UNDERWATER EXPLOSIVE ORDNANCE

Underwater Explosive Ordnance, Geneva International Centre for Humanitarian Demining (GICHD), April 2025 © GICHD

Cover: A Ukrainian explosive ordnance disposal diver recovering remnants of a S-8 rocket.
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The present study was developed by Armen Harutyunyan, Pedro Basto, and Stephen Robinson from the GICHD.

CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS

AI	Artificial intelligence
ASV	Autonomous surface vehicles
AUV	Autonomous underwater vehicles
AXO	Abandoned explosive ordnance
BSI	British Standards Institution
DIN	Deutsches Institut für Normung e.V. (german institute for standardization)
EMI	Electromagnetic induction
EO	Explosive ordnance
EOD	Explosive ordnance disposal
ERW	Explosive remnants of war
GICHD	Geneva International Centre for Humanitarian Demining
IMAS	International Mine Action Standards
IMCA	International Marine Contractors Association
ISO	International Standards Organization
NATO	North Atlantic Treaty Organization
NGO	Non-governmental organization
ROV	Remotely operated vehicles
SDGs	Sustainable Development Goals
SESU	State Emergency Services of Ukraine
SMAC	Serbian Mine Action Centre
SSTS	State Special Transportation Services of Ukraine
TNT	Trinitrotoluene
UN	United Nations
UAV	Uncrewed aerial vehicle
UXO	Unexploded ordnance

PURPOSE AND METHODOLOGY

The present study examines the literature on underwater explosive ordnance (EO) contamination. It offers a comprehensive review of existing studies, technical reports, international legal frameworks, standards, protocols, and guidelines, focusing on historical sources of underwater EO contamination. These include military conflicts, the deployment of sea mines, and large-scale munitions dumping. It also looks at the environmental implications of underwater EO contamination, including the risks to marine biodiversity and the climate-related factors that affect the degradation of munitions.

The study includes, in the Annex, analysis of open-source information on 153 underwater EO incidents recorded from 2014–2023, which shows recent contamination trends from a qualitative perspective. The dataset was built using publicly available records, including the reports of international news agencies, government security updates, maritime security bulletins, and mine action reports. The study categorizes the incidents by geographical location, type of EO, and the frequency of the type of incident. Given regional disparities in reporting, variations in terminology, and challenges regarding detection, the dataset represents a bestavailable approximation rather than a complete record. The actual scale of underwater EO contamination is likely to be greater than shown, owing to unreported or undetected cases. The study does not fully capture incidents that stem from new conflicts or those that have continued since 2023. To complement the dataset, selected case studies highlight good practices in underwater EO detection and clearance.

This combination of a literature review, data-driven analysis, and case-study evaluation enables the present study to share qualitative insights and to show quantitative trends in underwater EO contamination. It provides a knowledge base for addressing one of the most complex and underreported challenges in mine action and maritime security.

BACKGROUND

Following the publication, in December 2014, of *IMAS 09.60: Underwater Survey and Clearance of Explosive Ordnance*[1] of the International Mine Action Standards (IMAS), the GICHD conducted a survey that revealed that at least 64 countries were affected by underwater EO and that 33 developing nations had requested assistance in mitigating its impact. During the same period, the GICHD also commissioned a technology demonstration report for underwater survey equipment,[2] which led to the publication of *A Guide to Survey and Clearance of Underwater Explosive Ordnance*.[3]

Despite advances at a technical level in addressing underwater EO contamination, the subject remains underdiscussed but of increasing relevance.[4 and 5] Underwater EO originating from deliberate dumping, military conflicts, and naval operations poses a significant threat to rivers, lakes, and other inland waterways, coastal communities, maritime development, offshore industries, and tourism.

As noted during the GICHD Innovation Conference 2023, "the growing need to use maritime resources, such as wind farms and intercontinental maritime cables and pipelines, has given rise to renewed debate on the subject. This is due, on the one hand, to the need to tackle legacy contamination and, on the other, to the implications of recent and current conflicts attempting to disrupt freedom of navigation. These elements have come at the same time as a deeper understanding of the wider implications of underwater explosive ordnance contamination (such as the environmental impact of dumpsites in the sea, lakes and other inland waterways) for the achievement of many of the Sustainable Development Goals".[6]

The presence of explosive remnants of war (ERW), both unexploded ordnance (UXO) and abandoned explosive ordnance (AXO), is widespread, particularly ordnance from past wars and decommissioned military sites. The impact of underwater EO varies, with humanitarian, socioeconomic, and environmental consequences influencing the need for action. Military naval forces and commercial companies have led efforts in this field, but the broader impact of contamination increasingly requires a wider discussion about capabilities, equipment, legal and regulatory frameworks, and methods.

Presently, the issue of underwater EO contamination goes beyond legacy contamination. The ongoing conflicts in Ukraine and Yemen continue to generate contamination. The conflict in Ukraine has seen active naval warfare, with the deployment of sea mines in the Black Sea that pose a substantial risk to shipping lanes and neighbouring countries. Other munitions are being found in Ukrainian rivers, waterways, and coastal waters. Similarly, in Yemen, the prolonged conflict has led to the extensive use of sea mines, including those of an improvised nature, and other conventional ordnance, resulting in numerous incidents that affect both maritime activities and coastal communities.

CHAPTER 1. UNDERWATER EXPLOSIVE ORDNANCE CONTAMINATION

TYPES OF UNDERWATER EXPLOSIVE ORDNANCE CONTAMINATION

By nature, EO designed to be used underwater is different from landbased EO in terms of how it is made and how it functions. This is particularly the case with sea mines, torpedoes and depth charges.

Underwater EO or ERW are generally categorized based on their status in post-conflict situations. They are usually termed as follows:

Unexploded ordnance (UXO), which is "explosive ordnance that has been primed, fuzed, armed or otherwise prepared for use or used. It may have been fired, dropped, launched or projected yet remains unexploded either through malfunction or design or for any other reason";

Abandoned explosive ordnance (AXO), which is "explosive ordnance that has not been used during an armed conflict, that has been left behind or dumped by a party to an armed conflict, and which is no longer under control of the party that left it behind or dumped it. Abandoned explosive ordnance may or may not have been primed, fuzed, armed or otherwise prepared for use".[7]

Sea mines account for a large proportion of the underwater UXO in coastal areas (67 per cent of the total number of incidents reported in open-source materials between 2014 and 2023). They are the result of legacy sea "minefields". Despite being more commonly associated with land warfare, this term has also been used for naval warfare, together with others such as "mine barrage" and "laid sea mines". Sea minefields can be very wide geographically and contain a large number of sea mines. Other UXOs in the water include munitions that have malfunctioned, which can be particularly concentrated in maritime battle areas and military training ranges. In some cases, until the late 1980s, coastal areas and lakes were used for live fire exercises involving naval ordnance, land-based artillery, and aircraft bombs.

The majority of AXO, can be found in dumping sites or where ammunition-laden vessels have sunk or been stranded. While this ordnance may present a lower explosive risk, as it has not been fuzed, armed, and prepared to function, it can still have a longterm toxic effect on the environment and pose a significant explosive hazard, owing to the high net explosive weight of multiple items in the same place. Dumping sites are typically located in territorial sea waters and in lakes, the latter being more common in countries with no coastline. Sunken vessels can be found both in coastal areas and the high seas, such as in the North Sea and the Baltic Sea, or in large inland waterways, as seen in the Mekong River in Cambodia or the Danube River in Serbia.

The following section of this chapter provides an overview of and further detail about the different types of underwater EO contamination – sea mines, torpedoes, aerial munitions, munitions fired or launched from land, naval and aerial platforms into the sea (such as artillery shells and aerial bombs), dumped munitions and shipwrecks containing UXO.

Sea mines

Sea mines (also often referred to naval mines) are defined by the North Atlantic Treaty Organization (NATO) as "explosive device laid in the water with the intention of damaging or sinking ships or of deterring shipping from entering an area".[8] Sea mines have been used since the American Revolution when Yale student David Bushnell discovered that gunpowder could detonate under water.[9] They have since been used widely in conflicts, not just against the opposing forces, but also to disrupt trade and harm civilian and commercial ships.[10]

Historical data on ship losses demonstrate the effectiveness of sea mines in naval operations. Table 1 below shows the Axis power vessels that were sunk, by different means, by the Allied powers during the North-West Europe campaign (1944 to 1945) of the Second World War. This highlights the significant role of sea mines in maritime warfare. Sea mines accounted for 40 per cent of total vessel losses compared with other methods of attack.

	Method of attack			
	Surface Vessels and Submarines	Direct Air Attack	Air Raids	Mines
Vessels sunk (percentage)	376 (17%)	485 (23%)	429 (20%)	850 (40%)

Table 1: Axis ships sunk by Allied attacks during the North-West Europe campaign in the Second World War (adapted from Naval Minewarfare; Politics to Practicalities by Chris O'Flaherty[11])

Like landmines, sea mines are built to last. They are typically laid for the following reasons:

- To deny access to critical geographical features such as ports or harbours
- To control shipping routes by restricting or closing safe passage
- To carry out a direct attack on shipping by damaging or sinking vessels

A sea mine is seldom laid on its own; rather, several sea mines are laid to create an effective countermobility obstacle or minefield. Sea minefields can be vast, intended to defend or to block access to large areas. They can also be particularly effective in chokepoints, narrow seaways, rivers, or canals, where just a few mines can pose a major threat.

Sea mines are used against vessels rather than people. As such, they generally have a much higher net explosive weight per unit. For example, the locally produced, buoyant mines used in the Yemen conflict contain high explosive with a net explosive weight of about 21 kg.[12] This would be considered a small mine in a naval context; by comparison, the net explosive weight of a bottom sea mine could be, in some cases, as much as 1,000 kg (as the Russian MDM-1, the UK Stonefish MkII)[13].

At the water's surface, sea mines are designed to damage a ship's hull through the effect of a blast, like the function of a blast anti-vehicle landmine against an armoured vehicle. A detonation below the surface, however, not only produces a blast wave, but is also accompanied by one or more of the following: bubble pulses, reflected shock waves, surface cut-off, and bulk cavitation. All of these have the potential to cause damage not only to the vessel and its cargo but also to the environment and local infrastructure. The damage caused by the effects of the explosion can be as profound in littoral margins and shallow waters as it is in the open sea.

Buoyant sea mines that washed ashore. Given the high net explosive weight, in the order of magnitude of the hundreds of kilograms, these represent serious impact on coastal communities. © Spanish Navy

All types of sea mine share enough characteristics to be regarded as a single class of EO. At its core, a mine consists of a container, an explosive main charge, and a fuse (trigger) designed to initiate the main charge. Despite this common structure, there are a wide variety of types of sea mine. Two primary criteria are used to classify them: their position in the water and the method of initiation.

Bottom mines rest on the seabed, while buoyant mines float in the water column. If buoyant mines are anchored to the seabed (typically connected by a cable or a tether to a sinker), they are referred to as moored mines. Conversely, if they are not anchored, they are classified as drifting mines. Drifting mines should, in accordance with the *San Remo Manual on International Law Applicable to Armed Conflicts at Sea*,[14] disarm themselves after an hour. Not all do so, however, either by intent or because the disarming mechanism fails.

Top: a bottom sea mine resting in the seabed. Bottom: a moored sea mine. Despite the apparent deterioration, the main explosive content of these sea mines is typically in very good condition. © Spanish Navy (top) © Portuguese Navy (bottom)

Sea mines are designed to be initiated by the target, by being physically stuck (contact sea mines), by command (controlled sea mines), or through the detection of a signature radiated by the target (influence sea mines). Commonly detectable signatures include the noise produced by the target vessel (acoustic sea mines), the electromagnetic fields that it generates (magnetic sea mines), or the pressure waves caused as its hull moves through the water (pressure sea mines). These features can be combined in various ways depending on the design of the sea mine and intended purpose of the minefield. As with landmines, sea mines cannot distinguish between military vessels and other vessels.

There are also a few possible variations, as follows:

- Homing sea mines are released when they detect their target. They have some form of propulsion system that gets them closer to it before detonation.
- Sea mines can delay their arming and/or self-neutralize/self-destruct after a certain predefined length of time. "Sterilization" is the term used in naval warfare to describe the process of a sea mine disarming itself either by interrupting the triggering process or by detonating.
- Influence mines can have ship-counting mechanisms. This means that they will not detonate on detection of the first target, but only after the detection of a predefined number of targets.

As with land ordnance, these variations in sea mines often increase the chances of a malfunction, which makes them more unpredictable.

Table 2 gives an overview of the various types of sea mine.

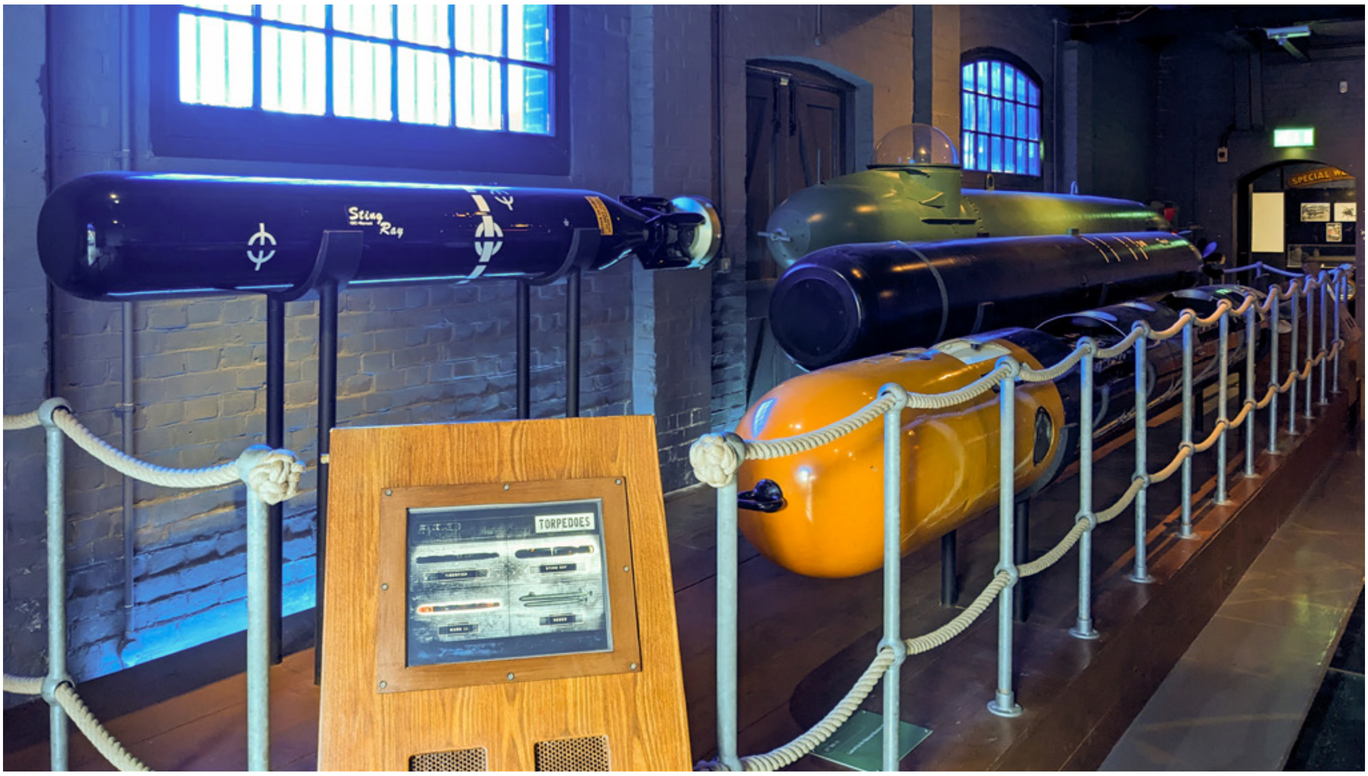
Classification of the sea mine	Type of sea mine	Description
By its position in the water	Bottom mine	Rests on the seabed and is commonly used in shallow waters.
	Buoyant mine	Floats in the water column.
	Moored mine	Anchored to the seabed by a cable or tether.
	Drifting mine	Not anchored and moves with the current.
By its initiation mechanism	Contact mine	Detonated upon physical impact with a target.
	Controlled mine	Detonated by remote command, typically from a control station.
	Acoustic mine	Triggered by the noise generated by a target vessel.
	Magnetic mine	Triggered by the electromagnetic fields of a vessel.
	Pressure mine	Triggered by the pressure waves generated as a vessel's hull passes through the water.
	Influence mine	Acoustic/magnetic/pressure mines can be designed or programmed to be triggered only by a specific target signature.
By its variation	Homing sea mine	Released when it detects its target and uses a propulsion system to approach before detonation.
	Delayed arming/ self neutralizing mine	Can delay its arming and/or self-neutralize/self-destruct after a predefined time.
	Ship-counting influence mine	Does not detonate on detection of the first target, but only after the detection of a predefined number of targets.

