sunken ammunition can be found in many works, *e.g.* [8], but this is only one side of the coin. In the alternative approach to sunken ammunition, the prevailing view is that it is better not to move these munitions until one is sure of the expediency of its extraction and disposal. Please note that 11% of found of the dumped ammunition was thrown back into the aquatic environment [9]. In the 1950s, sunken ammunition was extracted, but only to recover its metal elements [8].

In the common understanding, the problem of sunken ammunition is practically only associated with the Baltic Sea, including mainly the Danish Straits and the waters surrounding the island of Bornholm. Of course, the problems resulting from the presence of sunken munitions in the Baltic Sea are very serious, but this is not the only place where they occur. The focus of public attention on ammunition sunk in the Baltic Sea results from several premises.

Most of all, the most frequently cited data is on the ammunition dumped around Europe, especially in Baltic Sea, on the basis of international agreements was made at the Potsdam Conference in 1945 [10]. Based on this agreement, it was dumped in European waters over 15,000 tonnes of chemical warfare agents [11].

In addition, 9 countries have their maritime territorial waters in this body of water, and it is a community of about 90 million people. Other known places of ammunition sinkings are either territorial waters of a single state or extraterritorial waters. In addition, the Baltic states maintain relations with other countries, both in the sphere of life of individuals (due to the widespread tourist use of the Baltic Sea) and in the sphere of life of entire nations (economic development through offshore wind farms, transport routes, pipelines and cables laid on the bottom of the Baltic Sea, and fisheries). As a result, the need to reach agreements on a global scale is indicated by the expectations of the industry and the actual situation. A measurable loss caused by the presence of dumped ammunition is the limitation of the possibilities of economic use of these reservoirs.

What is more, the particularly strong interest of the Baltic states in this area, *i.e.* the widespread reference to the situation in the Baltic Sea, will not change quickly. Perhaps the most prosaic reason is that the Baltic Sea provides relatively the easiest conditions for conducting research on sunken ammunition. Conducting such research does not require organizing a long-term expedition to the bottom of the ocean. In addition, each Baltic state has its own scientific centers and armed forces operating in the Baltic ecosphere, so the problem of sunken munitions in the Baltic is in the center of interest of everyone in Europe.

What causes the greatest concern is the fact that most of the ammunition considered today as the most numerous group lying on the bottom of the seas and oceans comes from the Second World War. According to estimates of the rate of corrosion progression, we are currently going through the stage of maximum release of dangerous components of this ammunition into the aquatic environment. Additionally, it is estimated that currently available information covers only 40-50% of all ammunition dump sites. Therefore, even if most of the known locations were in the Baltic Sea, there is still the other 50% of locations about which we know nothing, except that they are located in other water reservoirs. Deliberately dumped munitions can also be found in European inland waters [12-14].

The aim of the presented work was to present three selected aspects related to sunken ammunition, which are not commonly taken into account by the explosives community. The lack of interest in these aspects is due to the fact that they are not scientifically supportive. Two of these aspects, *i.e.* the general pollution of water reservoirs and the development of methods for managing and analyzing big databases, seems to be a discussion in the genre of fighting myths. The third aspect taken up – the terrorist aspect – can be treated as a hypothetical consideration, but it seems that further neglect of this aspect may bring very dangerous consequences. Addressing this issue results from the recognition that the expected intensification of activities to solve the problem of sunken munitions will result in an increase in the scale and forms of terrorist threats.

2 General Pollution of Water Reservoirs

2.1 Dumped ammunition in the seas and oceans

The basic problem with sunken ammunition is that in addition to conventional ammunition, chemical weapons, more specifically chemical warfare agents, also rest on the seabed. In [8] 34 chemical warfare agents and explosives are listed. Since the thermal conditions on the bottom make it difficult for these substances to affect the aquatic environment, there is an ongoing discussion whether the start of the disposal of dumped ammunition will not cause greater threats to the marine environment than leaving this ammunition as it is. The crowning example here is 1-chloro-2-[(2-chloroethyl)sulfanyl]ethane (mustard gas), which is much safer in seabed conditions than when extracted to the surface. Mustard gas at a temperature close to 0 °C remains on the bottom in the form of a thick liquid and, after reacting with seawater, is covered with an insulating layer on the surface.

