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A Risk-Increasing Safety Strategy? Evaluating the Traditional Risk-mitigating Strategy in Dealing with Dumped Ammunition and Explosive Remnants of War

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Introduction

Scattered in Norwegian waters and lakes, on land and in soil lay the remnants of five years of war. In excess of one hundred thousand sea mines were laid in Norwegian coastal waters during the Second World War (WWII), and it is estimated that tens of thousands of these mines still remain.[1] Hundreds of thousands of landmines placed in Norway during WWII are believed to have been dumped at sea or in nearby lakes within the first few years following the end of the war. There are still several hundred shipwrecks originating from WWII. The majority of the sunken warships still contain relatively large quantities of explosive ordnance, several hundred tonnes in some cases.

[1] Justis- og politidepartementet og Forsvarsdepartementet, *Ansvarsforhold og håndtering ved funn av eksplosive varer [Responsibilities and handling of explosive goods]*, Oslo: Ministry of Justice and Police and the Ministry of Defence, 2012, https://www.regjeringen.no/globalassets/upload/jd/vedlegg/rapporter/rapport_eksplosiver_2012.pdf?id=2327852.

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Immediately after the end of WWII, the Allied Joint Command in Norway ordered a large-scale destruction operation of the captured German war material, including weapons and ammunition. According to the Norwegian Army Supply Command, the hasty destruction and dumping operation that followed seemed to have been almost unplanned.[2] Reports from UK Explosive Ordnance Disposal (EOD) teams tasked with carrying out this work in 1945-46 seem to confirm this view and state that the official Allied policy at the time was that all German ammunition in Norway was to be disposed of within the first months following the end of World War II in Europe.[3] This resulted in a massive dumping operation, in which derelict vessels were often loaded with unwanted material and scuttled in designated areas. On other occasions, unwanted explosive ordnance was simply thrown overboard or from the shore, at will. The latter was particularly relevant where stockpiles of ammunition were located on the coastline, e.g. in the vicinity of coastal fortifications and fortresses, harbours, naval bases, and protective minefields.

There is no way to determine the exact amount of explosives originating from these dumping operations that remain in Norwegian waters, but the Allied dumping alone seems to surpass 200,000 tonnes. Just outside the country's capital, in the Oslofjord, it is estimated that there are over 30,000 tonnes of ammunition from planned dumping operations[4] and over 2000 sea mines are remaining.[5] This is in addition to hundreds of thousands of dumped landmines, ammunition dumped from coastal installations, and ammunition contained within shipwrecks. One wreck alone, the German cruiser Blücher, is believed to still contain over 700 tonnes of ammunition.[6]

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[2] Sverre Steinbakken et al., ed., *Ammunisjonstjenesten i Hæren etter 1945: Bind 1 [The Army ammunition service after 1945: Volume 1]* (Kolsås: Hærens forsyningskommando, 2000).
[3] F.L.W. Cartwright, "*RAF Bomb Disposal Norway." BBC: WW2 People's war*, 2005, https://www.bbc.co.uk/history/ww2peopleswar/stories/72/a7018472.shtml.
[4] Aftenposten, "Til bunns med død- og ødeleggelsestruselen [Sinking the threat of death and destruction]," *Aftenposten*, 9 October 1945.
[5] FFI, "Lanserer ny karttjeneste for dumpet ammunisjon [Launches new mapping services for dumped ammunition]," Norwegian Defence Research Establishment, Last modified 6 September 2018, https://www.ffi.no/aktuelt/nyheter/lanserrer-ny-karttjeneste-for-dumpet-ammunisjon.
[6] Kystverket, "Status 2006 for tidligere undersøkte vrak med potensiell olje langs norskekysten [Status 2006 for previously investigated wrecks along the Norwegian coast potentially containing oil]," Norwegian Costal Administration, 2006, https://www.kystverket.no/globalassets/beredskap/vrak/vrakrapport_2006.pdf.

In the years following WWII, several governments continued to believe that the best method for disposing of explosive ordnance was to dump it at sea, as the sea was seen to have unlimited absorptive capacity.[7] The sheer amount of ordnance also made it impracticable to store, and the amount of ammunition considered to be in surplus meant that the cost of proper management and/or in-land disposal would far exceed its monetary value.

In many countries, the dumping of ammunition continued on an unparalleled scale after the end of WWII. The dumping even escalated, not only in terms of sheer numbers but also in that the previous limitations in the form of regulatory restrictions, which had been in place for decades, were now systematically ignored. As a result, in many countries, including Norway, both bulk explosives and ammunition were now dumped into waste places, pits, streams, and shallow lakes, seemingly forgetting why there had once been such strict prohibitions against this practice.