Table 2: Classification of sea mines by their position, initiation mechanism, and variation[15]

Sunken moored mine, Swedish FE31. On the left, the anchor and tether can be seen. On the right the same type of sea mine partially covered by sediments. As the images show, underwater turbidity and visibility conditions in the Baltic Sea can add to the challenge of technical survey and clearance operators. © Swedish Navy

Torpedoes

Torpedoes are another important weapon of naval warfare. Although they are both used by submarines, surface ships, and aircraft to target vessels, they are particularly important in submarine warfare. Having evolved after sea mines, torpedoes combine the large blast effect of a sea mine with a self-propulsion engine and guiding system. As with sea mines, torpedoes typically have main charges with high net explosive weights. Today, these range most of times from around 45 kg (in the US MK54 or the Chinese Yu-7/8 lightweight torpedoes) to 300 kg (in the US MK48 or Chinese Yu-4 heavyweight torpedoes). Super heavyweight torpedoes can have main charges of up to 400 kg (Chinese Yu-5) and 550 kg (Russian Type 65)[16]. Examples of torpedoes from the Second World War are the US MK13–15 series[17] and the Japanese Type 93, with net explosive weights ranging from 360 kg to 470 kg. Like many landbased ordnance, however, fired torpedoes did not always reach their intended targets. Some malfunctioned, missed, were fuel-depleted, or were abandoned owing to technical failures. Those that remained unexploded now lie on the seabed, presenting a lingering hazard, especially in areas of heavy wartime naval activity.



Display of free from explosive torpedoes of the Explosion Museum of Naval Firepower, Portsmouth, UK. In black with white markings, the lightweight Sting Ray (45 kg of high explosive, shaped charge, 1983), and the heavyweight Mark 24 Tigerfish (134 kg of high explosive, 1983), of the UK Royal Navy. In the bottom right the US Navy Mark 11 (227 kg of high explosive, 1926). In the back, the Neger, a Second World War German torpedo carrying craft. © The wub

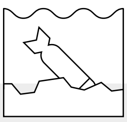
During both World Wars, the waters around the United Kingdom of Great Britain and Northern Ireland (UK) saw intensive submarine and surface naval combat, with countless torpedoes fired. German U-boats patrolled British waters, launching torpedoes at military and civilian vessels, while British and Allied forces responded with their own attacks. The precise number of torpedoes lost in UK waters is unknown, as wartime records focused on confirmed hits rather than on failed attacks. Some torpedoes were also dropped from aircraft during raids on shipping, further contributing to the number of unexploded weapons in the sea.

These historical weapons continue to surface unexpectedly. In a recent case, a live torpedo was discovered on a beach near Weston-Super-Mare in Somerset, UK, after being exposed by a low tide. The unexpected find prompted an immediate response from explosive ordnance disposal (EOD) specialists, who enforced a 1.5 km exclusion zone and temporarily closed local airspace while they conducted a controlled detonation.[18]

Unexploded torpedoes have also been found in deeper waters. In Scapa Flow, Orkney, UK, the site of a historic naval base used during both World Wars, an underwater survey revealed a wartime torpedo lying on the seabed. The discovery prompted an immediate response, with a Royal Navy bomb disposal team dispatched to assess the situation.[19] Scapa Flow is also well known for being the site of the 1919 scuttling of the German High Seas Fleet, where over 50 warships were deliberately sunk to prevent them from falling into Allied hands. The area is popular for recreational diving in the shipwrecks, but the presence of UXO and AXO continues to pose safety risks.[20]

In another recent case, in December 2024, a Second World War torpedo was caught by a fishing net in the Firth of Forth, near Edinburgh, UK, triggering the response of the Royal Navy EOD team.[21]

Torpedoes are not limited to British or European waters. Throughout the Second World War, submarines and warships launched thousands of torpedoes across the Atlantic Ocean, the Mediterranean Sea, and the Pacific Ocean. Many failed to detonate and remain scattered across the seabed. In some cases, they are buried under layers of sediment; in others, they remain partially exposed, corroding over time and potentially releasing hazardous materials.



Underwater unexploded ordnance

Aerial bombing has historically been another common means of naval warfare, complementary to the use of sea mines and torpedoes. During such campaigns, many types of munitions fall into the sea without detonating. These include conventional bombs, depth charges (typically dropped by aircraft to target submarines) as well as explosive payloads from aircraft crashes or emergency jettisoning (a procedure used by aircraft in certain emergency situations to reduce their weight before returning to the airport shortly after take-off or before landing short of their intended destination). Wartime combat zones such as the Mediterranean Sea, the North Sea, the Atlantic Ocean, and the waters of the Pacific Islands remain littered with UXO, which often rest on the seabed or are buried beneath layers of sediment.

Also in December 2024, a UXO was found next to a major gas pipeline that supplies energy to the UK. The UXO, which was believed to date back to the Second World War, was detected during a routine inspection of the 40-year-old Far-North Liquids and Associated Gas System (FLAGS) Pipeline, located 40 miles east of the Shetland Islands, in the North Sea.[22]

The Baltic Sea was also heavily mined and bombed during both World Wars, and numerous pieces of UXO have been discovered in its waters and many more remain to be dealt with. As an example, the Swedish Maritime Administration provides notice to mariners information about the risk areas and types of UXO.[23] During the Second World War, nations developed a variety of aerial bomb types and sizes widely dropped in areas such as the Gulf of Finland, Gdańsk Bay, and off the coasts of Estonia, Latvia, and Lithuania. Soviet, UK and US bombs were deployed across the Baltic Sea, from the Gulf of Finland to the Polish City of Świnoujście and the Danish island of Bornholm. Consequently, the waters near the German cities of Kiel, Lübeck, Rostock, and Sassnitz, the German-Polish island of Usedom, the Polish cities of Świnoujście and Gdańsk, and the Russian city of Kaliningrad have a high concentration of submerged bombs.[24]

The Pacific Islands, including the Marshall Islands, Palau, and the Solomon Islands, saw significant military activity during the Second World War, which left behind numerous unexploded bombs. Underwater clearance operations have been going on for decades, funded through both humanitarian aid and joint military initiatives, such as Operation Render Safe,[25] under which, in 2024 for example, eight nations collaborated with the Royal Solomon Islands Police Force to remove over 3,200 items of EO.

In some areas, underwater EO contamination is the result of military training and target practice. This is the case in a former Soviet military firing range situated south of Batumi, Georgia, on the shores of the Black Sea. The site was originally used by the Soviet military until 1991, then by Russian forces until 2003, and later, periodically, by the Georgian military until 2012. This activity left behind a substantial amount of UXO, a significant portion of which are 125 mm artillery shells used for targeting exercises along the seaward edge of the range. Additionally, at least one small vessel, likely a former target, remains sunk near the shore, further contributing to the contamination of the site.[26]

When another former Soviet military camp, on the eastern edge of Lankaran city, Azerbaijan, was abandoned between 1991 and 1992, EO was left behind in shallow waters, along with UXO from a nearby tank firing range. An ammunition storage facility, later destroyed by rising sea levels and erosion, has also contributed to the contamination of the site. To the south, a 600 m-long area suspected hazardous area lies in front of the former tank and small-arms range, where missed artillery shots likely ended up in the sea. Soviet nautical charts also show a sunken vessel near the range, probably also used as an artillery target.[27]

Dumped munitions

For much of the twentieth century, military forces routinely disposed of obsolete and surplus munitions, including a wide range of conventional munitions and explosives, by dumping them into the sea or deep lakes. This practice was rationalized by its perceived efficiency and cost-effectiveness compared with other disposal methods. Many coastal nations, particularly those engaged in largescale conflicts, used deep-sea trenches and offshore dumping sites as repositories for decommissioned or excess ordnance. This practice was not exclusive to EO. It was a general practice also used for industrial chemicals, radioactive materials, and sewage, for example.

By the 1960s, however, there was growing environmental concern about the practice, and scientific research highlighted the long-term danger of dumping for marine ecosystems. In response to these growing concerns, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter was adopted in 1972.[28] The treaty aimed to regulate and restrict the disposal of hazardous waste, including munitions, in large bodies of water. It laid the groundwork for international cooperation in waste management and pollution control, ultimately leading to stricter environmental policies governing the disposal of military ordnance. Nevertheless, this important change did not remove the damage already done, and many locations remain littered with conventional munitions. Several examples of dumped munition are given below.

Located between Scotland and Northern Ireland, Beaufort's Dyke is a deep trench that was extensively used by the UK Government for the disposal of munitions after both World Wars. It is estimated that over 1 million tonnes of explosives were dumped there. While the deep waters were originally believed to contain these materials safely, AXO has since washed up on nearby shores, and concerns have been raised about the long-term stability of the munitions. The area continues to be monitored for emerging risks.[29]

The Baltic Sea is one of the most heavily contaminated marine environments owing to the extensive dumping of not only conventional munitions, but also chemical munitions, after the Second World War. The Allies disposed of tens of thousands of tonnes of weapons in this region, primarily near Bornholm, Gdańsk Bay, and the Gulf of Finland. Many of these are chemical munitions which have started leaking its toxic loads, causing concerns about the contamination of fish and ecosystem damage. Fishing communities in Denmark, Germany, and Poland have caught munitions in their nets, which have sometimes caused burns and led to toxic exposure.[30 and 31]

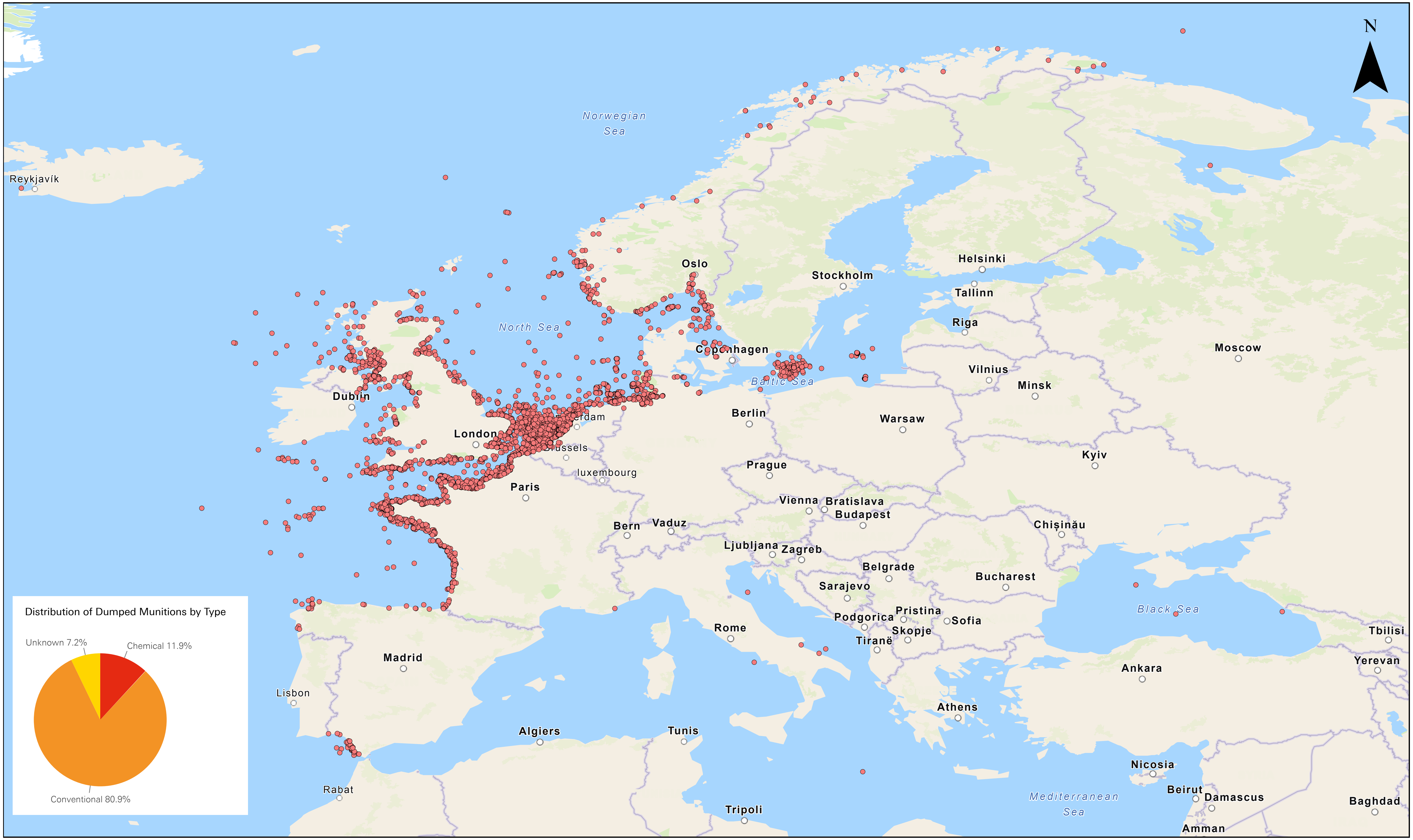
Another example is the Skagerrak, a strait situated between Denmark and Norway used for the largescale dumping of munitions after the Second World War. It is deep, and the underwater terrain is difficult, making the removal of UXO particularly challenging.[32] While little is known about the exact number of munitions disposed of there, past assessments suggest that there are thousands of tonnes of explosives and toxic agents.

Several areas of the North Sea were also used for munitions disposal, particularly off the coasts of Belgium and the Netherlands.[33] These locations pose a significant risk as they are close to busy shipping routes and offshore energy projects.

The Bay of Lübeck is one of the many places where the largescale disposal of munitions took place after the Second World War. The disposal site is 20 m below the surface and contains a significant volume of ordnance, including sea mines, artillery shells, and aerial bombs. The German Government has allocated EUR 100 million (USD 105 million) to the development of a large-scale clearance system for the systematic removal of these munitions.[34]

This type of contamination is not limited to seas and oceans. For example, Switzerland, a landlocked country, has historically dumped obsolete or surplus munitions in its deep lakes. Between 1918 and 1964, the Swiss Army disposed of over 12,000 tonnes of unused munitions in various lakes, notably Lake Thun, Lake Lucerne, and Lake Brienz. This practice was considered an efficient solution at the time. In recent years, however, concerns have arisen about potential environmental contamination and the safety of the water. The Swiss Government continues to seek innovative methods for the environmentally safe removal of these submerged munitions.[35]

Ordnance Dumping Data from EMODnet



Point distribution of known munition dumping sites in European waters, provided by the European Marine Observation and Data Network (EMODnet)[195] © GICHD

Disclaimer: This map is published by the Geneva International Centre for Humanitarian Demining (GICHD) using data sourced from external providers. GICHD does not own or generate the underlying data and cannot guarantee its accuracy, completeness, or reliability. The data is provided "as is" and should be used for informational purposes only. Neither GICHD nor the data providers assume any liability for errors, omissions, or any decisions made based on this map.