The basic explosive found in dumped classic ammunition is 2,4,6-trinitrotoluene (TNT). TNT is a carcinogenic compound and toxic to aquatic organisms. Traces of TNT were found in the tissues of mussels and fish caught near dump sites. Heavy metals and other harmful elements are also released from corroding dumped ammunition, *e.g.* Pb, Hg, As. This type of contamination poses a threat not only to marine organisms, but indirectly also to people who consume seafood. Ecological effects may include the destruction of local populations of benthic organisms, disruption of the food chain (*e.g.* the extinction of invertebrates that fish feed on) and the long-term degradation of marine habitats.

In addition to TNT, as in the case of other explosives, the aquatic environment is also polluted by the products of their biotransformation and biodegradation, *e.g.* [15, 16]. TORPEX (*ca.* 42% hexogene, 40% TNT and 18% powdered aluminum) [17] and mercury fulminate ($Hg(CNO)_2$) are detected in large quantities in the Baltic Sea. It is estimated that about 300 tonnes of mercury are present in dumped munition in the Baltic Sea.

In order to illustrate the possible differentiation of the types of ammunition sunk in a given place, it is worth quoting the following proportions after [8]:

– artillery shells: 63.7%,
– aircraft bombs: 14.3%,
– gas pots: 12.9%,
– boxes of explosives and grenades 1.1%,
– mines: 5.3%,
– containers, cylinders, barrels and cans: 2.7%.

In turn, the estimated amounts of chemical warfare agents coming from the sunken munitions indicate how enormous the scale of actions necessary in the event of undertaking the extraction and/or destruction of chemical munitions. on the complexity of the problem:

– S-mustard (about 25000 tonnes),
– arsenic oil (about 7000 tonnes) [8],
– phosgene (about 5000 tonnes) [8],
– tabun (about 12000 tonnes) [11],
– CI-chloroacetophenone (about 7000 tonnes) [11],
– 10-chloro-5,10-dihydrophenarsazine (Adamsite) (about 4000 tonnes) [8],

In addition, in quantities below3,000 tons each was dumped [8, 11, 18]:

– N-mustard,
– Clark I,
– Clark II,
– arsenic-containing chemical warfare agents,
– dichloro-(2-chlorovinyl) arsine (lewisite),
– riot control munitions.

According to Beldowski *et al.* [19], there are roughly 150 to 300 sites worldwide with dumped chemical weapons. That number includes around 50 sites along the American coastlines, with a significant proportion in Hawaii. The total amount is unknown but a group of researchers from the Middlebury Institute of International Studies in Monterey, California, calculated that the total amount of chemical munitions in known locations amounts to 1.6 million tons, while roughly the same amount has been dumped elsewhere. The Chemical Weapon Munitions Dumped at Sea (CWMDS) database contains information about 127 locations where chemical warfare ammunition has been dumped [20]. There are more than 40 dumped ammunition dumps in the waters surrounding Europe [8]:

– off the coast of Iceland: 1 chemical munitions dump site,
– between Great Britain and Ireland: 1 chemical and 4 conventional ammunition dump sites,
– in the channel between Great Britain and continental Europe: 2 chemical and 8 conventional ammunition dump sites,
– in the Norwegian fjords: 3 conventional ammunition dump sites,
– off the coast of Spain: 2 conventional ammunition dump sites,
– between Denmark and Norway: 1 chemical weapons, 4 conventional ammunition and 4 dump sites, for which it is not known what ammunition ended up there.

In the Atlantic Ocean, relatively close to the French and Spanish coasts, there is a concentration of 13 chemical weapons and 1 conventional ammunition dump sites. The problem of the presence of dumped ammunition also applies to the Mediterranean Sea [18]. Between 1946 and 1997, more than 200 cases of serious burns caused by mustard gas from dumped ammunition were recorded among fishermen in the Adriatic Sea, 5 of which resulted in death [20]. Mustard bombs were found Manfredonia Bay (Italy), in the Gulf of Mexico and off the coast of Cape Moreton (Australia). In the latter case it was found a one-ton cylinder of sulfur mustard [20]. It is estimated that from 1918 to 1970, the United States was responsible for dumping more than 350,000 short tons of surplus, damaged and captured chemical weapon materials.