Although recognized in general, the risks related to the explosive remnants of war in Norway are little studied. Norway, like many other countries, has gradually taken a "passive monitoring" attitude towards both shipwrecks and other locations known to be heavily contaminated with explosive ordnance.[8] Some measures have been taken to monitor certain locations with raised concern about other contaminating constituents, such as oil and heavy metals, and in some cases, oil has been offloaded from potentially polluting WWII shipwrecks in Norwegian waters.[9] But the risks related to explosive ordnance are normally disregarded and often written off as more of a "hypothetical" risk, as reflected in this statement from The Norwegian Coastal Administration:[10]

[7] Rean Monfils, "The global risk of marine pollution from WWII shipwrecks: Examples from the seven seas," *International Oil Spill Conference Proceedings*, (2005): pp. 1049–1054. https://doi.org/10.7901/2169-3358-2005-1-1049.

[8] Ibid.

[9] Rune Bergstrøm, "Lessons Learned from Offloading Oil from Potentially Polluting Ship Wrecks from World War II in Norwegian Waters," *International Oil Spill Conference Proceedings*, (2014): pp. 804-813, https://doi:10.7901/2169-3358-2014.1.804.

[10] Arne Edvardsen, "Rustne tønner på det tyske krigsvraket er trolig smøreolje [Rusty barrels on the German war wreck are probably lubricating oil]," *Bergens Tidene*, 10 July 2015. https://www.bt.no/nyheter/lokalt/i/6Bq1o/rustne-toenner-paa-det-tyske-krigsvraket-er-trolig-smoereolje

> There is little doubt that there are explosives on board these war wrecks, but the danger of something being triggered is more theoretical. It cannot be stated that it is safe to dive on such war wrecks, but normally it takes a greater external strain for explosives to go off after so many years on the seabed.[11]

It is recognized, however, that the ammunition can contain potentially harmful chemicals, but, even so, a tacit assumption by decision-makers is that, if left alone, the ammunition will slowly become harmless. It is therefore repeatedly stated by official sources that dumped conventional ammunition is not considered to be a major threat to the environment.[12] There is, however, no scientific evidence to support this idea.

History shows us that leaking and bioaccumulation of toxic chemicals from corrosive munitions pose a threat to the ecosystem. It has been known for over a century that several of the chemicals used in ammunition are poisonous to humans, and recent studies show that chemicals from dumped ammunition in the sea may also enter the marine food chain and thereby directly affect human health.

Dumped ammunition, however, represents not only an environmental risk but also a security and safety risk, as the population eventually can come into contact with it, and fear grows that aging munitions can explode and/or be misused. In recent years, several concerns have been raised by the presence of dumped ammunition and explosive remnants of war, and the potential dangers they represent.

Traditional risk assessments, solely reliant on the probability-based risk perspective, on which our national strategy is generally founded,[13] do not take into account the complex risk and coherent uncertainty that dumped ammunition and explosive remnants of war represent. As the probability-based regime provides too narrow an approach to risk and uncertainty assessments, the consequences could be that the decisions are strongly misguided, as important aspects of risk and uncertainty

[11] Author's translation.

[12] Rune Bergstrøm, "Lessons Learned from Offloading Oil from Potentially Polluting Ship Wrecks from World War II in Norwegian Waters," *International Oil Spill Conference Proceedings*, (2014): pp. 804-813, https://doi:10.7901/2169-3358-2014.1.804.

[13] Hæren, *Risikohåndtering [Risk Management]*. Hæren, 2020; Hæren, *UD 2-1 Forsvarets sikkerhetsbestemmelser for landmilitær virksomhet 2020/2021 [The Norwegian Armed Forces Safety Rules and Regulation for Land Based Military Activities]*, Hæren, 2020.

are concealed and/or inadequately described.[14] Nor does it address the strength of the background knowledge on which the probabilistic risk indices are based. This raises a concern that our current risk-mitigating strategy might be founded on what could prove to be incorrect or incomplete information, and that the strategy consequently needs to be revised on the basis of improved risk assessments highlighting the complex risk picture and the strength of the knowledge concept.

In this article, we will first provide an insight into how the strategy has evolved over time and what could be some of the crucial issues facing this strategy, as well as how this strategy could be revised.

The Basis of Our Current Risk-Mitigating Strategy

Early on in WWII, as stockpiles of obsolete and deteriorating ammunition were building up, it became apparent to the relevant governments that their experiences from WWI were being repeated. The waste stockpiles of unserviceable ammunition, together with unexploded ordnance from both training and warfighting, required hasty destruction. Previously, burning or detonation of explosives was often regarded as the most practical solution for disposing of ammunition, but, when faced with larger quantities, dumping at sea could be considered a more relevant disposal technique.