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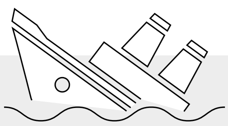
Diver holding a sonar and navigation system investigates shipwreck. Shipwrecks and sunken vessels in former naval battle areas often contain the ordnance depots that were onboard. Although these abandoned explosive ordnances pose a lesser risk because they were not fused and armed, they may constitute a source of environmental contamination. © Spanish Navy



Shipwrecks with explosive ordnance

Many sunken warships and cargo vessels still contain the live ammunition that went down with them. Some ships were deliberately scuttled with their ammunition on board, while others were destroyed in battle and sank with full loads of weapons. Even if this ordnance falls under the category of AXO, the effects of the underwater environment on their casings and structures can eventually lead to uncontrolled detonation and environmental contamination. The shipwreck of the *SS Richard Montgomery*, an American Liberty ship that sank in the Thames Estuary near London in 1944 remains a major concern. It still holds 1,400 tonnes of unexploded bombs, buried in its deteriorating hull.[36]

Numerous Japanese warships and transport vessels that were sunk during the Second World War remain scattered across the Pacific Ocean. Many were targeted by American air raids and submarines, and sunk with their torpedoes, depth charges, and other EO still on board.[37] In some locations, these wrecks pose significant hazards to shipping routes, fisheries, and underwater construction projects.

Other unexploded ordnance

Uncrewed platforms–aerial, waterborne, and underwater–are an emerging vector for the deployment of EO, potentially creating new sources of EO contamination. The use of such platforms has generally been a result of wartime ingenuity, thus largely experimental, with a greater likelihood that the ordnance will fail or malfunction. This can be the case with uncrewed aerial vehicles (UAV) that crash into water bodies before reaching their targets or the weaponized underwater uncrewed platforms that are currently being used, for example, in Ukraine.[38 and 39]

The recovery of an uncrewed aerial vehicle in Ukraine.

UNDERWATER ENVIRONMENT

The underwater environment is typically harsh on manufactured structures. Water infiltrates mechanisms, salt water corrodes most metals, and the water is in constant motion (tides, currents and streams) which moves objects, stresses tethers and shifts substrates). Water is widely considered to be the single greatest influence on the ageing of EO, degrading internal components, particularly in salty and corrosive environments.[40] While the degradation of internal components will typically lead to the EO not being able to function as designed, this does not render it safe as the main charges remain present and most of time in good conditions.

Further research is needed on the impact, over time, of the underwater environment on the explosive filling of EO.[41] The impact depends on the types of material used to contain the explosive charge, the type of explosive, and the type of underwater environment. Hypothetically, corrosion and the degradation of casings and components could lead to chemical sensitization, which could provoke an uncontrolled detonation, but there are also cases where EO has been retrieved with little to no corrosion marks, owing to the specific composition of the soil on the seabed.

The impact on the environment of the degradation of ordnance over time is another facet of underwater EO contamination, and one of growing importance. A possible effect is the introduction of carcinogenic and toxic substances into the food chain.[42 and 43]

Moving water can lead buoyant mines to oscillate and dip on their tethers, which alters their depth and position beneath the surface. Moored mines anchored to sinkers that are too light to hold them can move away from their designated locations. The tethers of moored mines have been known to come away, and, if the mines do not have a render-safe switch that interrupts the firing circuit when the tether breaks, they become drifting mines. Furthermore, changes in the tide can lift vessels above a threat or lower them into it.

The boundaries of any hazard areas can therefore change. In the case of drifting mines, the area in which they might be found can be vast. Although the risk of a vessel encountering a mine in such an area might be very low, the consequences can be devastating, for example if an oil tanker is hit at sea.[44]

Water movement can also affect bottom sea mines (and buoyant mines that have sunk), moving them from where they were laid. Tidal-powered shifts in sediment can also hide and reveal sea mines and other EO.

Although, unlike land traffic, shipping traffic is not constrained by the terrain, but rather by the depth of the water above the underwater terrain, the seabed is still an important aspect of underwater EO survey and clearance. Its profile and make-up have a major impact on the effectiveness of technical survey techniques to collect and analyse data about the presence, type, distribution, and surrounding environment of EO contamination.[45 and 46] For example, shallow waters and coastal transition areas present significant challenges to the deployment of survey equipment such as towed magnetometers.

The conditions within the water are equally important. Water columns are seldom uniform. They vary in temperature and salinity, which profoundly affects active detection methods. For example, changes in water conditions can bend sonar beams such that they might not be able to detect objects on the seabed. Water turbidity and visibility under the water also have an impact on visual or laser-based detection methods.

Weather that affects the surface water (waves and swell) can have a major impact on the effectiveness of systems that are deployed on surface craft such as vessels, helicopters and UAV.

EXPLOSIVE ORDNANCE IN RIVERS AND INLAND WATERWAYS

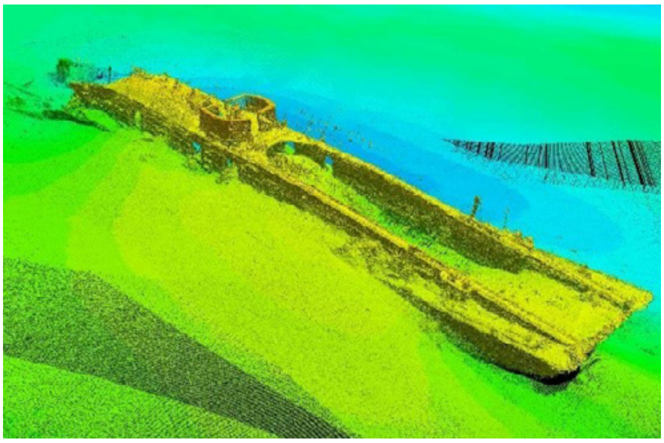
As a naval weapon, it is considered that sea mines were originally designed for use in coastal waters and on the high seas. Nevertheless, records of the use of sea mines in rivers and inland waterways date back to the nineteenth century during the American Civil War, when they were developed by naval engineers and employed by the Confederacy to defend harbours and waterways. During the Second World War the use of sea mines was massively expanded to rivers and inland waterways, in part because they could be laid by air. In 1940, for example, the UK Royal Air Force laid about 1,500 sea mines in the Rhine and Moselle Rivers.[47] Since then, sea mines, either those manufactured conventionally or those of an improvised nature, have been made available also to non-State actors and have been used extensively in conflicts, for example in Bangladesh (Pasur River), in Cambodia and Vietnam (Mekong River) and in the Korean War (Yalu River). As such examples show, the use of sea mines in rivers and waterways has been more common in large, navigable river systems.

Because of the proximity of rivers and inland waterways to land warfare and thus their strategic importance, EO other than sea mines are also commonly found therein. During the German retreat from the Soviet forces in the Second World War, in 1944 the Black Sea Fleet deliberately scuttled numerous vessels along the Danube River to prevent their capture. Many of these ships were sunk near Prahovo, Serbia, where they remain a persistent hazard. Some of the wrecks still contain significant amounts of ammunition and explosives, posing risks to navigation, infrastructure, and the environment. During periods of low water levels, particularly in times of drought, sections of these wrecks become exposed, increasing the risk of uncontrolled detonation and the spread of explosive residues. In recent years, severe droughts have further lowered the level of the water in the Danube River, revealing these hazardous remnants and further obstructing river traffic.[48]

While the term "underwater EO contamination" is usually applied to fully submerged environments, marginal areas–those that are intermittently or partially flooded–also present significant challenges. These areas include paddy fields, marshlands, and seasonal floodplains, where land-based EO contamination interacts with fluctuating water levels.

In addition to sea mines, landmines are often laid in riverbanks during conflicts, from which they may become dislodged and be swept away into the rivers and further downstream. Many landmines, particularly anti-personnel mines are lightweight–many are made from plastic–and can therefore easily be carried long distances by flood water and fast-moving rivers.

Documented examples of this happening can be found in Bosnia,[49] Honduras, Mozambique,[50] Nicaragua, the Republic of Korea and Vietnam, or more recently in Ukraine, after the breaching of the Kakhovka dam on the Dnipro River in June 2023.[51] Landmines can also be dislodged from mountainous areas and carried downslope by heavy rainfall over time and possibly carried downstream to rivers.



Bottom: a bathymetric image of one of 21 sunken German vessels in the Danube River near Prahovo. Top: a photograph of the same vessel after its recovery in 2022. © Serbian Mine Action Centre

Intermittently flooded areas, such as paddy fields, are also a concern. Feedback from the Vietnam National Mine Action Centre in Hanoi[52] indicates that technical and non-technical surveys are conducted primarily in the dry season or between rice-farming cycles. Surveys frequently detect landbased EO, often in good condition owing to its limited exposure to a corrosive underwater environment. Farmers also play an active role in identifying EO, and sometimes move it themselves, either to clear the land for cultivation or with a view to selling it for its scrap metal or its explosive content. This of course poses additional safety hazards.

Seasonal flooding presents a challenge for mine clearance in parts of Croatia, particularly in wetlands and marshes. Rising groundwater and rainwater can submerge areas under up to 2 m of water, restricting access and delaying operations. To manage this, the Croatian Mine Action Centre coordinates with operators to adjust tasking based on the flood conditions. Teams are assigned to alternative dry areas when flooding prevents their work or given larger clearance tasks to allow them to continue operations while waiting for the water levels to recede. If an active site becomes flooded, contractors must notify the Centre, and clearance is postponed until conditions improve. These requirements are included in the tasking documentation, allowing operators to plan accordingly during tendering and preparation.[53]

Partially flooded areas, such as marshlands, but may still hold landmines and other ERW. The fluctuating water levels in these areas complicate detection, clearance, and risk-assessment efforts. Mine action in such areas is often approached as an extension of landmine clearance operations and requires tailored methodologies that consider both dry and wet conditions.

CHAPTER 2. IMPACT OF UNDERWATER EXPLOSIVE ORDNANCE

Underwater EO poses a growing challenge to maritime security, trade, and economic stability. As global shipping routes intersect with areas of past and ongoing conflict, submerged EO present significant risks to commercial shipping, humanitarian aid delivery, and critical infrastructure. Moreover, the deterioration of the EO introduces environmental hazards, which further complicates efforts to mitigate its long-term effects.

EOD divers from the Romanian Naval Forces inspect a drifting sea mine near Eforie, south of Constanța in 2024. © Romanian Ministry of National Defence

DISRUPTIONS TO TRADE AND SUPPLY CHAINS

One of the most direct consequences of the presence of underwater EO for shipping, including vessels that supply the global economy and provide humanitarian relief to those affected by crisis, is the increase in insurance premiums for ships' hulls.[54] Premiums are typically imposed owing to increased exposure to war risks, piracy, political instability, or other hazardous conditions that elevate the likelihood of damage or loss. The entire littoral margin of Libya and the area around Crimea attract additional insurance premiums because of the presence of maritime EO. The fact that there has been no claim of responsibility for the presence of the EO further exacerbates the situation. Until the threat posed by the underwater EO diminishes, hull-risk premiums will remain high, with the additional costs passed on to businesses and consumers.

The Black Sea currently suffers from underwater EO contamination because of the war in Ukraine. Drifting mines pose a significant threat to commercial shipping, particularly in export corridors for Ukrainian grain, where they disrupt trade routes and endanger vessels navigating the region. Since the full-scale invasion of Ukraine, 18 sea mines, posing risks to maritime security, have been detected and neutralized in the Black Sea, in the territorial waters of Bulgaria, Romania, and Türkiye.[55]

Floating mines in the Black Sea have hindered the export of fuel and grain, thereby having a significant impact on the global economy and further compounding the global food crisis. The most vulnerable countries have been the worst affected.[56, 57 and 58] The presence of drifting mines has resulted in the significant rerouting of commercial vessels, affecting global supply chains, increasing transit times, and prompting an increase in war-risk insurance premiums. Notably, the additional hullrisk premiums for shipping routes in the north-western Black Sea have increased by an estimated 3 per cent since 2022, with insurers citing the ongoing threat posed by maritime EO as a primary factor.[59]

The ports of Misrata and Benghazi, Libya, have proved pivotal in the delivery of humanitarian aid to the country, but underwater EO poses a challenge.[60] Logistic and security-related operations have been hampered by the presence of moored contact mines, drifting contact mines, and bottom mines, which have required international maritime patrols to close the port facilities temporarily and engage in clearance activities.[61] In April 2011, humanitarian operations through Misrata were disrupted by the discovery of a variant of a former Soviet sea mine (the PDY3M) being laid by unknown belligerents.[62] The presence of these mines required military naval mine countermeasures in order to mitigate the risk posed to the shipping of humanitarian aid.

IMPACT ON LOCAL ECONOMIES AND LIVELIHOODS

Beyond the disruption of global trade, underwater EO contamination has direct and severe consequences for local economies, particularly those dependent on fishing and coastal industries. The presence of EO in key fishing zones not only threatens the safety of those who fish but also affects marine biodiversity and traditional livelihoods. The economic impact extends to tourism, aquaculture, and other industries that rely on healthy marine ecosystems.

Many communities in the Pacific Islands have lived and played among explosive material designed to sink warships or destroy fortified gun emplacements. While efforts to clear such underwater EO have been undertaken for almost 80 years, items continue to be recovered regularly, and the deteriorating munitions are becoming increasingly unstable.[63]

In the Solomon Islands, for instance, EO regularly washes up on beaches or is recovered from the seabed by workers when fishing. In 2021, a tragic accident occurred when a group of villagers attempted to dismantle an old shell for scrap metal, resulting in an explosion. The fear of such incidents may discourage fishing activities in areas known to be contaminated, reducing catch sizes and affecting food security.

In Palau, the Government has expressed concern about the impact of underwater UXO on its lucrative diving and tourism industry. Palau is home to pristine coral reefs and Second World War wreckage sites that attract thousands of recreational divers each year. The presence of UXO near some of these diving sites, however, poses the risk both of accidental explosions and of the slow leaching of toxic substances into the marine environment. Clearance operations have been slow owing to the financial and logistical challenges of underwater demining in remote island nations.

Similarly, in South-East Asia, particularly in Cambodia[64] and Vietnam,[65] underwater UXO from past conflicts continues to affect coastal communities. Many resort to dangerous makeshift disposal methods, unaware of the risks involved. In addition, the contamination of riverbeds and estuaries by UXO affects inland fisheries, a vital food source for millions. Those fishing have reported pulling up EO in their nets, sometimes with fatal results.

In Yemen, in October 2020 a sea mine exploded in AlHudaydah Governorate, Yemen, killing a man while he was fishing in the Red Sea.[66] This is one of several incidents to have occurred in the region.

An improvised sea mine found ashore. This type of sea mines has been very commonly found associated to the conflicts in Yemen and Lybia. © Gareth Collet

Just as recently, in the North Sea, on December 2020, the *Galwad-y-Mor*, a fishing vessel, disturbed a piece of EO while recovering crab pots in the North Sea, approximately 22 nautical miles off Cromer, UK, causing significant injuries to five of the seven crew and major damage to the vessel's hull and machinery.[67]

THREATS TO CRITICAL INFRASTRUCTURE

The growing strategic importance of the maritime domain is shaped by several inter-related factors. These include the expansion of global trade, increasing reliance on offshore infrastructure, and the geopolitical significance of contested waters. Evolving offshore industries and shifting international security dynamics have increased the focus on underwater EO contamination as a persistent challenge.

The development of underwater infrastructure, including renewable-energy installations, oil and gas extraction facilities, desalination plants, offshore platforms, ports, and subsea cables, has made more pressing the need to understand and tackle the challenges posed by underwater EO.

For example, the global economy is highly dependent on undersea telecommunications and power cables, which facilitate international data flow and energy transmission between nations. Approximately 95 per cent of international data transmission–and 99 per cent of transcontinental data transmission–is sent through subsea fibre-optic cables.[68] Despite their critical importance, these assets can be vulnerable to shifting underwater EO contamination. As subsea cables become ever more integral to the functioning of global financial markets and military communications,

Offshore wind energy has become a key component of the global energy transition, has given rise to new challenges related to underwater EO contamination. Wind farms installation and cable laying operations are one of the main activities of a growing market for underwater EOD commercial operators. © BOEM-OPA (above) / © andjohan (below)

the presence of ERW in key maritime regions introduces an additional layer of risk that must be accounted for in both national security and economic resilience strategies.