2.2 Other risks to the marine environment

Nowadays, the importance of the state of the oceans and seas for all of humanity is emphasized. This is understandable, if only because the surface of the seas and oceans makes up about 71% of the surface of the globe. For centuries, these waters have been the subject of anthropogenic activity. Some forms of human activity are transforming marine ecosystems in far-reaching ways, *e.g.* through the extraction of raw materials. It is not only the extraction of oil and natural gas from under the seabed. From the seabed of Baltic Sea, in Schleswig-Holstein territorial waters, from 1820 to 1976 there were extracted about 3.5 to 5.5 million tons of stones and boulders, ranging in diameter from 60 to 150 cm [21]. Nowadays, in many places in the world, changes in the seabed caused by anthropogenic activity are observed, *e.g.* [21, 22]:

– fishing with mobile bottom-contacting gear,
– anchoring and mooring,
– dumping of dredge material,
– dredging and aggregate extraction,
– dredging Fe-Mn concretion,

– propeller scour,
– installation of cables or pipelines,
– litter and installation of other structures,
– and the most interesting for researchers dealing with explosives - craters formed as a result of ammunition blasting.

It is well known that inland activities are a threat to the marine environment. Chemicals used on land pollute rivers flowing into the sea or ocean, such as pharmaceutical and productions [23, 24]. On the other hand, toxic waste [25] was deliberately dumped into the oceans.

In the literature, *e.g.* [26], attention is drawn to the fact that the wrecks of merchant ships and warships, as well as their fuel and cargo transported by them, are a source of pollution. In particular, the authors [26] report that there are about 2100 sunken ships larger than 100 deadweight tonnage resting in Norwegian territorial waters alone, and there are more than 20,000 wrecks in US waters. Most shipwrecks in Norwegian waters have been categorized as creating no potential pollution risk, but about 350 of the shipwrecks were classified to be of moderate pollution risk, and 30 of them (all sunk during WWII) potentially pose a high polluting risk. Among them, in the North Sea, rests a German submarine that transported about 65 tonnes of elemental Hg. In 2017, according to [26], the concentration of mercury was 100 g/kg d.w. in the immediate vicinity of this boat, and about 1 mg/kg d.w. at 100 m from the hotspot.

According to [26], 1,500 oil tankers (over 150 gross tonnes), about 7,000 non-tank vessels (over 400 gross tonnes), and many thousands of smaller vessels using petroleum-based fuels have sunk worldwide. It is estimated that these wrecks may contain a total of 4 to 23 trillion tons of petroleum hydrocarbon oil. Hydrocarbon leaks have also occurred as a result of accidents. In the largest accident in U.S. history in the Gulf of Mexico in 2010, spilled 4.0 million barrels (of which 810,000 barrels were collected) [27]. In turn, as a result of the accident of the tanker Exxon Valdez, in 1989, 257000 barrels of crude oil [27] leaked. Hydrocarbon pollution of the marine environment is not limited to petroleum products. The interruption of the Nord Strea II gas pipeline, in September 2022, caused methane pollution of the Baltic Sea, *i.e.* 10-50 thousand tonnes of methane dissolved in the Baltic waters.

3 Development of Methods for Managing and Analyzing Big Databases

It is very popular to expect that the so-called artificial intelligence (AI) will solve all of humanity's problems. However, there are skeptical voices, indicating that transferring, for example, all the functionalities of methods for managing and analyzing big databases to the world of AI may cause humanity to cease to be the master of the world. What can be stated at the current stage of development of Big Data technology are that the challenges associated with the disposal of dumped ammunition exceed the capabilities of the current state of technology. Such an approach is justified by the following premises.

Starting with the basic premise, it should be pointed out that data processing requires having an apparatus that allows for organizing the collected data. A useful structure of a Big Data database should take into account that very different views clash on many levels today. There are discussions – from the most general, *i.e.* whether it is better to leave sunken ammunition on the seabed as it is, to very specific ones, such as – how much sea fish can be safely eaten in a year. The use of Big Data should solve technical activities, but if researchers do not agree on these topics, then IT professionals implementing Big Data will not receive unambiguous guidelines.