As one contemporary regulation states:[15]

> In the demolition of duds or of large quantities of unserviceable ammunition there are many expedients that have been used. Perhaps the most satisfactory means of disposing of large quantities of ammunition is to dump them at sea. If the proper spot is selected, the dumping ends all further problems and eliminates the handling as well as being the safest method.

[14] Terje Aven, *Risk, Surprises and Black Swans. Fundamental Ideas and Concepts in Risk Assessment and Risk Management* (New York: Routledge, 2014).
[15] US Ordnance School, *Ordnance Field Guide, Volume III (Vol. 3)*, Harrisburg, Pennsylvania: Military Service Publishing Company, 1945.

The same regulation states in another unrelated paragraph, however, that particles found within certain types of ammunition (in this example, white phosphorus) will be poisonous to food and water.

Another regulation[16] correspondingly states that "whenever possible, having due regard to safety in handling, blind and unserviceable ammunition may be dumped in deep water." This regulation emphasizes that dumping in the sea is even a viable solution for disposing of ammunition containing white phosphorus (i.e. a substance used in the manufacture of munitions, pyrotechnics, and explosives considered "extremely toxic to humans)."[17]

The general perception that dumping at sea is considered the safest and easiest way to destroy unusable ammunition was confirmed by *most* relevant documents and regulations at the time. There are, however, some restrictions to be found in *some* of the regulations. Since long before WWI, it has been stated in various regulations[18] that, whilst dumping at sea is considered particularly advantageous, the dumping of explosives or ammunition into waste places, pits, wells, marshes, shallow streams, or inland waterways is absolutely prohibited. This must be viewed in the context of the fact that most of the high-explosive compounds found in ammunition were considered to be poisonous.[19] In yet other contemporary regulations, it was clearly stated that all dumping of ammunition should be avoided, as the explosives could result in future accidents and as the chemical components within the ammunition were considered to be poisonous.[20]

Due to the sheer number of obsolete and unserviceable explosives and ammunition components in and after the two world wars, in addition to a lack of

[16] The War Office [UK], *Regulations for Army Ordnance Services, Part II, Pamphlet No. 4* (London: William Clowes & Sons, Ltd.), 1933.
[17] Environmental Protection Agency, *Phosphouros, A summary* (EPA, 2000). https://www.epa.gov/sites/production/files/2016-09/documents/phosphorus.pdf.
[18] US War Department, *Miscellaneous Ammunition, Ammunition General, TR 1370-A* (Washington: War Department, 1930; US War Department, *Technical Manual - Ammunition, General, TM 9-1900*. Washington: War Department, 1942); US War Department, *Technical Manual - Ammunition, General, TM 9-1900* (Washington: War Department, 1945).
[19] Naval Ordnance Department [UK], *Handbook on Ammunition 1945, B.R. 932 (1945)* (Naval Ordnance Department, 1945).
[20] Riks- og Reservepolitiet, *Veiledning i ammunisjonstjeneste [Ammunition Field Guide]* (Stockholm: Militærattacheen, 1944).

alternative means of disposal, the decision was taken by several governments to dump the ammunition in deep waters. If dumping in deep waters was not practically feasible, for example, due to the chemical or technical condition of the ammunition, time or weather constraints, etc., the ammunition was dumped in the sea wherever it seemed practicable. The personnel tasked with the dumping did not always stick to the rules either, as they were "well motivated to get rid of this stuff as fast as they could,"[21] which meant that, in many cases, the ammunition was dumped on route to the designated dumping area, and not in it.

It seems that this behaviour gradually led to a false sensation that the dumping of ammunition was not regarded as harmful to the environment, and over time the dumping of ammunition escalated enormously.[22] Decision makers (both military and civilian) seemingly forgot earlier warnings about poisonous ammunition constituents, and that the regulations up until then had strict provisions for the dumping of ammunition. Consequently, explosives and ammunition were now dumped not only in deep sea but also in shallow water, waste places, pits, streams, and lakes.[23] This behaviour continued right up until the 1970s and 80s, when, due to the acute pollution situation, the world was once again reminded of the environmental risk that dumped explosives and ammunition represent.[24]

Faced with this "new" knowledge or, rather, old re-confirmed knowledge that the various chemical constituents in the ammunition are not only explosively hazardous but are also frequently of toxic character, most governments discontinued the dumping

[21] Daniel Ross, "Government won't remove thousands of tons of potentially toxic chemical weapons dumped off US coast," *Truthout,* 3 October 2017. https://underwatermunitions.org/2017/10/17/government-wont-remove-thousands-of-tons-of-potentially-toxic-chemical-weapons-dumped-off-us-coasts/.