Oil and gas infrastructure in historically contested maritime regions is also at risk. The North Sea, for example, contains large quantities of sea mines and other ordnance from the Second World War, with an estimated 1.3 million tonnes of ERW in its waters.[69] A report has been written on the financial implications of current measures to mitigate the impact of EO in the North Sea and highlights that over EUR 100 million has been allocated to ERW risk management.[70]

The increasing reliance on offshore wind energy as a key component of the global energy transition has given rise to new challenges related to underwater EO contamination. Many of the world's largest offshore wind farms are being developed in areas of historical naval conflict, with the North Sea and the Baltic Sea the focus of both ERW clearance efforts and renewable energy expansion. In 2024, for example, the enterprise Rovco undertook a survey and clearance project for the Windanker offshore wind farm developed by Iberdrola in the German sector of the Baltic Sea. This operation involved the identification and removal of ERW to facilitate construction of the wind farm.[71]

During the development of the Danish Anholt offshore wind farm, extensive EO surveys and clearance operations were necessary to enable the safe installation of the infrastructure. The Danish Energy Agency required all findings of potential EO to be properly assessed and,

if necessary, the EO to be cleared before construction could proceed.[72] Similarly, the NorthConnect project, which aimed to establish a subsea cable between Norway and Scotland, had to navigate areas known to be historical munitions dumping sites. This required comprehensive risk assessments and clearance operations to be carried out to mitigate the potential hazards associated with the EO.[73]

Underwater EO also poses significant risks to offshore wind energy projects in other parts of the world. For instance, the Danish company Ørsted commissioned EO risk assessments for offshore wind farm sites in Taiwan, highlighting the industry's recognition of these hazards in East Asia,[74] owing to historical naval engagements and mine-laying operations.

ENVIRONMENTAL IMPACT AND CLIMATE-CHANGE CONSIDERATIONS

As mentioned, underwater EO presents significant challenges for marine ecosystems, local communities, and protected habitats. Pollution and chemical contamination may result from the degradation, detonation, or disposal of underwater EO. The effects of climate change can exacerbate these risks by accelerating corrosion and increasing the spread of the contaminants.

The environmental impact of EO contamination depends on three key factors: the source (the item of EO or the detonation process), the pathway (how the contaminants travel through water, sediment, and marine food chains), and the receptor (the affected organism or ecosystem, including marine life and humans). This chain of contamination is known as the source–pathway–receptor model or the pollutant linkage model. In areas with high concentrations of underwater EO, the risk of pollution is significantly greater.

Energetic materials such as trinitrotoluene (TNT) are highly persistent and toxic. TNT can slowly degrade to form 2-amino-4,6-dinitrotoluene (2-ADNT) and 4-amino-2,6-dinitrotoluene (4-ADNT), which are known for their toxicity, mutagenicity, and carcinogenicity. Their presence in areas near historical dumping sites or regions with high concentrations of corroding munitions proves the release of energetic compounds to the environment.[75] Contamination is especially problematic in sandy soils or areas with high groundwater, as toxic compounds can travel more easily to surface water. Exposure pathways include ingestion, inhalation, and dermal contact, leading to serious health complications, such as oxidative stress, anaemia, liver damage, and impairment of the nervous system.

Some marine organisms in contaminated areas, particularly bottom-dwelling species, show elevated concentrations of TNT and its metabolites.[76] Studies have found high TNT levels in mussels and flatfish near munitions disposal sites.[77] Species that feed at the bottom near explosive materials and detonation craters exhibit even greater contamination. Risk assessments indicate that regular consumption of these marine species poses a cancer risk to humans.[78]

As EO casings corrode, toxic substances, including heavy metals like lead, can leach into the marine environment. The main environmental concern regarding lead is its potential for bioaccumulation (toxic substances building up in organisms over time) and the subsequent contamination of the human food chain.[79 and,80] Over time, energetic materials from degrading EO can cause water deoxygenation and disrupt aquatic ecosystems. Although much remains unknown about the bioavailability, bioaccumulation, and toxic effects of EO in marine environments, existing evidence suggests that these contaminants threaten both marine biodiversity and human health.[81 and 82]

The rate of corrosion of EO is a key driver of underwater contamination, with degradation timelines ranging from 25 to 250 years.[83] The effects of climate change, such as the increase in water temperature and water acidification, which weaken metal casings, are expected to accelerate corrosion, leading to faster chemical leaching from the submerged munitions, and to increase contamination risks.[84 and 85] Mechanical turbulence caused by intensified storm activity may also contribute to the mobilization of contaminants, increasing their spread in marine ecosystems. According to the Arrhenius equation, a mathematical formula widely used in science to predict reaction rates under different conditions, an increase in temperature accelerates chemical degradation. This suggests that climate change may cause TNT contamination to occur more rapidly, increasing exposure risks for marine life and coastal populations.[86]

Despite recent advances, however, there needs to be further research into the impact of the underwater environment on the degradation of EO and the impact of that degradation on the environment.[87]

Another source of contamination can occur during clearance of UXO. For safety reasons, preferred disposal methods are often to detonate in situ. Such methods can generate additional environmental hazards. Blast-in-place disposal frequently results in incomplete detonations that may leave significant quantities of explosive material in the marine environment.[88] Beyond chemical contamination, underwater detonation creates blast pressure and noise pollution, which can harm marine fauna. A study on the Dutch continental shelf found that underwater EO detonations can cause permanent hearing loss in harbour porpoises, disrupting their ability to communicate, hunt, and navigate.[89] The ecological effects extend to fish populations, coral reefs, and other communities that live at the bottom of bodies of water.

The method of disposal thus plays a crucial role in limiting contamination. Low order deflagration techniques are increasingly preferred over blast-in-place methods in sensitive marine areas, as they reduce the spread of carcinogenic compounds and minimize the immediate harm to reef structures and marine life.

Effective environmental management requires the use of improved disposal techniques and proactive environmental monitoring to safeguard marine biodiversity, in alignment with international good practice and national regulatory frameworks, as described in chapter 3 of the present report. Moreover, the recent revision of *IMAS 07.13*: *Environmental Management and Climate Change in Mine Action*,[90] along with the publication of a corresponding technical note for mine action (TNMA), 07.13/01,[91] provide a framework and detailed guidance to help stakeholders implement appropriate measures to mitigate the environmental impact of mine action operations, which can be adopted as well for underwater EO contamination.

LONG-TERM EFFECTS OF THE DUMPING OF EXPLOSIVE ORDNANCE

As described in the previous chapter, the disposal of obsolete ordnance by deep-sea dumping was common globally until 1972; it was a legal practice and considered a fast and cost-efficient means of disposal.[92] In many cases, however, this EO has now become source of pollution.

Contamination tends to be localized and, at sea, tends to be rapidly diluted once it moves beyond the immediate vicinity. Nevertheless, this does not necessarily diminish the significance of the contamination.[93] In the littoral margins of the Baltic Sea, several million tonnes of accumulated, toxic, energetic materials have been found.[94]

It is thought that at least 1.6 million tonnes of munitions from the World Wars remain in the North Sea and the Baltic Sea.[95] The problem of historical dumping has also been identified in other regions, including the Mediterranean Sea and the Pacific Ocean, and in inland waterways that serve as vital resources for drinking water, agriculture, and transportation. Assessment of the extent of contamination is a critical first step in defining the problem and ensuring appropriate mine action responses.[96]

A 2005 assessment of the obsolete and surplus munitions that had been dumped in Swiss lakes found that all available recovery methods risked disturbing up to 2m of fine sediment, thereby threatening the lakes' fragile ecosystems by depleting oxygen and further disrupting aquatic life. On the other hand, it found little evidence of degradation and contamination, leading to the adoption of a monitoring strategy instead of removal. In 2024, the Government of Switzerland launched a call for innovative solutions to the problem, offering funding for technologies that could safely recover submerged munitions while minimizing the environmental impact.

The persistent threat posed by underwater EO contamination, such as in the example above, highlights the need for greater coordination between mine action initiatives, maritime industries, and national security frameworks. While significant progress has been made in developing technical solutions for ERW clearance, including autonomous underwater vehicles (AUV) and specialized survey and clearance vessels, the regulatory frameworks governing EO risk mitigation remain fragmented. Enforcement of such measures also varies considerably across jurisdictions, leading to inconsistencies in riskmanagement practices.

A key challenge is the balancing of economic priorities with safety considerations. Given the growing reliance on offshore resources, including for energy production and digital connectivity, the economic imperative to accelerate infrastructure projects is often in conflict with the time needed for UXO clearance.

Given the increasing strategic relevance of the water domain, there is a need for sustained investment in EO survey and clearance, regulatory reform to enhance maritime safety, and strengthened international cooperation on ERW risk management. Without such measures, the full economic and environmental potential of maritime spaces cannot be realized, and the risks posed by EO contamination will continue to hinder global security and development objectives.

CASE STUDY

IMPACT OF MARITIME EXPLOSIVE HAZARDS ON LIVELIHOODS, THE ENVIRONMENT AND THE ECONOMY IN THE RED SEA AND GULF OF ADEN

The floating oil storage and offloading vessel *Safer* is moored approximately 8 km off the coast of Yemen and 50 km north-west of the country's port of Hodeida. The single-hulled vessel is 362 m long and was constructed in 1976 as an oil tanker and converted in 1987 to a floating oil storage facility. Since 2015, *Safer* has been under the control of the de facto authorities in Sana'a. Oil production and offloading operations have been suspended because of the conflict, and no maintenance has been undertaken for several years. As a result, alarm was raised about the vessel's deteriorating condition and the risk of structural failure. With an estimated 1.148 million barrels of light crude oil on board, there was an imminent risk of a catastrophic environmental and humanitarian disaster. Given the presence of sea mines in the area, however, and the unstable security situation, gaining access to the tanker for an urgent intervention was a complex challenge.

In 2023, the United Nations (UN) led a USD 120 million emergency operation to prevent a catastrophe. Over 18 days, specialists worked to transfer the crude oil from *Safer* to another tanker. Although the operation successfully averted the risk, significant challenges remain.[97]

The next phase will involve the decontamination and disposal of the *Safer*, a process that requires additional funding and logistical coordination. Furthermore, the fate of the recovered oil remains unresolved, as Yemeni factions continue to dispute its ownership and how the profits from it should be distributed.

The risk posed by underwater EO was taken very seriously during the initial planning stages of the salvage operation. According to reports from the national authorities, 142 sea mines have washed up on shore in Yemen since 2017, some of them striking commercial cargo ships in the southern Red Sea and causing damage.[98]

An oil spill from *Safer* would likely have seen the shipping route through the Bab-el-Mandeb strait and the Red Sea disrupted for many months. The economic impact of a spill at such a scale is difficult to quantify, but it is estimated that the clean-up alone would have cost USD 20 billion.[99] There would also have been a knock-on effect on global shipping, with the oil spill affecting the main international shipping routes and costing the shipping business and the industries that it services tens of billions of dollars.[100] For comparison, recent events affecting global shipping include, in 2021, a container ship that became stuck in the Suez Canal, freezing trade to the value of USD 10 billion of trade in just one day,[101] and the Red Sea crisis, which began in 2023 and, according to the Freightos Index,[102] within two weeks caused shipping container prices to increase by around 100 per cent and to continue up to 350 per cent in certain routes, during the month of February 2024.[103]

A sea mine strike on *Safer* would likely have caused a fuel–air explosion within one of the storage tanks from the combustion of the explosion gases above the oil. Such an explosion occurred on the *Trinity Spirit* in February 2022. While it was not triggered by a sea mine, it demonstrates how catastrophic a fuel-air explosion on an oil tanker can be.[104] The detonation of gases in just one storage tank would destroy underwater life in a volume equivalent to Lake Erie.[105] Mammals and fish with swim bladders would be the most affected, with a devastating impact on the fishing industry, which Yemen relies so heavily upon.

CASE STUDY

UNDERWATER EXPLOSIVE ORDNANCE CONTAMINATION AS A BARRIER TO SUSTAINABLE DEVELOPMENT

The presence of underwater EO contamination in oceans, seas, lakes, and rivers presents a multifaceted challenge for sustainable development. As demonstrated above, contamination from EO affects marine ecosystems, human health, economic activities, and international security, with consequences for economic growth, livelihoods, and environmental preservation. These impacts can only be reduced if the issues presented by underwater EO are addressed.

One way of analysing these impacts is by mapping how underwater EO can affect progress towards achievement of multiple Sustainable Development Goals (SDGs), the results framework of the 2030 Agenda for Sustainable Development[106], as is shown below.

The slow corrosion of underwater EO casings is a continuous source of pollution of water resources, potentially affecting achievement of SDG 6 (Clean water and sanitation), and especially target 6.3, which involves improving water quality by reducing pollution and minimizing the release of hazardous chemicals and materials.

In terms of SDG 14 (Life below water), the presence of EO and chemical munitions on the seabed can destroy coral reefs, harm marine mammals such as whales and dolphins, and disrupt critical habitats for fish populations[107]. Under target 14.1, which involves preventing and significantly reducing marine pollution, efforts to survey, monitor, and clear underwater EO

contamination are critical for sustaining biodiversity and preventing further degradation of marine ecosystems. The selection of the method of clearance has an important role in mitigating impacts, as described in Chapter 3.

The degradation of EO which may occur in aquatic environments leads to the release of hazardous substances, including TNT, RDX (research department explosive: cyclotrimethylene trinitramine), lead, and mercury, this contamination enters the food chain, affecting coastal populations, fishing communities, and broader public health.[108] The impact on SDG 3 (Good health and well-being) is evident, particularly in relation to target 3.9, which involves reducing the number of deaths and illnesses from hazardous chemicals and pollution. Studies in the Baltic Sea and the North Sea have shown that fish caught near munition dumping sites contain elevated levels of carcinogenic substances, leading to concerns about seafood safety and consumption by humans.[109]

Beyond chemical exposure, the direct physical threat posed by EO in maritime environments remains significant. People fishing, divers, and maritime workers face the risk of accidental detonation, which affects both individual safety and economic stability. Clearance is essential to ensure safe working conditions in alignment with SDG 8 (Decent work and economic growth), particularly target 8.8, which involves protecting labour rights and promoting safe working environments for all workers.

The presence of underwater EO can thus create significant obstacles for economic development, particularly for industries reliant on fishing, shipping, tourism, and offshore energy production. In heavily contaminated waters, unexploded bombs and mines are routinely caught in fishing nets, forcing workers to discard entire catches because of safety concerns. This disrupts livelihoods, increases operational costs, and threatens the sustainability of coastal economies. This has consequences for achievement of target 8.9, which involves the promotion of sustainable tourism, and the protection of economic activities linked to marine resources.

Many maritime infrastructure projects, including the construction of ports, underwater pipelines, and wind farms, require extensive underwater EO survey and clearance before they can proceed. As seen in examples earlier in this chapter on threats to critical infrastructure, in some cases, the costs and risks associated with the removal of underwater EO have delayed or even halted projects, hindering economic development and access to renewable energy sources. This limits progress towards SDG 9 (Industry, innovation, and infrastructure), particularly target 9.1, which emphasizes the need for sustainable and resilient infrastructure to support economic development. The sheer volume of EO in Beaufort's Dyke between Scotland and Northern Ireland, one of the largest underwater munitions dumping sites,[110] has created significant challenges for subsea cable installations and offshore energy projects, requiring extensive and costly survey and clearance operations before any infrastructure development can take place.

Finally, the presence of sea mines in international waters continues to pose security threats, particularly in areas of ongoing geopolitical tension. The resurgence of sea mine usage in the Black Sea and the Sea of Azov, for example, disrupts trade routes and endangers civilian shipping. These risks heightening or creating new conflicts, with implications for SDG 16 (Peace, justice, and strong institutions), under target 16.1, which aims to reduce all forms of violence and related deaths everywhere.