Secondly, we currently have no real way to comprehensively identify every piece of ammunition in a given location in a given water reservoir. To demonstrate the scale of the problem, it is worth noting that the total area of the Baltic and Mediterranean Seas is estimated at almost 3,000,000 km². Each part of these seas requires a different approach to dumped ammunitions problems.In other words, in the case of each dump site, the first stage of the operation aimed at its decommissioning must be an inventory based on the analysis of the image of the entire seabed within a relatively large radius from the place of dumping of ammunition indicated in the documentation. This is indicated by literature reports indicating that:

– lack of complete documentation of all ammunition dumping operations,
– because in the first half of the twentieth century the possibilities of determining the position of a ship at sea were less accurate than today, there is no certainty that a given ship made several drops in exactly the same location, as recorded in the documentation,
– when sailors who were to dump ammunition, especially chemical weapons, realized what they were transporting, they began to throw the ammunition overboard even before reaching the target drop site,
– the ammunition was sometimes thrown away in closed transport boxes, which resulted in the fact that the boxes with ammunition drifted on the surface of the sea and sometimes sank at a considerable distance from the assumed location.

The ammunition was to be dumped in the depths of the sea and oceans, assumed at depths above 100 m. Therefore, reaching these landfills requires appropriate technical means.

Further dilemmas resulting from the technical possibilities of destroying the dumped ammunition result from the fear that the very start of extracting this ammunition will not cause an even greater threat to the natural environment than leaving it on the seabed, *i.e.:*

– thousands of tons of still dangerous chemical weapons are at stake, and in corroded shells,
– it is common to accidentally mix different types of ammunition in one dump site, or even dumped the ammunition together with the ship, so there is a real threat of causing uncontrolled and in a huge-scale explosion over there,
– some of the ammunition or its components may go unnoticed, *e.g.* immersed in bottom silt, so the elimination of all pieces of ammunition visible on the seabottom does not necessarily mean that the surrounding waters are completely free from the presence of toxic substances.

However, taking into account other forms of explosive remnants of war, mainly unexploded ordnance (UXO), it seems reasonable to conclude that the issue of the disposal of accidentally found munitions is the most important problem for researchers on explosives, in a global scale, and concerns all seas and oceans around the world. On the other hand, the variety of explosives resting in the aquatic environment makes it difficult to dispose of them. Difficulties arise already at the stage of assessing what kind of product we are dealing with. The issue of databases allowing for the identification of explosive products lying in the marine environment has recently been taken up by Szala and Chołuj [28]. To sum up, Big Data systems must ensure that they are doing the right thing to:

– Inventory and classification of DM: The first step to solving the problem is to accurately map the munitions: to know the location of all relevant caches and identify what objects (of what type and condition) are there. Traditional methods of detecting underwater munitions include side-scan sonar, magnetometric sounding, and possibly searches by divers or remotely operated vehicles (ROVs) equipped with cameras. However, the data from such searches is vast in volume and often difficult to interpret.
– Environmental monitoring and threat forecasting: In the field of chemical monitoring, automatic sensors deployed in the environment are becoming increasingly important – measuring buoys, underwater stations placed on the bottom or ROVs capable of taking water samples. However, the challenge is to interpret the huge amount of data from these sensors in the context of changing environmental conditions (sea currents, salinity fluctuations, temperature, *etc.*).
– Forecasting the spread of pollution: A neural network fed with oceanographic data and concentrations of selected compounds, *e.g.* TNT, could "learn" a pattern and then, after several measurements in a given area of the sea, could estimate where the pollution will reach in a day or two and what concentrations may occur.

Another challenge for Big Data is the biological material and processes taking place in the food chain in the aquatic environment, which need to be controlled. The essence of the problem is that it is not enough to collect data on the chemical composition of water remotely, but it is also necessary to conduct research on large populations of animals and plants. The following bioindicators were used to determine the level of environmental contamination, including bioaccumulation, by explosives and chemical warfare agents, as well as by their decomposition products:

– (Atlantic) Hagfish (*Myxine glutinosa*): phenylarsenic chemical warfare agents, especially biotransformation product of Clark I/II,
– Atlantic salmon (*Salmo salar*): TNT,
– bivalves,
– Blackbelly rosefish (*Helicolenus dactylopterus*): yperite,
– Cod (*Gadus morhua*): chemical warfare agents,
– European conger (*Conger conger*): yperite,
– harbour porpoises (*Phocoena phocoena*): underwater clearance of unexploded ordnance,
– marine flatworm (*Macrostomum lignano*): TNT and its derivatives 2-ADNT and 4-ADNT,
– *Nitocra spinipes*: TNT,
– (transplanted) blue mussels (*Mytilus edulis*): TNT and degradation products,
– Japanese oysters: heavy metals and explosives.