[22] Jacek Bełdowski, Matthias Brenner, and Kari K. Lehtonen. " Contaminated by war: A brief history of sea dumping of munitions," *Marine Environmental Research*, no. 162 (2020). doi:https://doi.org/10.1016/j.marenvres.2020.105189.

[23] Sverre Steinbakken et al., ed., Ammunisjonstjenesten i Hæren etter 1945: Bind 1 [The Army ammunition service after 1945: Volume 1] (Kolsås: Hærens forsyningskommando, 2000).

[24] United Nations, *Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (with annexes), Signed at Oslo on 15 February 1972*, UN, 1974. https://treaties.un.org/doc/Publication/UNTS/Volume%20932/volume-932-I-13269-English.pdf.

of ammunition as a means of disposing of old and unserviceable munitions.[25] Consequently, the dumping of ammunition was subject to international agreements banning the dumping at sea of hazardous or industrial waste, as stated in the Oslo Convention of 1972 and subsequent amendments.[26]

As dumping of waste material in the sea and pollution from all sources (both military and non-military) proved to have a negative environmental effect,[27] new facilities had to be set up to handle pollution abatement and waste recycling. Contemporary regulations state that "disposal by dumping in the world's oceans (…) has been shown to be not only dangerous but an addition to world pollution and as such, a persistent universal health hazard," and that the former practice of dumping ammunition in deep sea was now to be considered "absolutely prohibited."[28]

The question then subsequently arose of what to do with the millions of tons of explosives and ammunition that had already been dumped. Most governments concerned with challenges related to explosive remnants of war now seemed to take a mutual line of approach in dealing with this problem. A common denominator seems to be that risks related to large accumulations of explosive ordnance, such as dumping areas and shipwrecks, were intentionally neglected.[29]

It was recognized, however, that the ammunition *could* contain some amounts of potentially harmful chemicals, but, nevertheless, a tacit assumption by decision makers was that, if left alone, the ammunition would slowly become harmless over time.

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[25] Jacek Bełdowski, Matthias Brenner, and Kari K. Lehtonen," Contaminated by war: A brief history of sea dumping of munitions," *Marine Environmental Research,* no. 162 (2020). doi:https://doi.org/10.1016/j.marenvres.2020.105189.

[26] Adrian Wilkinson, "Stockpile Management: Disposal and Destruction," in *Conventional Ammunition in Surplus*, edited by James Bevan (Geneva: Small Arms Survey, 2008).

[27] United Nations, *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention),* Adopted on 29 December 1972, UN, 1977. https://treaties.un.org/doc/Publication/UNTS/Volume%201046/volume-1046-I-15749-English.pdf.

[28] US Department of the Army, *Military Explosives TM 9-1300-214,* Department of the Army, 1984.

[29] David E. Alexander, "The strange case of the Richard Montgomery: on the evolution of intractable risk," *Safety Science,* no. 120 (2019): pp. 575-582; Jacek Bełdowski, Matthias Brenner, and Kari K. Lehtonen, "Contaminated by war: A brief history of sea dumping of munitions," *Marine Environmental Research,* no. 162 (2020). doi:https://doi.org/10.1016/j.marenvres.2020.105189.

It was therefore considered a safety measure to make sure that areas contaminated by ammunition, such as dumping sites and shipwrecks, remained undisturbed. This has been the prevailing policy for both Norway and most other countries when faced with an incomprehensible problem such as large accumulations of dumped explosives and ammunition, for which there is no obvious solution, and where the only certainty is that any action will involve a great deal of risk-taking and large-scale costs.

As the explosive objects have been regarded as reasonably stable and safe, as long as they are left undisturbed, the focus on major environmental threats caused by the remnants of war has traditionally been on the risk of contamination of land, water, and soil from other harmful substances, such as the various chemicals, metals or oil found in shipwrecks.

Risk assessments that led to a prioritization of what was to be considered the best possible action on managing the environmental risk regarding remnants of war have therefore typically been based on the type and amount of oil and other dangerous chemicals and metals present,[30] apart from those contained within the ammunition,[31] as well as the assessed environmental vulnerability of the area in which the contamination is located. As far as dumped ammunition is concerned, the view has generally been that, although most of the ammunition could be considered as dangerous today as when it was new, it is also viewed to pose no significant environmental threat by itself. As appearing in various reports regarding the environmental threat represented by various shipwrecks, it has until recently been stated that it is only considered necessary