CHAPTER 3. MANAGEMENT OF UNDERWATER EXPLOSIVE ORDNANCE CONTAMINATION

INTRODUCTION

Given underwater EO survey and clearance capacities are still largely based on naval military capacities, there is a danger that underwater EO contamination is seen as a military problem. As described in the previous section, it is not.

Historically, national militaries have been the entities primarily responsible for survey, disposal or removal of underwater EO.[111] In recent years, however, there has been a notable shift, with an increasing number of NGOs, private companies, and specialized commercial entities becoming involved in underwater survey and clearance efforts.[112] This shift accompanied the wider use of the water resources, particularly the sea, for critical infrastructure and trade. This growing diversification of actors has highlighted a need for internationally recognized norms and standards to ensure that the approaches used are effective, safe, and environmentally responsible.

INTERNATIONAL LAW

The international instruments address underwater EO aspects from two different angles: regulating the use and clearance of certain types of underwater EO, namely naval EO, and addressing broader environmental and pollution related aspects. They are chronologically presented.

1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines

The Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines, adopted in The Hague as early as 1907, [113] remains one of the key legal instruments governing the use of sea mines. It is particularly relevant to discussions on underwater EO because it is the only legally binding instrument that explicitly regulates their deployment.

The Convention prohibits the laying of unanchored automatic contact mines unless they become harmless within one hour of control being lost; anchored automatic contact mines (moored mines) that do not become harmless if they break loose from their moorings; and torpedoes that do not become harmless if they miss their target. It also forbids the laying of automatic contact mines off enemy coasts and ports solely to disrupt commercial shipping.

Additionally, the Convention requires belligerents to record and share information about minefields to ensure that neutral shipping is safeguarded from unintended encounters with explosive hazards. It furthermore states that sea mines should not be used in a way that blocks neutral ports or international navigation routes, in accordance with the principle of freedom of navigation. Another provision stipulates that the Contracting Powers undertake to do their utmost to remove the mines that they have laid, with each Power removing its own mines.

Despite being over a century old, the Convention remains relevant today. Many of its principles are reflected in customary international law and have been further developed in later legal instruments. Nevertheless, there are also some limitations to the Convention. As it was drafted long before modern naval mine technology was developed, it does not regulate remotely controlled or influence-activated mines, which are widely used today.

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and the Protocol thereto

The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter[114] and its updated version, the 1996 Protocol thereto[115] are international agreements that aim to prevent the marine pollution caused by the dumping into the sea of waste and hazardous materials. While they do not explicitly regulate sea mines or EO, they are relevant to discussions on the disposal of underwater munitions and their environmental impact.

The Convention was one of the first global treaties to address ocean pollution. It introduced controls on the disposal of industrial waste, chemical substances, and potentially hazardous materials at sea. It categorized wastes in three annexes: Annex 1 listed wastes or other matter that might be considered for dumping and prohibited the dumping of highly dangerous substances, such as highlevel radioactive wastes; Annex 2, on assessment of wastes and other matter than may be considered for dumping, required special permits for materials like arsenic and lead; and Annex 3, on the arbitral procedure, allowed general permits for less harmful substances, provided certain conditions were met. While it placed restrictions on dumping, it operated under a system where waste disposal was allowed unless specifically banned, with some exceptions allowed through permits.

In recognition of the need for stricter environmental protection, the Protocol was adopted in 1996 to strengthen and modernize the original Convention. Once ratified by a State, the Protocol replaces the 1972 Convention. Unlike its predecessor, the Protocol reverses the approach to waste disposal by establishing a general prohibition on dumping unless explicitly authorized under its Annex 1. That Annex lists a limited set of materials–like dredged material or organic waste–that can be considered for disposal with rigorous assessment. This precautionary principle significantly limits what can be disposed of in the ocean, and disposal requires stronger justification and oversight.

United Nations Convention on the Law of the Sea

The United Nations Convention on the Law of the Sea,[116] adopted in 1982, is a broad legal framework that governs maritime activities, setting out State responsibilities regarding navigation, resource use, and environmental protection.

Although the Convention does not specifically regulate sea mines or underwater EO, some of its broader principles can still be applied to those devices. The instrument primarily addresses pollution of the marine environment, which it defines as the introduction by humans, directly or indirectly, of substances or energy into the marine environment. Such pollution is considered harmful if it negatively affects living resources and marine life, poses hazards to human health, hinders maritime activities such as fishing and navigation, impairs water quality, or diminishes the overall usability of marine environments. This broad definition could encompass the hazards caused by underwater EO, including sea mines and other ERW, particularly when they threaten marine ecosystems or create risks for maritime industries.

San Remo Manual on International Law Applicable to Armed Conflicts at Sea

The *San Remo Manual on International Law Applicable to Armed Conflicts at Sea*,[117] published in 1995, is a key document that builds on the principles established in the 1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines and that reflects modern customary international law governing naval warfare.[118] Although not legally binding, it serves as an authoritative guide on how international law applies to armed conflicts at sea, particularly with regard to the use of sea mines.

It focuses on specific provisions of international law that deal with environmental protection, mines, missiles, and torpedoes. The manual builds on or further hones earlier frameworks.

Paragraph 11 of the manual, for example, encourages parties to the conflict to agree that no hostile actions will be conducted in marine areas containing rare or fragile ecosystems or habitats of depleted, threatened, or endangered species. This provision, which does not appear in the 1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine

Contact Mines, reflects newer environmental priorities drawn from the 1977 Protocol I additional to the 1949 Geneva Conventions and the 1982 United Nations Convention on the Law of the Sea, which stress the need to protect nature during naval conflicts.

Several paragraphs update the rules regarding weapons and tactics. Paragraph 35 states that a belligerent placing mines in the exclusive economic zone[119] or continental shelf of a neutral State shall notify that State, ensuring that the mines do not unduly disrupt artificial structures or resource activities, and give due regard to protection of the marine environment. This expands on the 1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines by addressing modern maritime zones and adding environmental considerations. Paragraphs 80 to 84 further refine the use of mines: they must have a legitimate military purpose and neutralize if they break loose or control over them is lost. Free-floating mines are prohibited unless they target military objectives and become harmless within an hour of loss of control. The laying of armed mines must be notified unless they detonate only against military vessels, and belligerents must record the locations where they have laid mines.

Furthermore, paragraph 78 ensures that missiles and projectiles, even those with an over-the-horizon reach, follow the principles of target discrimination principles, thereby applying to advanced weaponry the concept of distinction from the era of 1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines. Paragraph 79 bans torpedoes that do not sink or become harmless when they have completed their run.

Paragraph 90 obliges parties to the conflict, once the fighting has stopped, to do their utmost to remove or neutralize their mines, with each party handling its own mines, and notifying the position of and clearing mines in enemy territorial seas. This enhances, with clear duties, the principles of safe navigation in the 1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines. Paragraph 91 provides for cooperation among parties to the conflict, other States, and international organizations in sharing information and assisting with mine clearance. Paragraph 92 states that neutral States that clear illegally laid mines do not breach their neutrality, thereby solidifying practical customary norms.

The manual thus goes further than the basic limits set in the 1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines, integrating customary law and more recent treaties to clarify the norms of contemporary naval warfare.

Protocol V, on Explosive Remnants of War, to the Convention on Certain Conventional Weapons

Adopted in 2003, Protocol V to the Convention on Certain Conventional Weapons[120] addresses the humanitarian problems posed by ERW. It obliges High Contracting Parties to clear, remove, and destroy ERW in areas under their control after active hostilities. While the Protocol focuses primarily on land-based conflicts, some of its provisions could have relevance for maritime environments, especially regarding dumped munitions, underwater UXO, and post-conflict contamination in rivers and lakes.

Regional frameworks to address underwater explosive ordnance

While there are various frameworks providing a basis for the regulation of underwater EO, their implementation requires inter-State cooperation at the regional level. Many of these have origins in marine environmental protection initiatives.

For example, in the North Sea and the North-East Atlantic Ocean, the 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic (also known as the OSPAR Commission)[121] establishes measures to control marine pollution and hazardous substances, indirectly addressing the risks posed by legacy underwater EO.

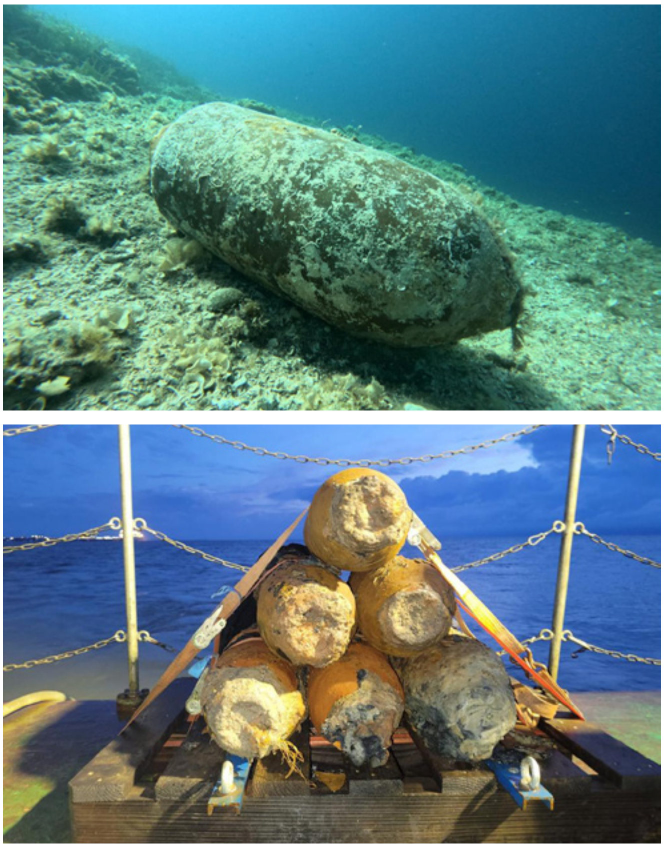
In the Mediterranean Sea, the 1995 Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (also known as the Barcelona Convention) and the seven protocols thereto[122] promote marine environmental protection and safety, including mitigation of the risk posed by underwater EO.

In the Baltic Sea region, a particularly robust framework exists since the 1972 Convention on the Protection of the Marine Environment of the Baltic Sea Area (also known as the Helsinki Convention). It integrates measures to manage hazardous substances particularly chemical munitions in dump sites since 1994. In 2023, the Council of the Baltic Sea States adopted declarations reinforcing their commitments[123], and the Baltic Sea Action Plan[124] of the Helsinki Commission which includes provision to coordinate underwater conventional EO and chemical munitions remediation. The Our Baltic Conference 2023 organized by the European Union, on 29 September 2023 in

Palanga, Lithuania, catalysed focused regional action. It brought together ministers from the European Union and representatives of Baltic Sea Member States to address underwater EO. This initiative built on the principles of international cooperation in the United Nations Convention on the Law of the Sea, the environmental mandate in the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, and the UXO clearance requirements in Protocol V to the Convention on Certain Conventional Weapons. Key commitments at the conference included:[125]

- Regional cooperation: strengthening collaboration with the Baltic Marine Environment Protection Commission and the Council of the Baltic Sea States to address underwater EO risks;
- Bridging knowledge gaps: prioritizing data-sharing, monitoring, and remediation technologies;
- Mapping and risk assessment: supporting maritime safety by identifying priority remediation areas, including offshore wind farms and marine protected zones.

These concerted efforts reflect a unified regional approach to addressing the legacy of submerged munitions, aiming to safeguard both the marine environment and public safety.



Aerial bombs found in German territorial waters in the North and Baltic Seas. Offshore explosive ordnance disposal operations in German territorial waters are regulated by the Quality Guideline for Offshore Explosive Ordnance Disposal published by the German Institute for Standardization – DIN. @ Seaterra GmbH

Guidance, standards and protocols

In 2014, the GICHD supported the IMAS Review Board in developing *IMAS 09.60: Underwater Survey and Clearance of Explosive Ordnance*.[126] The standard, which applies to EO located in territorial waters, coastal areas, lakes, rivers, ports, and harbours up to a depth of 50 m, outlines fundamental principles and requirements for conducting underwater EO survey and clearance operations to ensure their safety, efficiency, and effectiveness. It supports national authorities in establishing policies and national standards, provides guidance for organizations engaged in underwater survey and clearance, and offers structured methodologies for technical and non-technical surveys and risk management. It also outlines accreditation requirements, and environmental considerations.

As is the case in land-based mine action operations, as underwater EO survey and clearance operations expand, there is a growing need to incorporate environmental and climate-change considerations. The revised edition of *IMAS 07.13*: *Environmental Management and Climate Change in Mine Action*[127] and the related new technical note, *TNMA 07.13/01*,[128] emphasize the importance of identifying and evaluating environmental risks, mitigating negative effects, and implementing measures to restore or improve the environment following damages or loss.

While IMAS 09.60 serves as the general guidance for the survey and clearance of underwater EO in humanitarian contexts, operators often need to comply with other national, regional and international frameworks containing other legal, environmental, and technical provisions, including, for example, those related to maritime shipping and international sea trade.

A good example is the *Quality Guideline for Offshore Explosive Ordnance Disposal*, a comprehensive document developed to address the challenges associated with the disposal of EO in marine environments and to serve as a proposal for and guide to the normative regulation of offshore EOD.[129] Published in 2020 by the German Institute for Standardization (DIN), the Guideline was created during a research project funded by the German Federal Ministry for Economic Affairs and Energy. It aims to guide users through the entire EOD process, from preliminary surveys to clearance operations and final reporting. Outlining procedures and quality standards related to organizational aspects, personnel qualifications, and technical requirements, it seeks to enhance transparency and traceability in offshore EOD operations. While the Guideline focuses on German territorial waters and the German exclusive economic zone, its methodologies and standards may be applicable to similar operations in other regions. It emphasizes the importance of minimizing environmental impacts during EOD activities and promotes the adoption of best practices to ensure the safety of both personnel and marine ecosystems.


On the left, a diver with a propulsion vehicle ("scooter") makes visual inspection of the seabed. On the right, a diver checks the equipment before the dive. The training and deployment of explosive ordnance disposal divers requires specific qualifications and capabilities, which remains largely naval military capabilities defined by NATO and national standards. © Spanish Navy (left) © Portuguese Navy (right)

Another example is the *Protocol for In-Situ Underwater Measurement of Explosive Ordnance Disposal for UXO* is a guidance document also published in 2020, by the UK National Physical Laboratory, and funded by the UK Department for Business, Energy and Industrial Strategy through its Offshore Energy Strategic Environmental Assessment programme.[130] It offers recommendations related to best practice in measuring the underwater sound produced during the disposal of UXO in marine environments. The Protocol is particularly relevant for activities such as the construction of offshore wind farms, the installation of oil and gas platforms, and other marine renewable energy projects for which UXO disposal is necessary. It provides guidelines for practitioners to ensure that underwater sound measurements are consistent, comparable, and meet regulatory requirements for environmental assessments.

In relation to training, the British Standards Institution (BSI) in both 2022 and 2023 proposed the establishment of a standard covering qualification and training standards for commercial marine EOD and UXO operations, under the Steering Committee for Ships and Marine Technology of the International Organization for Standardization (ISO).[131 and 132] The intention of such proposals is to specify the requirements for and competencies of personnel who conduct EO surveys and disposal operations above and under water, inshore, and offshore for commercial projects. Also in 2022, the International Marine Contractors Association (IMCA) launched the Marine Explosive Ordnance Operations Logbook, which offers offshore personnel a convenient, consistent, and standardized way of demonstrating their training, competence, and work experience.[133]

While the projects of standardization proposed by the BSI have yet to come to fruition, military standards continue to be important references, particularly in a field in which military actors and capacities remain in the lead. The NATO-published *Explosive Ordnance Disposal (EOD) Principles and Minimum Standards of Proficiency* provides the foundation for standardization of EOD capacities, including the definition of minimum standards of proficiency for an underwater EOD operator. Another relevant set of technical documentation for the identification and disposal of EO across various environments is the *NATO EOD Publications Set–Identification and Disposal of Surface, Air, and Underwater Munitions*. This is based on the US Army Field Manual, series 60 (Amphibious).