4 Terrorist Threats

So far, terrorist threats in the aspect of dumped munitions have not been discussed in the scientific literature. The 21st century is a century of dynamic development of terrorist threats, which is why the authors of the work decided that this aspect should also be addressed – even if it is only hypothetically possible. The basic argument is that dumped ammunition dump sites, although much more difficult to access than land military bases, are more attractive as uncontrolled sources of thousands of tons of explosives and chemical weapons.

The literature on the subject lacks works showing the problem of sunken munitions in the light of the development of terrorist strategies. In general, the reference to terrorist threats results from the possibility of using the threats posed by sunken munitions to achieve the expected changes in a given society by using imaginary or exaggerated threats to the natural environment. This strategy is called ecoterrorism. However, it is also possible to point out the reasons why the analysis of terrorist threats in the aspect of sunken munitions should be undertaken by scientists dealing with explosives. First of all, as a result of the publication of hundreds of articles and many scientific books every year, as well as media reports on this subject, it is certain that terrorists know about this difficult to access, but still uncontrolled and huge source of explosives and chemical warfare agents. Secondly, terrorists may want to hide their actions by taking advantage of the widespread knowledge about the possibility of spontaneous action of sunken ammunition, its free movement in water reservoirs, or the possibility of throwing it ashore. In other words, there is a potential risk that terrorists will carry out the attack in such a way that it looks like an accident caused by the "accidental" presence of dumped ammunition and/or the aging processes taking place in it. This threat seems to be particularly relevant for offshore critical infrastructure such as wind farms, pipelines, power and telecommunications cables, or approaches to ports and waterways.

5 Conclusions

- ♦ It has been known since the 1990s that the problem of threats from dumped munitions cannot be ignored. However, the complexity and number of issues necessary to solve is enormous, that solving the problem of dumped munitions is rather a matter of the distant future.
- ♦ Progress is enormous, but it seems that the resources at our disposal, such as Big Data, are not sufficiently developed to reliably monitor changes in the fauna and flora living in the aquatic environment on a scale of millions of square kilometers.
- ♦ The most important expected effect of the implementation of Big Data techniques seems to be the possibility of ending the discussion "should we start decommissioning dumped ammunition?" and – if the answer is "yes" – it will be possible to obtain a verifiable answer to the question "what to do with the ammunition dumped in a given site?".

Acknowledgements

This work was supported by the Polish Ministry of Science and Higher Education under project No. RID/SP/0042/2024/01, *Increasing competences in identifying threats related to hazardous materials*, from program Regional Excellence Initiative, 2024-2027.