[30] Kystverket, "Status 2006 for tidligere undersøkte vrak med potensiell olje langs norskekysten [Status 2006 for previously investigated wrecks along the Norwegian coast potentially containing oil]," Norwegian Costal Administration, 2006, https://www.kystverket.no/globalassets/beredskap/vrak/vrakrapport_2006.pdf.; Kystverket, "Sentralt styringsdokument for Miljøtiltak ved vraket av U-864 [Central guidance document for environmental measures at the wreck of U-864]," Norwegian Costal Administration, 2014. https://kystverket.no/oljevern-og-miljoberedskap/ansvar-og-roller/skipsvrak/u-864/; National Oceanic and Atmospheric Administration, "Risk Assessment for Potentially Polluting Wrecks in U.S. Waters," NOAA, 2013, https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/protect/ppw/pdfs/2013_potentiallypollutingwrecks.pdf

[31] Jacek Bełdowski et al., "Sea-dumped ammunition as a possible source of mercury to the Baltic Sea sediments," *Science of The Total Environment*, no. 674 (2019): pp. 363-373. doi:https://doi.org/10.1016/j.scitotenv.2019.04.058

to perform a risk assessment on the explosive objects as such, if there is a risk of disturbing the ammunition whilst performing any work on the wrecks, during survey or oil recovery operations for example, and if there is a possibility that the ammunition could be affected. The only threat to be regarded then is, or so it seems, the threat of a possible explosion occurring as a result of a disturbance of the ammunition caused by some sort of work in an area known to contain explosive ordnance. In addition, no particular attention is paid to any other aspects of ammunition that can prove to represent a societal and environmental risk. Although it is sometimes recognized that the ammunition contains chemical components known to be hazardous to the environment, this is normally not followed by a specific environmental assessment, as ammunition is pre-defined as not to be considered a major environmental threat.[32]

In a White Paper on societal safety and civil-military cooperation from 2004,[33] the Norwegian Royal Ministry of Justice and Police states that there is a need to identify the issues that may arise around the responsibilities for and handling of buried explosives originating from WWII. This is further deliberated in a White Paper on fire safety from 2009,[34] in which it is stated that, if explosive remnants of war are expected to represent an acute threat to life, health or public movement, the government is responsible for removing the risk that the explosives represent, and that it is of vital importance to remove the explosives as soon as possible, so that the public is not exposed to any danger and can feel safe. It continues, however, to deliberate on the fact that, when it comes to dumped ammunition, as well as certain explosive remnants of war, the inter-governmental responsibilities need clarification. The subsequent report regarding these issues[35] states that the explosive remnants of war generally represent no danger where

[32] Rune Bergstrøm, "Lessons Learned from Offloading Oil from Potentially Polluting Ship Wrecks from World War II in Norwegian Waters," International Oil Spill Conference Proceedings, (2014): pp. 804-813, https://doi:10.7901/2169-3358-2014.1.804.

[33] Justis- og politidepartementet, *Samfunnssikkerhet og sivilt-militært samarbeid [Societal safety and civil-military cooperation]* (St.meld. nr. 39 (2003-2004), Oslo: Ministry of Justice and Police, 2004.

[34] Justis- og politidepartementet, *Brannsikkerhet [Fire safety] (St.meld. nr 35 (2008-2009).* Oslo: Ministry of Justice and Police, 2009.

[35] Justis- og politidepartementet og Forsvarsdepartementet, *Ansvarsforhold og håndtering ved funn av eksplosive varer [Responsibilities and handling of explosive goods]* (Oslo: Ministry of Justice and Police and the Ministry of Defence, 2012), https://www.regjeringen.no/globalassets/upload/jd/vedlegg/rapporter/rapport_eksplosiver_2012.pdf?id=2327852.

they lie, as long as one does not physically come into contact with the ammunition. It does, however, include a proviso that, over time, the ammunition will deteriorate and that it may contaminate the environment and that the current risk assessment is based on available knowledge but that there has been just too little comprehensive research to make any general conclusions regarding the risks related to human and environmental safety. The report suggests various recommendations and actions but states that the government must assume overall responsibility for the problem, regardless of whatever authority is responsible for any singular subject matter area. Some of these recommendations have been implemented, especially regarding mapping and further research on implications, but in general the overall strategy remains virtually unaffected.[36]

As to why exactly this blindness-to-risk approach first arose is not easily identifiable. There are an overwhelming number of sources that document not only the potential explosive hazards the ammunition represents but also the fact that some of the constituents are frequently of a toxic character, many of them highly poisonous. Regardless of the origin of the current policy, it has resulted in the avoidance-/ignorance-based strategy that we employ today, which further contributes to the erroneous conclusion that over time the ammunition will become harmless, despite research clearly indicating that the negative consequences related to dumped ammunition and explosive remnants of war may be greater than we first anticipated and that they may still increase over time and as recent studies provide us with new knowledge.