Governments have started issuing additional guidance documents on minimizing the environmental impact of underwater demolition. In 2025, for example, the UK Government issued guidance on minimizing environmental impacts during the clearance of UXO in marine environments.[134] It promotes the use of low-order clearance methods as the default approach, to minimize the effects of underwater detonations on the environment, and reserves high-order detonations for exceptional circumstances only. Such techniques and technologies, which are already broadly used in the disposal of EO on land, have not been adopted as quickly in the underwater domain given the challenges associated with their use in such environment. Additionally, a better understanding of the environmental impact of the underwater pressure waves generated by blasts is leading to the adoption of new guidelines and regulations. Applicants seeking licences for marine UXO clearance are expected to demonstrate their use of low-order technologies and provide robust evidence supporting the environmental benefits. The UK guidance also outlines monitoring requirements to ensure the proper use and effectiveness of the chosen clearance methods.

The wide array of regulatory frameworks, originating from different disciplines and areas of economic activity, is representative of the complexity of the subject of underwater EO contamination. There is often conflict among them, which poses challenges to operators and national authorities alike.

Institutional frameworks and approaches related to the management of underwater explosive ordnance

National militaries have typically held most of the expertise in clearance of underwater EO. Nowadays, however, NGOs, commercial companies, international and intergovernmental organizations, and local authorities are increasingly involved in such operations. Despite this diversification, none of their approaches alone fits all contexts, as underwater EO clearance presents varied technical, environmental, and jurisdictional challenges.

According to *IMAS 09.60: Underwater Survey and Clearance of Explosive Ordnance*, a country's national mine action authority, or relevant government ministry, bears ultimate responsibility for the management of underwater survey and clearance projects within a country's jurisdiction.[135] This includes:

- Definition of survey and clearance requirements;
- Accreditation and monitoring of survey and clearance organizations;
- Post-clearance inspections before accepting responsibility for a cleared area;
- Establishment of national policies and standards aligned with the IMAS and other relevant regulations.

Institutional frameworks were originally developed for landmine clearance and have evolved to encompass all the pillars of mine action and management of the challenges posed by other EO. They have been set up within wider national frameworks and jurisdictions related to land use. In many countries, however, the coastline, sea, lakes, and other inland waterways have historically fallen under a jurisdiction outside that of the traditional mine action governance frameworks. It is not uncommon for the coastline, sea, and inland waterways of a country to fall within the responsibilities of different national bodies. Although the structured framework promoted by IMAS 09.60 seeks to ensure a centralized, consistent and accountable approach to underwater EO survey and clearance operations, in practice, its implementation poses many challenges. National mine action authorities may be inexistent, lack the necessary technical capacity, or face the national jurisdictional constraints mentioned above. There can also be international constraints such as those arising from exclusive economic zones and the international laws applicable to the sea.

A key decision to be made in underwater EO governance is therefore whether underwater survey and clearance operations should fall within the responsibility of an existing national mine action authority/mine action centre or that of a mine action centre established specifically for that purpose, or whether they should be assigned to a relevant national ministry or agency. In Ukraine, for example, underwater EO operations are conducted by the State Emergency Service of Ukraine (SESU) and the State Special Transport Service of Ukraine (SSTS), as ad hoc EOD spot tasks. These efforts do not necessarily form part of the national mine action response or national strategy. Conversely, in Serbia, underwater EO survey and clearance operations are a responsibility of the Serbian Mine Action Centre (SMAC).

Multisectoral collaborative approaches at the national level are a way of maximizing the strengths of national industry, the government, NGOs, the military, and academia, but are likely to bring greater coordination challenges.[136]

Where national capacities are limited, multinational, regional approaches, combined with private sector initiatives, are likely the most efficient option. A handful of international initiatives illustrate the importance of global partnerships in mitigating EO contamination, such the UN resolution 65/149 on cooperative measures to assess and increase awareness of environmental effects related to waste originating from chemical munitions dumped in the sea, 2013, promoted by Poland and Lithuania, the Operation Beneficial Cooperation, a Dutch-Belgium initiative supported by the Standing NATO Mine Countermeasures Group 1[137] and the several European Union initiatives funding advances in the field of underwater EO survey and clearance, through research, technology, innovation and capacity-enhancement projects.[138]

The MUNI-RISK Project (Risk Assessment of Sea-Dumped Munitions in the Baltic Sea) is one of the projects funded by the European Union through its European Maritime, Fisheries and Aquaculture Fund. It assesses environmental risks posed by dumped munitions in the Baltic Sea and aims to fill knowledge gaps, create a consolidated database, conduct risk assessments, and establish priority areas for remediation, particularly in offshore wind-farm zones.

Despite the challenges faced, national authorities should clearly define their national governance framework for regulating and supervising underwater EO survey and clearance operations, tailoring it to the specific national, regional and international context. This is of growing importance as the impact of underwater EO contamination is better understood and the private sector and commercial entities become increasingly involved in this field.

EOD operator retrieves the remotely operated vehicle Seafox during exercise. This is an expendable sea mine disposal vehicle. © U.S. Naval Forces Central Command/U.S. Fifth Fleet

TECHNOLOGY AND INNOVATION

The survey and clearance of underwater EO requires specialized tools and techniques adapted to the underwater environment. *IMAS 09.60: Underwater Survey and Clearance of Explosive ordnance,*[139] the GICHD technology demonstration report for underwater survey equipment,[140] and *A Guide to Survey and Clearance of Underwater Explosive Ordnance*[141] also by the GICHD continue to provide good guidance as to the types of sensors, technologies and platforms to be used. Acoustic sensors, such as side-scan sonar, multibeam sonar, and sub-bottom profilers, as well as geophysical sensors, such as magnetometers and electromagnetic induction (EMI), remain the key tools of the trade. Recent advances have been incremental, with the most relevant being the wider use of AUV and underwater remotely operated vehicles (ROV), including expendable systems for disposal and seabed crawlers for technical survey.

These advances have been made possible, and the technology will continue to evolve, owing to advances in artificial intelligence (AI) and robotics, even if challenges remain in terms of collection of the dataset that would allow for stronger AI applications.[142] There have also been strides in signalprocessing and analysis software, although significant technical knowledge in geophysics is still required for analysis of sensor data. Recent research into the environmental impact of traditional blast-in-place demolition procedures, which shows severe damage to surrounding fauna and flora, has led to a push for new low-order deflagration techniques.

Different tools and technologies are deployed at different stages of underwater survey and clearance operations, according to the conditions specific to the site. Identification of these conditions takes place during desktop assessments carried out during non-technical survey or during the preliminary survey and involves looking at historical information. As for technical survey, the tools, technologies, and processes required will often differ for inland waterways, lakes, coastal areas, and offshore sites, owing to differences in depth, turbidity and visibility, currents, and proximity to infrastructure, for example.

Towed magnetometer deployed in an uncrewed aerial vehicle. The use of water surface magnetometer survey is particularly efficient in shallow waters, including coastal transition areas, where vessels towed systems can't be used to systematically survey. © Marine Magnetics

Technical survey is of particular relevance in the underwater domain, given the lack of other available sources of information and visual cues. It is normally conducted in two distinct phases: first, "survey, classify and map (S/C/M)", followed by "reacquire and identify (R/I)".

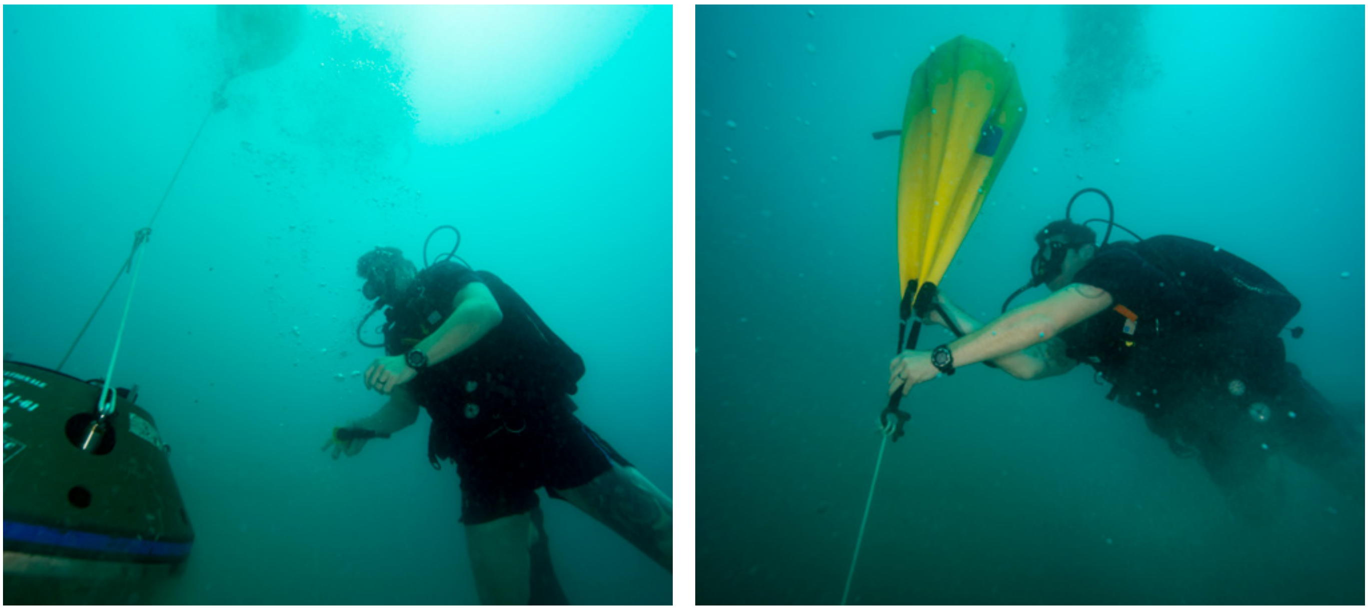
The first phase involves locating potential EO in the given area. Small boats or vessels, autonomous surface vehicles (ASV), and AUV play a crucial role in this process, as they can conduct wide-area searches in short periods of time, without the need for many human divers and manual survey. These platforms are equipped with side-scan sonar and magnetometers (typically towed in the case of small boats or vessels and ASV) that help detect anomalies on the seabed that may indicate the presence of EO. Magnetometers identify metallic masses, which is particularly relevant for EO buried beneath sediment. Magnetometers, however, need to be deployed close to the seabed, which is a challenge for towed systems when the surface of the seabed is not regular. For this reason, AUV and, more recently, seabed crawlers carrying magnetometers in fixed frames are becoming preferred alternatives.[143 and 144] In shallow waters and transition coastal areas, where depth may limit the deployment of towed magnetometers, the complementary deployment of magnetometers at the level of the water's surface via UAV has provided good results for comparison.[145]

Once the information gained during the first phase has been analysed and mapped, the second phase takes place to confirm the results through the gathering of additional information by EOD divers and/or ROV. EOD divers conduct hands-on identification using hand-held sonar, metal detectors, and tactile inspection, where required, to verify the nature of the object. This is typically the case in shallow waters and other conditions in which a ROV cannot be deployed. In deeper or more hazardous environments, ROV are becoming the preferred option, instead of EOD divers, and can be used for real-time visual inspection. Advances in robotics have increased such vehicles' payloads and capacities so they can are becoming increasingly better not only capturing high-resolution video and images for further analysis, but also using robotic arms, neutralization charges and almost any type of sensor.[146 and 147] Not only are computer vision and imagery recognition, powered by AI algorithms, expanding fields of technological development,[148 and 149] autonomy, propulsion, navigation systems, and human interfaces have also advanced significantly.[150] Both EOD divers and ROV rely heavily on underwater navigation and positioning equipment.

The consolidated data collected during the technical survey is then integrated into an underwater geographic information system that consolidates the mapping information to enable systematic clearance efforts. At this second stage, site-specific assessments are also carried out to determine the risks and impacts associated with the different potential methods of neutralization in situ and to assess the possibility of moving the ordnance. Some munitions can be highly unstable owing to corrosion or degradation. In the case of in inland waterways or in the vicinity of ports, the possibility of damage to infrastructure must be considered. In addition to the safety concerns, teams must consider the potential environmental impact both of neutralization methods and of inaction. Risk assessment is a continuous cross-cutting process in all underwater survey and clearance operations and not exclusive to this phase.

Clearance and disposal activities typically follow technical survey and assessment. If an EO is deemed stable enough to be moved, mechanical lifting techniques are employed. This may involve the use of lifting balloons, ROV equipped with gripping arms, or cranes mounted on salvage vessels. If the ordnance is too unstable to be safely moved, disposal needs to be performed in situ. Historically, the preferred disposal method has been high-order, controlled demolition, which involves using donor charges to trigger the device. Careful estimation of the blast wave propagation is required to determine and then minimize the impact on the surrounding environment, including on marine life and underwater structures. Concerns about the impact on marine life of the blast wave and sound impulse generated by high-order explosions under water[151, 152 and 153] has led to the greater testing and use of low-order neutralization techniques, such as deflagration using shaped charges (or explosively generated plasma) specifically designed for underwater use.[154 and 155]. It has also prompted research into other methods, such as laser ablation.[156]

Towed magnetometer deployed in a small vessel. One of the challenges of deploying these systems is that they are much more difficult to adapt to variations in the seabed profile. Autonomous underwater vehicles which can automatically adjust distance to the seabed profile are becoming therefore more and more used, when depths allow its use. © Marine Magnetics



Explosive ordnance disposal diver fills a lift balloon attached to a simulated bottom mine in the Mediterranean Sea during an exercise. When underwater explosive ordnance is deemed safe to move, removal is a clearance method that minimizes environmental impact. Removal can be done also with a remotely operated vehicle or a salvage vessel crane. © U.S. Naval Forces Central Command/U.S. Fifth Fleet

The case study of a Tallboy air bomb with a net explosive weight equivalent to 3,600 kg of TNT, detected in the fairway connecting the Polish Baltic ports of Świnoujście and Szczecin, provides a real-life example of what needs to be considered when planning a clearance and disposal operation. In this case, a deflagration neutralization method was successfully used.[157]

Following clearance there must be confirmation that the neutralization has been successful and that no remnants of the disposed EO or other EO remains in the area. Environmental monitoring and post-operation surveys might be required. Again, ROV and AUV can be a very efficient means of confirmation, reducing the logistical burden and the risks associated to the deployment of EOD divers. Environmental scientists may also undertake ecological assessment and monitoring to check for any contamination or disruption to marine habitats caused by the clearance operations or when there has been a decision to monitor instead of clearing. In certain locations, longterm monitoring is required, especially in areas where shifting sediments could uncover previously undetected ordnance. Through the continuous mapping of these sites, the authorities can track any changes and take proactive measures if new threats emerge.

In some cases, survey and monitoring might be reasonable decision in an integrated riskmanagement approach. Technological advances make such an approach more viable and effective. The case study of the exploration of the munition dumpsite Kolberger Heide in Kiel Bay, Germany, is a good example, providing a very detailed account of the underwater technical survey process, which combined hydroacoustic and optic monitoring by divers and AUV.[158]

Underwater remotely operated vehicle with disposal system attachment being deployed. © Helix Robotic Solutions Ltd

On the left, an underwater shaped charge positioned to dispose of an unexploded ordnance (air dropped bomb) by low order deflagration. On the right, the result of a successful deflagration underwater. This disposal method mitigates impact on marine life and underwater structures. © Helix Robotic Solutions Ltd

Despite technological advances, however, more research and innovation are needed in this field, as the priorities and initiatives of leading organizations, described in the next section, show.