References

[1] Albright, R.D. *Death of the Cheasapeake. A History of the Military's Role in Polluting the Bay.* Scrivener Publishing LLC, **2013**, ISBN: 978-1-118-68627-0.
[2] *Boost Applied Munition Detection through Smart Data Integration and AI Workflows.* Project BASTA, 2019-2022, https://cinea.ec.europa.eu/featured-projects/basta_en [accessed May 20, **2025**].
[3] *AI for Munitions Recovery.* CleanSeas Project, **2023**, https://sea-technology.com/dfki-ai-robot-munitions [accessed May 20, 2025].
[4] *Ex-situ, Near-Real-Time Explosive Compound Detection in Seawater.* ExPloTect Project 2019-2022, https://cinea.ec.europa.eu/featured-projects/explotect_en [accessed May 20, **2025**].
[5] *Marine Ammunition Dump Site Exploration by Surface- and Underwater-based Laser Mass Spectrometric Tracing Technology.* AMMOTRACe Project, GEOMAR, https://www.geomar.de/en/ammotrace [accessed May 20, **2025**].
[6] *Professional Intelligent Munitions Assessment Using 3D Reconstructions and Bayesian Neural Networks.* ProBaNNt Project, https://www.probannt-munition.eu/ [accessed May 20, **2025**].
[7] *Marine Munitions in Europe – Solutions with Economic and Ecological Profits for Efficient Remediation.* MMinE-SwEEPER Project 2024-2028, HORIZON Research and Innovation Actions, European Research Executive Agency, European Commission; https://helcom.fi/helcom-at-work/projects/mmine-sweeper/ [accessed June 20, **2025**].
[8] Beddington, J.; Kinloch, A.J. *Munitions Dumped at Sea: A Literature Review.* IC Consultants Ltd., London, **2005**; http://www.environet.eu/pub/pubwis/rura/000ic_munitions_seabed_rep.pdf.
[9] *Overview of Past Dumping at Sea of Chemical Weapons and Munitions in the OSPAR Maritime Area 2010 update.* OSPAR Commission, **2010**.
[10] *Chemical Munitions Buried in the Baltic Sea.* Council of Europe, Resolution 1612, **2008**.
[11] Greinert, J.; Kampmeier, M.; Buck, V.; Frey, T. Marine Dumped Munition - Example from Lübeck Bay where Test Clearance will Start in 2024. *Munition im Meer III*, *Hydrographische Nachrichten* **2024**, *128*(*6*): 34-41; https://doi.org/10.23784/HN128-05.
[12] Laugesen, J.; Bjornstad, H. Dumped Ammunition – An Environmental Problem for Sediment Management? *Proc. 5th SedNet Conf.* **2008**.
[13] Foulkes, I. *Switzerland Offers Cash Prize to Get Munitions Out of Lakes.* BBC **2024**, https://www.bbc.com/news/articles/cdd7y3nm09lo.

[14] *Munition in Schweizer Seen.* (in German) Schwezerische Eidgenossenschaft, **2023**, https https://www.vbs.admin.ch/de/munition-in-schweizer-seen.
[15] Serrano-González, M.Y.; Chandra, R.; Castillo-Zacarias, C.; Robledo-Padilla, F.; de J. Rostro-Alanis, M.; Parra-Saldivar, R. Biotransformation and Degradation of 2,4,6-Trinitrotoluene by Microbial Metabolism and Their Interaction. *Def. Technol.* **2018**, *14*(2): 151-164; https://doi.org/10.1016/j.dt.2018.01.004.
[16] Lee, B.U.; Cho, Y.S.; Park, S.C.; Oh, K.H. Enhanced Degradation of TNT by Genome-Shuffled *Stenotrophomonas Maltophilia* OK-5. *Curr. Microbiol.* **2009**, *59*: 346-351; https://doi.org/10.1007/s00284-009-9443-6.
[17] Miętkiewicz, R. High Explosive Unexploded Ordnance Neutralization - Tallboy Air Bomb Case Study. *Def. Technol.* **2022**, *18*(3): 524-535; https://doi.org/10.1016/j.dt.2021.03.011.
[18] Della Torre, C.; Petochi, T.; Corsi, I.; Dinardo, M.M.; Baroni, D.; Alcaro, L.; Focardi, S.; Tursi, A.; Marino, G.; Frigeri, A.; Amato, E. DNA Damage, Severe Organ Lesions and High Muscle Levels of As and Hg in Two Benthic Fish Species from a Chemical Warfare Agent Dumping Site in the Mediterranean Sea. *Sci. Total Environ.* **2010**, *408*(9): 2136-2145; https://doi.org/10.1016/j.scitotenv.2010.01.001.
[19] Bełdowski, J.; Klusek, Z.; Szubska, M.; Turja, R.; Bulczak, A.I.; Rak, D.; Brenner, M.; Lang, T.; Kotwicki, L.; Grzelak, K.; Jakacki, J.; Fricke, N.; Östin, A.; Olsson, U.; Fabisiak, J.; Garnaga, G.; Nyholm, J.R.; Majewski, P.; Broeg, K.; Söderström, M.; Vanninen, P.; Popiel, S.; Nawała, J.; Lehtonen, K.; Berglind, R.; Schmidt, B. Chemical Munitions Search and Assessment – An Evaluation of the Dumped Munitions Problem in the Baltic Sea. *Deep. Res. Part II Top. Stud. Oceanogr.* **2016**, *128*: 85-95; https://doi.org/10.1016/j.dsr2.2015.01.017.
[20] Newman, J.; Verdugo, D. Building Awareness of Sea-dumped Chemical Weapons. In: *Maritime Security*. (Vignard, K., Ed.), United Nations Institute for Disarmament Research, Switzerland, **2010**, pp. 45-53.
[21] Díaz-Mendoza, G.A.; Krämer, K.; von Rönn, G.A.; Heinrich, C.; Schwarzer, K.; Reimers, H.C.; Winter, C. Hotspots of Human Impact on the Seafloor in the Southwestern Baltic Sea. *Continental Shelf Research* **2025**, 285 paper 105362; https://doi.org/10.1016/j.csr.2024.105362.
[22] Canals, M.; Pham, C.K.; Bergmann, M.; Gutow, L.; Hanke, G.; van Sebille, E.; Angiolillo, M.; Buhl-Mortensen, L.; Cau, A.; Ioakeimidis, C.; Kammann, U.; Lundsten, L.; Papatheodorou, G.; Purser, A.; Sanchez-Vidal, A.; Schulz, M.; Vinci, M.; Chiba, S.; Galgani, F.; Langenkämper, D.; Möller, T.; Nattkemper, T.W.; Ruiz, M.; Suikkanen, S.; Woodall, L.; Fakiris, E.; Jack, M.E.M.; Giorgetti, A. The Quest for Seafloor Macrolitter: A Critical Review of Background Knowledge, Current Methods and Future Prospects. *Environ. Res. Lett.* **2021**, *16*(2) paper 023001; https://doi.org/10.1088/1748-9326/abc6d4.
[23] Moro, H.; Vaya, R.; Casado, M.; Piña, B.; Domínguez-García, P.; Gómez-Canela, C.; Barata, C. Biomonitoring Emerging Hazards of Pharmaceuticals in River Water Using Gut Microbiome and Behavioural *Daphnia magna* Responses. *Chemosphere* **2024**, *367* paper 143612; https://doi.org/10.1016/j.chemosphere.2024.143612.