Current Risk Mitigation Strategy

Unexploded ordnance plays an instrumental part in major societal challenges in many countries today. Historically, the risk related to explosive remnants of war has

[36] FFI. "Lanserer ny karttjeneste for dumpet ammunisjon [Launches new mapping services for dumped ammunition]," Norwegian Defence Research Establishment, Last modified 6 September 2018, https://www.ffi.no/aktuelt/nyheter/lanserrer-ny-karttjeneste-for-dumpet-ammunisjon; Mareike Kampmeier et al., "Exploration of the munition dumpsite Kolberger Heide in Kiel Bay, Germany: Example for a standardised hydroacoustic and optic monitoring approach," *Continental Shelf Research* 198, 104108 (2020) doi:http://dx.doi.org/10.1016/j.csr.2020.104108.

typically only been regarded from a one-dimensional perspective: the risk of an unplanned explosion due to physical impact or disturbance of some sort. We have generally focused on disturbances caused by human activity, as either an intended or unintended act, as this generally has been considered to have the greater likelihood of direct consequences, human casualties and/or damage to infrastructure for example. Apart from the personnel directly involved in handling and disposing of such munitions, it seems that the explosives pose especially great risks to children, who may be unaware of the danger.[37] It is predicted that civilian casualties will increase as civilians gain access to formerly inaccessible areas and as interest in and technology for discovering war relics is improving and becoming more readily available to the public. Research also indicates that some explosives can become increasingly sensitive to external stress[38] and have proved to explode spontaneously, even without human interaction.[39]

The risk related to explosive remnants of war is, however, multifaceted, and, aside from the risk of an unplanned explosion, there are more dimensions that need to be considered.[40] While an explosion may be the most apparent danger from unexploded ordnance, there is a more covert threat from munitions' constituents leaking into the ground and water. Primarily derived from explosives, munitions' constituents include residue resulting from munitions that have partially detonated, the corrosion of explosive objects, and the breakage of munitions without detonation.[41] Toxic substances from the explosives can contaminate living organisms, as well as the surrounding soil

[37] Jacqueline MacDonald Gibson and Carmen Mendez, *Unexploded ordnance cleanup costs: implications of alternative protocols* (RAND Corporation, 2005) https://www.rand.org/pubs/monographs/MG244.html.
[38] Richard Albright, *Cleanup of Chemical and Explosive Munitions: Location, Identification and Environmental Remediation* (2nd ed.) (Massachusetts, United States: William Andrew, 2012).
[39] G. Ford, L. Ottemöller, and B. Bapite, *Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004* (British Geological Survey, 2005) https://webarchive.nationalarchives.gov.uk/20121203195642/http://www.mod.uk/NR/rdonlyres/712B6133-E353-4030-9DD0-F677DC3B6F38/0/bgs_beauforts.pdf.
[40] Odd Einar Olsen et al., *Standardization and Risk Governance: A Multi-Disciplinary Approach*. Milton: Routledge, 2020.
[41] Jacqueline MacDonald Gibson and Carmen Mendez, *Unexploded ordnance cleanup costs: implications of alternative protocols* (RAND Corporation, 2005) https://www.rand.org/pubs/monographs/MG244.html.

and groundwater,[42] and may also enter the food chain, directly affecting human health upon the consumption of contaminated food.[43]

The proliferation of Improvised Explosive Devices (IED) by armed groups, resulting from accessible explosive materials of military origin, is also a growing and substantial issue facing the international community.[44] Easy access to military explosive components and the subsequent pilfering of manufactured precursor materials has been a significant driving factor behind the proliferation of IEDs.[45] Various terrorist organizations are tending to increase their use of explosive remnants of war and abandoned ammunition as key ingredients in their IEDs. Security is therefore a serious factor that must be taken into account if, as in Norway, explosives are contaminating wide areas and liable to illicit retrieval and harvesting for use in terrorism or other criminal activity.[46]

As previously mentioned, traditionally, risk assessments related to dumped ammunition and explosive remnants of war have largely been probability-based, in the sense that there has been a strong focus on estimating or assigning probabilities and meeting predefined probabilistic risk acceptance criteria. Over recent decades, the underlying view on risk, as conceptualized in terms of probability, has been challenged, and there has been an increased focus on the knowledge dimension when assessing and

[42] ATSDR, *Toxicological profile for 2,4,6-trinitrotoluene*, US Department of Health and Human Services – Agency for Toxic Substances and Disease Registry, 1995. https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=677&tid=125; Jehuda Yinon, *Toxicity and Metabolism of Explosives*. Florida, United States: CRC Press, 1990; FFI, *Påvirkes fisk og skalldyr av dumpet ammunisjon? – en undersøkelse i fire dumpefelt for krigsetterlatenskaper [Does dumped munitions harm fish and shellfish? – an assessment in four dumping grounds], FFI-Rapport 21/01396*, Norwegian Defence Research Establishment, 2021, https://publications.ffi.no/nb/item/asset/dspace:7168/21-01396.pdf.