EMERGING TECHNOLOGIES

Europe continues to grapple with the legacy of twentieth-century wars, with vast quantities of EO scattered throughout its coastal waters, especially in the North Sea and the Baltic Sea. As offshore infrastructure projects – such as wind farm installations and subsea cable laying – expand, the need for efficient EO survey and clearance has become more urgent. Recent research and innovation projects, funded by the European Union, aim to improve significantly how EO is detected, mapped, and ultimately removed from the seabed. Addressing underwater EO contamination has been one of the priorities of the European Commission in terms of funding for research and technology since at least 2014.[159]

BASTA: AI-driven detection and mapping

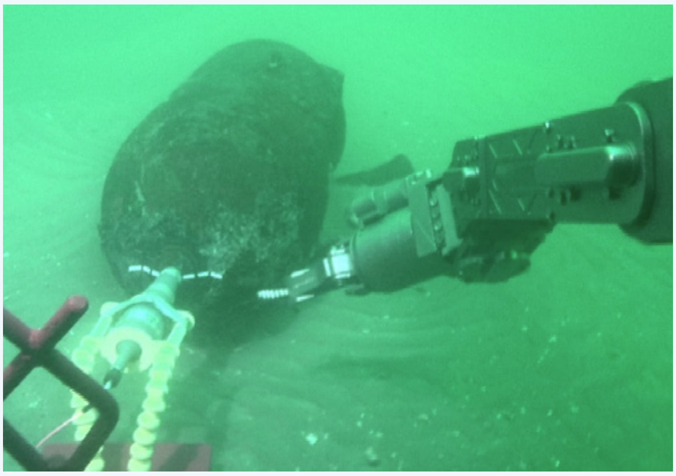
The BASTA (boost applied munition detection through smart data integration and AI workflows) project (2019–2022) aimed to increase the accuracy of EO detection using advanced data integration and AI. It piloted the use of AUV equipped with ultra-high-resolution 3D sensors for sub-bottom profiling and magnetometers to create detailed maps of suspected EO sites. The project was based on the premise that more-capable AUV could operate independently, covering large areas rapidly and cost-effectively, while multiple such vehicles could work together, further accelerating the process. The project included tests in, and the evaluation of, multiple EO dump sites on the coast of Germany.

As a second objective, the project aimed to collect data in a multisensor database, which also incorporated historical wartime records. By applying big-data processing and AI methods, the EO survey data could be used more efficiently for clearance operations.[160]

ExPloTect: Rapid chemical detection of unexploded ordnance

While BASTA focused on geophysical mapping, the ExPloTect (ex-situ, near-real-time explosive compound detection in seawater) project (2019–2022) aimed to develop technologies to detect munitions-derived chemicals in seawater. The goal of the project was to develop, optimize, and test a prototype seagoing device for the detection of chemicals associated with underwater EO in the marine environment. By passing seawater through specialized filtration systems, the system sought to capture and concentrate traces of chemicals, which were then analysed using a combination of liquid chromatography and mass spectrometry. This aimed to reduce dramatically the length of the detection process; a task that once took two to three months could potentially be completed in as little as 15 minutes. The ability to identify hazardous chemicals quickly and accurately, in real time, was intended to provide critical information for clearance teams, potentially increasing operational safety and improving environmental monitoring efforts.[161]

The BASTA and ExPloTect projects, which were both coordinated by the GEOMAR Helmholtz Centre for Ocean Research Kiel[162], Germany, built on previous projects funded by the Germany Federal Ministry for Economic Affairs and Energy, such as the UDEMM (environmental monitoring before, during, and after delaboration of munitions in the sea) project[163] and the RoBEMM (robotic underwater salvage and disposal process) project,[164] which were both completed in 2019. These



On the left, a remotely operated vehicle digging up an unexploded ordnance (air dropped bomb). On the right, the robotic arm of the remotely operated vehicle helps the placement of a low order deflagration shaped charge. © Helix Robotic Solutions Ltd

projects have accelerated research and development to make underwater EO survey and clearance safer, faster, and more cost-effective, as demonstrated by the case study of the underwater EO clearance project in the Bay of Lübeck, northern Germany. It employed a range of advanced robotic technologies and automation systems to tackle the large-scale problem of dumped munitions from the Second World War.[165]

MMinE-SwEEPER: Marine munition in Europe–solutions with economic and ecological profits for efficient remediation

The MMinE-SwEEPER project funded by Horizon Europe of the European Commission was launched in October 2024 with a planned duration of 3.5 years. Its focus is on the development of advanced technologies for detecting, identifying, and monitoring underwater EO, while developing non-military capacities among seven European Union and two associated countries to tackle the challenges of underwater EO.[166]

The latest call for proposals by the European Commission was launched in June 2024, under the theme "Saving our seas–Reducing danger of munitions dumped in European seas".[167]

NICELE: Neutralization in challenging environments using lethal effects

In December 2024, the Office of Naval Research of the US Navy launched a call for proposals under its Seabed and Underwater Explosive Ordnance Disposal programme. This is another indication of the need for advances in technology in this field. The call focuses on deep-water sea mines and waterborne improvised explosive devices, seeking to develop payloads for divers, ROV and AUV for survey and identification, neutralization, including detonation, deflagration and render-safe operations and to ensure better command and control of such vehicles over extended ranges.[168]

AUV and ROV have become a focus of attention in the military naval domain. Since 2017, NATO, the European Defence Agency and the Portuguese Navy have conducted an annual exercise series entitled "Robotic Experimentation and Prototyping with Marine Unmanned Systems" (REPMUS). It involves the testing of dozens of advanced underwater technologies in realworld operational scenarios. Additionally, in 2024, the NATO Support and Procurement Agency placed an order for AUV for advanced demining that are designed to detect and neutralize landmines and EO. The vehicles are guided towards detected mines, where they attach themselves and neutralize the threat using a precise explosive charge. They are considered expendable and are designed to be used only once for the destruction of a target.[169]

As defence requirements develop and marine industries continue to expand, cutting-edge technologies play a crucial role in ensuring that offshore operations can proceed safely while minimizing ecological risks.

LIABILITY CONSIDERATIONS

Liability is a crucial aspect of any mine action operation, including the phase of residual risk management. According to *IMAS 07.11: Land Release*, liability encompasses the legal responsibilities, duties, or obligations that a country, organization, or individual may hold.[170] In the context of mine action, liability is typically associated with non-compliance with established policies or procedures, especially when an adverse event occurs, such as an accident or the discovery of an undetected item of EO in a cleared area. The potential for related financial claims or legal repercussions can create hesitance in accepting the handover of land.

In the underwater domain, liability is governed by a combination of international conventions, national laws, and contractual agreements. The United Nations

A light autonomous underwater vehicle scanning the sea bottom. These systems can efficiently deploy a wide range of survey sensors, reducing the logistical burden and risks associated to deploying EOD divers. © Portuguese Navy

Convention on the Law of the Sea establishes coastal States' responsibilities for maritime safety and environmental protection, but it does not explicitly define liability for underwater EO contamination. This legal ambiguity complicates clearance efforts, particularly in disputed maritime zones or areas with legacy UXO contamination.

For example, in the Black Sea region, where sea mines have been displaced owing to ongoing conflict, the responsibility for clearance operations and liability post-clearance are unclear. Similar legal challenges exist in the Baltic Sea and the Pacific Ocean, where multiple States have dumped munitions, making it difficult to attribute liability to any one of them.

At the national level, Governments define legal obligations relating to EO clearance through policies, maritime safety laws, and regulations on environmental protection. National authorities bear primary responsibility for regulating survey and clearance activities, ensuring compliance with international legal frameworks, including those outlined in the section above on international law. Additionally, private sector operators and insurance providers require liability to be clearly defined before engaging in EO risk management, particularly in commercially significant maritime zones.

Insurance plays a pivotal role in the management of the financial risks associated with underwater EO contamination. The presence of drifting sea mines and UXO significantly increases hull-risk insurance premiums, as outlined in chapter 2 in relation to the conflicts in Ukraine and Yemen.

A well-documented, transparent, and evidence-based approach to underwater EO survey and clearance operations is essential for addressing liability concerns. Such an approach enables national authorities and stakeholders to make informed decisions with confidence. It is crucial that national policies clearly define aspects of liability, including the transfer of responsibility from survey and clearance organizations to government bodies once established criteria have been met.

According to *A Guide to Survey and Clearance of Underwater Explosive Ordnance* by the GICHD, the following key principles should apply:[171]

- Underwater EO contamination is ultimately a national responsibility. Governments should accept accountability and liability for affected areas, whether known or unknown, as well as for areas that have been surveyed, cleared, and officially handed over. An underwater EO survey and clearance organization is considered liable for injuries or damages only if it is directly responsible for overseeing the area at the time of an incident. Even in such cases, liability must be assessed on a case-by-case basis.
- A formal agreement outlining the underwater EO survey and clearance plan should include a clear definition of "all reasonable effort" to reduce ambiguity and to prevent any liability disputes between stakeholders.
- If a government approves an underwater EO survey and clearance plan and handover is accepted upon completion, this implies that the remaining risk is deemed tolerable by the national authorities. This

principle ensures that liability does not remain indefinitely with the clearance operators once an area has been handed over in accordance with established protocols.

- Organizations conducting underwater EO operations should not be held liable for having missed ordnance or for accidents if an investigation confirms that the clearance was conducted in accordance with the approved survey and clearance plan. Adherence to international good practices and compliance with *IMAS 10.60: Safety and Occupational Health–Investigation and Reporting of Accidents and Incidents* is crucial in such cases.[172]
- National policies or contractual agreements should explicitly define liability for EO discovered post-clearance. These policies must ensure that mechanisms are in place to manage residual contamination, including emergency response and follow-up clearance responsibilities.

Organizations engaged in underwater EO clearance require comprehensive insurance coverage to mitigate these risks for them, including: [173]

- Professional liability insurance to cover errors, omissions, and procedural liabilities in clearance operations;
- Employer's liability insurance for personnel engaged in hazardous underwater activities;
- Public liability insurance to safeguard against third-party claims, including damages to commercial shipping, fisheries, offshore energy infrastructure, and coastal communities;
- Environmental damage insurance, which is crucial in cases involving chemical munitions or hazardous substances, to cover pollution risks associated with clearance operations.

The *Quality Guideline for Offshore Explosive Ordnance Disposal* outlines specific requirements related to liability and insurance for contractors involved in UXO operations.[174] These requirements are designed to ensure that all parties have adequate coverage for potential risks associated with UXO. It specifically mentions that entities responsible for conducting surveys must provide verifications of suitability, including public liability insurance that covers UXO-related risks. This insurance should address personal injury, damage to property and the environment, and financial losses. The guideline also defines specific minimum suitability and competencies standards that all contractors must meet. These standards should be supplemented with verifications from standardized award procedures. Clients may also request additional verification as deemed necessary. Importantly, the client is responsible for defining the minimum coverage amount in the public liability insurance related to UXO risks. The guideline also defines the procedure for safety sign-off of target-free areas and the minimum requirements for UXO safety sign-off certificate.

Commercial providers of UXO survey and clearance services often provide "as low as reasonably practicable" (ALARP) certificates on their services, detailing risk analysis, methodologies used and risk estimations. ALARP is a common risk management principle used across industries, particularly marine, offshore, oil and gas sectors. According to *IMAS 07.14: Risk Management* application of "all reasonable effort" is consistent with the achievement of ALARP level of residual risk.[175] The need and requirements for these certificates must be defined by national authorities in accordance with national and international regulations. They may not replace the issuing of safety sign-off or completion reports, as it is the case under the German *Quality Guideline for Offshore Explosive Ordnance Disposal* which explicitly states that risk estimations cannot replace a qualified UXO sign-off certificate. [176]

Beyond legal, financial and environmental risks, underwater EO clearance must also address the protection of culture, as clearance areas can overlap with archaeologically significant shipwrecks. This may necessitate compliance with provisions applicable to the sites on the World Heritage List of the United Nations Educational, Scientific and Cultural Organization.

Liability might also need to be determined in the case of inaction, which can be much more complex, particularly when environmental risks are involved. This challenge was evident in Switzerland when the 2005 assessment of the munitions dumping sites in Swiss lakes revealed that all available recovery methods risked disturbing up to 2 m of fine sediment. Given the fragile lake ecosystems and potential oxygen depletion, the authorities faced the dilemma of whether to leave the munitions undisturbed, despite the long-term contamination risks, or to attempt recovery, potentially causing immediate environmental harm. The new competition for ideas on how to develop environmentally friendly and safe methods for recovering the submerged ammunition, launched in 2024, aims is to involve academia and industry in exploring solutions for deep-lake ammunition recovery, should it ever become urgent.[177]

Given the economic, legal, and environmental risks associated with underwater EO contamination, clear liability-management and risk-mitigation strategies are essential. It is crucial to ensuring legal clarity, to secure appropriate insurance coverage, and to adhere to environmental regulations in order to mitigate risks and facilitate safe, effective, and accountable clearance operations.

CONCLUSION

Underwater EO contamination represents a persistent and evolving challenge with far-reaching implications for security, the marine environment, and economic stability. The presence of legacy EO from past conflicts continues to disrupt global trade, threaten critical infrastructure, and endanger marine ecosystems. While military forces have historically led efforts, the complexity and scale of underwater EO contamination require a broader, multi-stakeholder approach.

Advances in technology have significantly improved survey and clearance operations. Nevertheless, high costs, limits in technology, and lack of national regulatory frameworks prevent them from occurring on a large scale. International legal frameworks provide some guidelines for underwater EO contamination management, but implementation mechanisms remain weak, necessitating stronger global cooperation.

The environmental risks associated with underwater EO are tending to increase, particularly as rising ocean temperatures and water acidification accelerate the corrosion of munitions. The release of toxic substances into marine food chains poses a growing health hazard, further emphasizing the need for proactive survey and clearance operations, monitoring frameworks, and pollution-mitigation strategies.

Governments, international organizations, and private stakeholders must collaborate to integrate underwater mine action into broader initiatives on maritime security, infrastructure planning, and climate resilience. Moving forward, the establishment of a structured institutional framework on state, regional and global levels, the improvement of data-collection and -sharing mechanisms, and the prioritization of environmentally sustainable methods of disposal will be critical in mitigating the risks posed by underwater EO. Without decisive action, the legacy of past conflicts will continue to present significant threats to current marine safety, economic development, and environmental sustainability.

ANNEX: COMPILATION AND ASSESSMENT OF OPENSOURCE DATA ON GLOBAL UNDERWATER EXPLOSIVE ORDNANCE CONTAMINATION

As part of the present study, open-source data from reports on incidents involving underwater EO were compiled for the period of 2014–2023. This provides an overview of 146 recorded incidents, with a view to aiding understanding of the scale, distribution, and impact of underwater EO contamination worldwide.

The analysis does not claim to include all incidents involving underwater EO. The number of incidents could be significantly higher owing to gaps in data collection, limited reporting mechanisms, or the challenges of underwater EO detection. As such, the actual scale of EO contamination may be much greater than what is reflected in the dataset.

DATA ANALYSIS

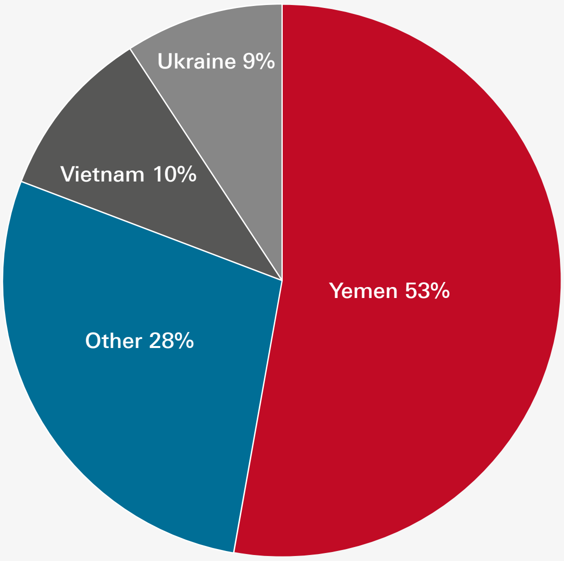
The data give an overview of EO contamination across different regions, both legacy contamination and that caused by ongoing conflicts. Yemen had the highest number of incidents, accounting for 78 cases (53 per cent). 75 of those 77 cases (96 per cent) refer to tethered sea mines manufactured locally, with several variants identified. This reflects the country's prolonged conflict and the widespread use of sea mines off the coast of Yemen. Despite the locally manufactured, the types of sea mines are designed and deployed to achieve same effects as conventional sea mines.