[24] Mayor, P.; Soliño, L.; Cartró-Sabaté, M.; Orta-Martínez, M. Impact of Hydrocarbon Extraction on Heavy Metal Concentrations in Lowland Paca (*Cuniculus paca*) from the Peruvian Amazon. *Sci. Total Environ.* **2024**, *930*(20) paper 172371; https://doi.org/10.1016/j.scitotenv.2024.172371.
[25] Häder, DP. Dumping of Toxic Waste into the Oceans. In: *Anthropogenic Pollution of Aquatic Ecosystems.* (Häder, DP.; Helbling, E.W.; Villafañe, V.E., Eds) Springer, Cham, **2021**. https://doi.org/10.1007/978-3-030-75602-4_16; https://link.springer.com/chapter/10.1007/978-3-030-75602-4_16.
[26] Ndungu, K.; Beylich, B.A.; Staalstrøm, A.; Øxnevad, S.; Berge, J.A.; Veiteberg Braaten, H.F.; Schaanning, M.; Bergstrøm, R. Petroleum Oil and Mercury Pollution from Shipwrecks in Norwegian Coastal Waters. *Sci. Total Environ.* **2017**, *593-594*: 624-633; https://doi.org/10.1016/j.scitotenv.2017.03.213.
[27] *Deepwater Horizon Oil Spill in the Gulf of Mexico.* Marine Mammals Commission, US, https://www.mmc.gov/priority-topics/offshore-energy-development-and-marine-mammals/gulf-of-mexico-deepwater-horizon-oil-spill-and-marine-mammals/ [assesed Dec. 6, **2024**].
[28] Chołuj, A.; Szala, M. Review of Explosive Ordnance Disposal (EOD) Databases: Interdisciplinary Relevance, Environmental Impact, and Future Directions. *Cent. Eur. J. Energ. Mater.* **2025**, *22*(3): 409-431; https://doi.org/10.22211/cejem/211563.

Authorship contribution statement

Tomasz Sałaciński:	conception, methods, performing statistical analysis, other contribution to the publication
Mateusz Szala:	conception, foundations, other contribution to the publication
Barbara Wiaderek:	conception, other contribution to the publication
Klaudia Rzadkowska:	other contribution to the publication

Submitted: May 22, 2025

Revised: December 31, 2025

First published online: December 31, 2025