[43] Edmund Maser and Jennifer S. Strehse, "Can seafood from marine sites of dumped World War relicts be eaten?" *Archives of Toxicology*, no. 95 (2021): pp. 2255–2261, https://doi.org/10.1007/s00204-021-03045-9.

[44] NATO, *Environmental Impact of Munition and Propellant Disposal*, NATO, 2010, https://www.sto.nato.int/publications/pages/results.aspx?k=RTO-TR-AVT-115&s=Search%20All%20STO%20Reports.

[45] Alex Firth, "The Consequences of Poor Storage of Ammunition Stockpiles and IED usage," AOAV, 20 January 2017, https://aoav.org.uk/2017/consequences-poor-storage-ammunition-stockpiles-ied-usage/.

[46] M.T K. Nordaas, "Ammunisjonen kan bli brukt til bomber i tilsiktede handlinger [The ammunition can be used for bombs in intentional acts]," *Nærnett*, 13 October 2019, https://www.nernett.no/artikler/nyhende/sjodumpet-ammunisjonukjente-konsekvenser; Small Arms Survey, *Unplanned explosions at munitions sites, excess stockpiles as liabilities rather than assets* (Geneva: Small Arms Survey, 2015).

managing risk.[47] One implication is that risk cannot be properly described without addressing the strength of the background knowledge on which the probabilistic risk indices are based.[48] As many aspects of risk assessments related to dumped ammunition and explosive remnants of war are based on assumptions, it will be impossible to truly evaluate and manage the risk related to societal and environmental safety without addressing the level of knowledge on which the assumptions are made. Some assessments can be made on the basis of one or several uncertain assumptions, which can have a significant influence on the risk we face. As the probability-based paradigm provides too narrow an approach to risk and uncertainty assessments, the consequence could be that decisions are strongly misguided, as important aspects of risk and uncertainties are concealed and/or inadequately described.[49]

The *true* risk related to explosive remnants of war consists of a number of factors, the most prominent being the risks of explosion, environmental contamination, and of explosives being misused for criminal activity. Regardless of policy choices, whether active or passive, there will also always be a risk of political, economic, and societal consequences. As these factors are inevitably evaluated based on uncertainties (lack of knowledge), any risk assessments related to these factors will consequently require additional characterizations that can provide further insights into knowledge and lack of knowledge, as well as potential surprises (relative to one's beliefs/knowledge) and surprising extreme events with a very low probability (i.e., "Black Swan Events").[50]

[47] Terje Aven, *Foundations of Risk Analysis*, 2nd ed. (Chichester: John Wiley & Sons, 2012); Terje Aven, "The risk concept-historical and recent development trends," *Reliability Engineering and System Safety*, no. 99 (2012): pp. 33-44; Terje Aven, *Risk, Surprises and Black Swans. Fundamental Ideas and Concepts in Risk Assessment and Risk Management* (New York: Routledge, 2014); Terje Aven and Roger Flage, "Risk assessment with broad uncertainty and knowledge characterisations: An illustrating case study." In Knowledge in Risk Assessment and Management, ed. Terje Aven and Enrico Zio (New York: Wiley, 2018), pp. 3-26.

[48] Christine Louise Berner, "Contributions to Improved Risk Assessments" (PhD diss., University of Stavanger, 2017).

[49] Terje Aven, *Risk, Surprises and Black Swans. Fundamental Ideas and Concepts in Risk Assessment and Risk Management* (New York: Routledge, 2014).

[50] Terje Aven, *Risk, Surprises and Black Swans. Fundamental Ideas and Concepts in Risk Assessment and Risk Management* (New York: Routledge, 2014).

Risk Factors

Risk of Explosion

For the most part, unplanned explosions in explosive remnants of war result from a sudden unintended incident or external stimuli. There are numerous examples of this, but, to mention a recent one, a German WWII aircraft bomb detonated under an aircraft hangar at an airport in Kirkenes in northern Norway in 2019.[51] The investigation concluded that the detonation was the result of a lightning strike.

The structural collapse of shipwrecks, physical alteration of the ordnance, the shifting of ordnance in the tide or deteriorating containers and packaging could all cause sufficient stress to potentially start an explosive reaction. In an ammunition dumping area, one such explosion, through detonation transfer, could evolve into a mass detonation involving hundreds or thousands of tons of explosives.