Vietnam (14 incidents) and Ukraine (13 incidents) are the second and third highest, reflecting the lasting impact of past conflicts and ongoing security challenges.

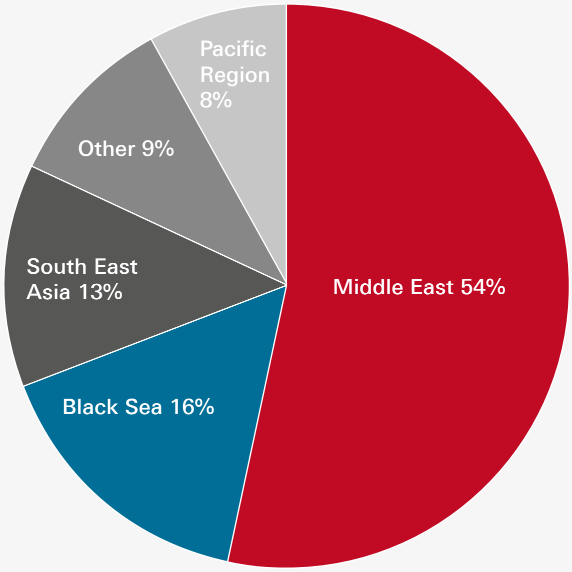
In terms of regions, Middle East has the highest number of incidents, 79 (54 per cent), predominantly originating from Yemen. The number of incidents in the Black Sea is 23 (16 per cent), 22 being drifting sea mines originating from the active conflict in Ukraine. South-East Asia accounts for 19 incidents (13 per cent) and the Pacific region for 11 (8 per cent). These are linked to historical contamination for past conflicts, being in both cases the majority submerged air-dropped bombs. In South-East Asia these are mostly found in rivers or inland waterways, whereas in the Pacific these are mostly found in coastal areas. The remaining 14 cases (9 per cent) are distributed across Northern Africa, Europe and South America.

The majority of the underwater EO incidents recorded during the period under review involved conventional or manufactured sea mines (67 per cent), primarily located in the southern Red Sea, the BabelMandeb strait, and the Black Sea. This is probably due both to the focus of media reporting on two major contemporary conflicts in those areas and to the impact of drifting sea mines in international shipping lanes in these key maritime routes.

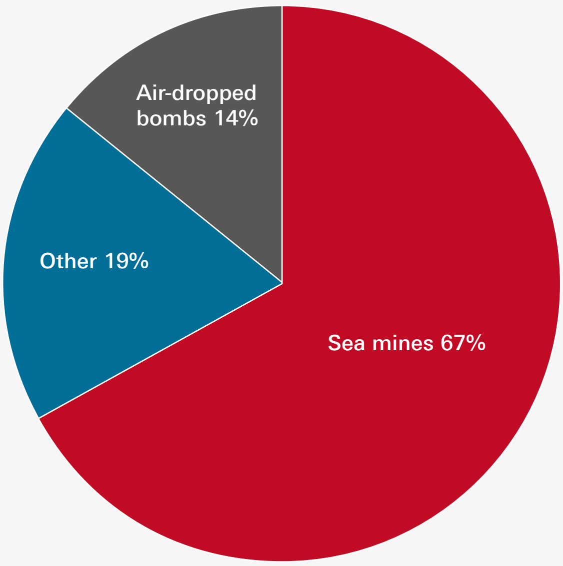
Distribution of recorded incidents per country, between 2014-2023. Top 3 countries highlighted.



Distribution of recorded incidents per region, between 2014-2023.



Distribution per type of underwater EO among the recorded incidents, between 2014-2023.



Air-dropped bombs classified as UXO account for the next largest proportion of incidents (14 per cent). Approximately two-thirds of these were recorded in Vietnam. All these incidents are related to historic conflicts and likely to have been caused by only a small proportion of the actual EO contamination in the Pacific region.

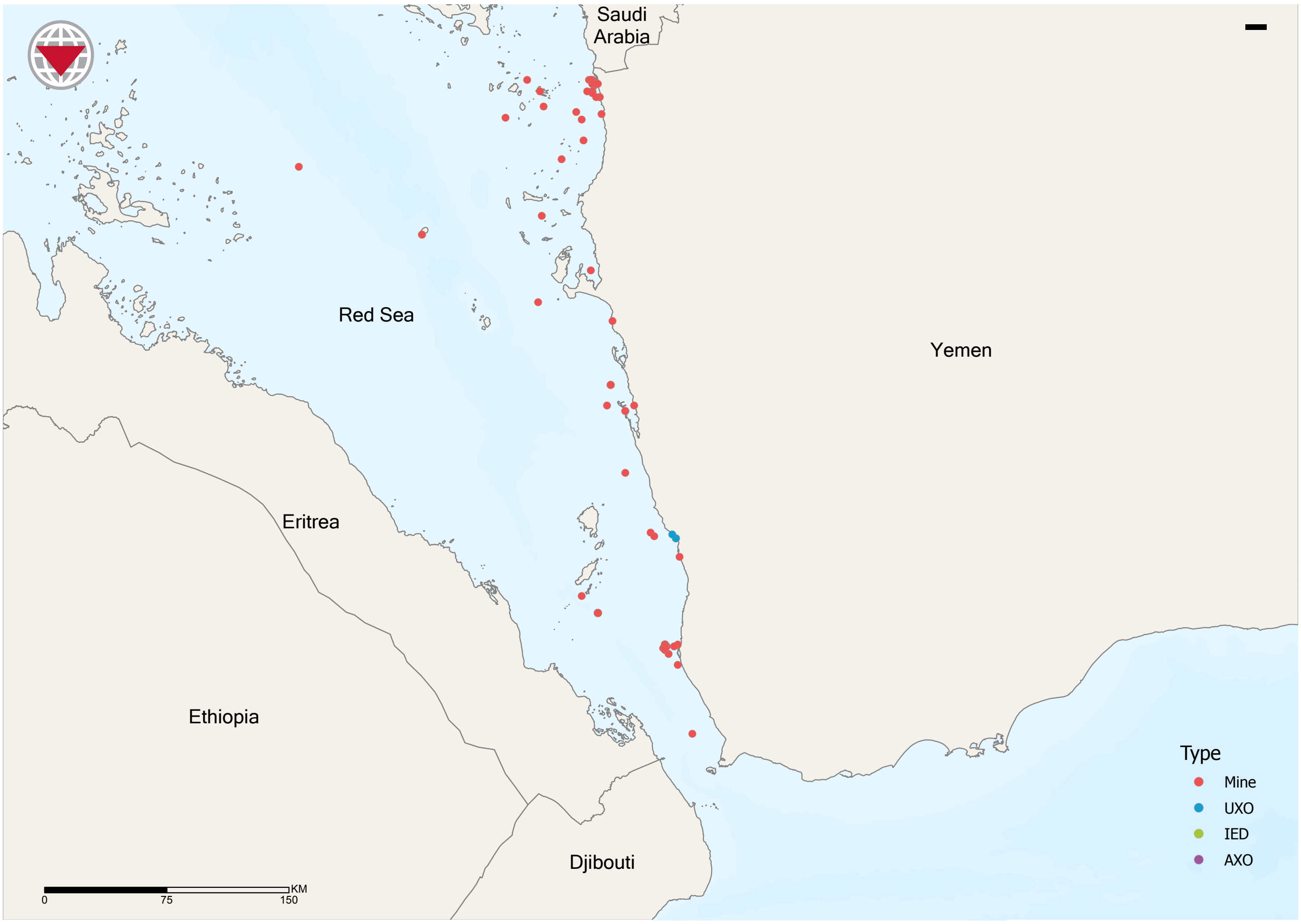
The data examined identified only limited EO contamination in some areas where conflict is ongoing, or where prolonged conflict has taken place, such as the coastal zone of Ukraine and the inland waterways of Colombia. It is possible, however, that areas such as these will the site of future incidents involving underwater EO.

The type of ordnance found further illustrates the nature of the threat. Sea mines suggest ongoing risks in maritime environments, air-dropped bombs point to the lasting impact of past aerial campaigns, while improvised explosive devices, UXO, and explosive materials reflect both older contamination and more recent threats.

RED SEA

More than three-quarters of the sea mine incidents recorded during the period under review took place off the western coast of Yemen in the Red Sea and the Bab-el-Mandeb strait. The sea mines were primarily of two types: the Midi/Mersad mine and the Thwaq mine. Both are locally manufactured, tethered sea mines deployed to disrupt access to ports and coastal population centres held by Houthi-aligned forces.[178] Approximately 85 per cent were reported found in the sea, whereas 15 per cent were reported washing ashore on beaches.

Given the number of incidents recorded, the scale of the ongoing threat is significant. That said, following the ceasefire agreement of April 2022, only four sea mine incidents were recorded until the end of the data collection period. This might suggest that the mining of coastal areas ceased or slowed as part of a wider avoidance of sustained conflict, including following the expiration of the ceasefire in October 2022. The recent escalation of armed conflict in the Middle East region is likely to show changes to this trend.



Map of the Red Sea showing the incidents involving explosive ordnance recorded 2013–2023. Majority of the incidents were originated by locally manufactured sea mines and were found in the sea. © GICHD

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Map of the Black Sea showing the incidents involving explosive ordnance recorded 2013–2023. Majority of the incidents were originated by conventional sea mines. Half of the incidents were reported in the sea. © GICHD

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BLACK SEA

The full-scale invasion of Ukraine by the Russian Federation, which began in February 2022, is the basis for of the next largest number of reported sea mine incidents, accounting for 16 per cent those reported 2013–2023. The source of the drifting mines is currently unclear, with some news agencies initially claiming that the Ukrainian Navy had released significant numbers in the Black Sea following February 2022[179], while other news agencies suggesting that Russia has laid sea mines to block Ukrainian ports and grain export[180].

Given the ongoing conflict and the role therein of the dissemination of disinformation, the scale of the threat of drifting sea mines is unclear. Most sea mine incidents within the Black Sea have affected the littoral zones and territorial waters of Ukraine and Romania (56 and 22 per cent, respectively). Approximately half have been reported found on beaches and rendered safe by Ukrainian or Romanian EOD operators while another half was found in the sea and dealt with by mine countermeasures vessels/naval divers teams. Only 55 per cent of recorded sea mine incidents took place in the area identified by international shipping insurance agencies as being of increased risk owing to the ongoing conflict.[181] This area encompasses the northern Black Sea and littoral margin, including areas along and off the coast of Odesa, where just over a third of incidents took place. To the south of this defined area, four incidents were recorded along the coasts of Georgia and Turkey and four others either off the coast of Constanța, Romania, or outside Romanian territorial waters during patrols by Romanian Navy vessels. This demonstrates the potential for incidents to occur in areas deemed to be outside the identified conflict-affected maritime zones, as well as the uncertainty regarding the threat currently posed by drifting sea mines because of the conflict.

The extent of EO contamination along sections of Ukrainian beaches remains unknown owing to information security and reporting restrictions. A suspected sea mine detonation that allegedly killed two civilians in Mykolaiv was reported in July 2022, but it appears to have been in a restricted area demarcated as EO-contaminated.[182] Given the ongoing nature of the conflict, it is possible that different types of EO, including mines laid as part of antiinvasion defences, are contributing to underwater EO contamination.

In addition to the threat from coastal underwater EO contamination, the destruction of the Kakhovka dam on 6 June 2023 created a significant risk of mines and other sources of ERW being displaced throughout the flood-affected areas. Although the scale of the contamination is unknown at the time of writing, a statement by the Mines Advisory Group highlights the likely consequences of displaced mines.[183] Available mapping and satellite imagery indicate that sections of the Russian defensive lines on the left bank of the Dnipro River opposite Kherson were completely submerged as at 7 June 2023.[184] Imagery and a video posted on 6 June 2023 also appear to show submerged antitank mines and the possible detonation of a drifting anti-tank mine in the area of the dam.[185 and 186] There is also evidence of potential ERW contamination in submerged areas.

Given the nature of the conflict and current military offensive action in the region, a more comprehensive assessment of the ERW contamination is unlikely to occur in the short term.

OTHER BODIES OF WATER

A total of 74 per cent of the underwater EO incidents recorded in South-East Asia during the period under review were in Vietnam. Most of the incidents reported originate from air-dropped bombs. Although there was no sea mine incident reported, an unexploded bomb identified at a depth of 3 m, approximately 100 m from the coast of Quang Binh Province, may have been a DST-36-type airdropped mine. The DST-36 fuze was fitted to a standard 500-lb airdropped bomb and was one of the primary munitions deployed by aircraft of the US Air Force and the US Navy during aerial mining operations in the armed conflict in Vietnam, Laos and Cambodia (1955 - 1975) both within the littoral zone of what was then North Vietnam and along inland waterways.[187 and 188]

The incidents recorded in Vietnam were primarily in rivers and inland waterways, including within large towns or cities that were subjected to aerial bombing during the war. The distribution of the incidents likely reflects the tactical bombing carried out in support of ground operations in what was then South Vietnam and the strategic bombing campaign that targeted lines of communication and supply in both the north and the south. The air-dropped bombs recorded in underwater environments ranged from 100-kg types (likely Mk81 high-explosive bombs) to 1000-kg types.

In the Pacific Ocean, Palau and the Solomon Islands accounted for some 80 per cent of the incidents recorded. The number of incidents in absolute terms is relatively small, and this does not reflect the potential scale of the underwater EO contamination from UXO sources, including in shipwrecks. The opensource reporting analysed suggests that EO clearance remains largely the responsibility of the military, with international naval forces in the region taking part in Operation Render Safe.[189] NGOs such as the Japan Mine Action Service and Norwegian People's Aid have, however, carried out specific underwater EO clearance tasks, such as the recovery of four Imperial Japanese Navy Type 91 torpedoes off the coast of Palau.[190]

In the Solomon Islands, recorded incidents involving underwater EO include the illegal recovery of explosive material from ERW for the purpose of blast fishing; the identification of an aircraft wreck following the dredging of a river; and the recovery of an air-dropped bomb from a river at a gravel site. EO remains a significant threat in the Solomon Islands, particularly in densely populated areas such as Honiara, with incidents involving the extraction of explosive material for blast fishing and ERW encountered during construction projects.[191] Given the density of shipwrecks from the Second World War off the northern coast of the island of Guadalcanal and around the New Georgia Islands, it is likely that there is significant underwater EO contamination outside known wreck sites. This issue has been identified as important at the government level, with oil and potential EO-related contamination from the wrecks acknowledged as issues of environmental concern.[192]

Although EO contamination has been linked to areas of historical or ongoing conflict, open-source information thereon is not always available. The most notable such area is Colombia, where intermittent conflict has been going on since 1964, with part of the conflict taking place along key riverine transport and communication routes.[193] EO has indirectly affected the underwater environment through oil leaks caused by attacks on sections of pipeline using improvised explosive devices.[194] Given the duration and varying intensity of the conflict over time and the importance of inland waterways for access to rural populations, it is possible that underwater EO remains a risk and a threat to development in these areas.

LIMITATIONS OF THE DATA COLLECTION

Searches were done within online open-source data, and in English language, for the period of 10 years since beginning of 2014 to the end of 2023. The limitation of the search to English language might impact the levels of reporting in South-East Asia, Pacific and South America regions. The use of online open-source may lead to underreporting in the north-eastern Atlantic, the North Sea, and the Baltic Sea because of the international, national, and commercial frameworks to mitigate the risk of underwater EO contamination that have been established.

Incidents associated with "blast fishing" were not considered.

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