Unintended detonations can of course also result from human interaction, which greatly increases the risk to human life. In 2019, a Norwegian newspaper[52] reported that human lives could be lost when Equinor ships found dumped war ammunition in an underwater cable route and decided to hoist it on board. According to the newspaper, some of the ammunition exploded when hoisted, and it was sheer luck that no one was hurt in this incident. In December 2020, seven fishermen were injured north of Cromer, Norfolk, UK, when what appears to be a WWII bomb detonated just beneath the hull of their ship.[53] The fishermen were hauling in a line of crab pots when they are believed to have dredged up the unexploded munitions.

[51] Christian Kråkenes, "Lynnedslag traff bombe fra andre verdenskrig [Lightning struck in WW2 bomb]," *NRK,* 24 August 2019, https://www.nrk.no/tromsogfinnmark/lynnedslag-traff-bombe-fra-andre-verdenskrig-1.14672572.

[52] "Gransking: Skudd gikk av da Equinor ryddet kabeltrasé for Johan Sverdrup [Investigation: Ammunition exploded when Equinor cleared cabel route for Johan Sverdrup]," *Stavanger Aftenblad*, 23 September 2019, https://www.aftenbladet.no/aenergi/i/kJXww9/gransking-skudd-gikk-av-da-equinor-ryddet-kabeltrase-for-johan-sverdr.

[53] Nick Enoch, "Seven crab fishermen escape death when their 42ft boat is blasted out of the water 'by a WWII bomb' 25 miles off the Norfolk coast," *Daily Mail*, 23 December 2020, https://www.dailymail.co.uk/news/article-9082601/Norfolk-crab-fishermen-injured-boat-blasted-sea-WWII-bomb.html.

Explosive remnants of war are coming into increasing contact with human activities like development and fishing. Some decades ago, for example, trawlers would rarely trawl below 120 metres; now, they can trawl in depths of 1500 metres,[54] and dumped waste material is becoming much more than a nuisance: it has become a direct threat to life and health. Increased underwater development and utilization of poorly surveyed land can lead to infrastructure being built in explosive-contaminated areas. Sometimes, this is even done on purpose, reassured by a false assumption that the ammunition does not pose any significant risk. In the spring of 2011, a German mine containing several hundred kilos of TNT was discovered right next to a gas pipeline that runs between the Norwegian and British sectors in the North Sea.[55] Any rupture in international pipelines (e.g. oil, gas, electric, communication) due to an explosion could have huge consequences, both economic and environmental.

Recent studies show, however, that explosive objects are not only prone to detonate when disturbed but are also inclined to self-detonate, even without external stimuli.[56] A recent example of this is a 205-kg US aerial bomb self-detonating in a field outside Limburg in western Germany in 2019. Authorities confirmed that the bomb had exploded by itself, without any external trigger, citing the decomposition of the detonator as the probable cause of ignition.[57] According to Wolfgang Spyra, a professor and engineer at the Brandenburg University of Technology in Cottbus, cited in

[54] Rean Monfils, "The global risk of marine pollution from WWII shipwrecks: Examples from the seven seas," International Oil Spill Conference Proceedings, (2005): pp. 1049–1054, https://doi.org/10.7901/2169-3358-2005-1-1049.

[55] Justis- og politidepartementet og Forsvarsdepartementet, *Ansvarsforhold og håndtering ved funn av eksplosive varer [Responsibilities and handling of explosive goods]* (Oslo: Ministry of Justice and Police and the Ministry of Defence, 2012), https://www.regjeringen.no/globalassets/upload/jd/vedlegg/rapporter/rapport_eksplosiver_2012.pdf?id=2327852.

[56] G. Ford, L. Ottemöller, and B. Bapite, *Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004* (British Geological Survey, 2005) https://webarchive.nationalarchives.gov.uk/20121203195642/http://www.mod.uk/NR/rdonlyres/712B6133-E353-4030-9DD0-F677DC3B6F38/0/bgs_beauforts.pdf; M.T K. Nordaas, "Ammunisjonen kan bli brukt til bomber i tilsiktede handlinger [The ammunition can be used for bombs in intentional acts]," *Nærnett*, October 13, 2019, https://www.nernett.no/artikler/nyhende/sjodumpet-ammunisjonukjente-konsekvenser.

[57] Jenipher Camino Gonzalez, "WWII bomb self-detonates in German field, leaves crater," *Deutsche Welle*, 24 June 2019, https://www.dw.com/en/wwii-bomb-self-detonates-in-german-field-leaves-crater/a-49331435.

Deutsche Welle,[58] the self-detonation of WWII-era bombs occurs once or twice per year in Germany. The British Geological Survey[59] has also detected spontaneous explosions in munition-dumping areas and, between 1992 and 2004, a total of 47 underwater explosions has been confirmed in the Beaufort's Dyke area. It is stressed, however, that the database almost certainly remains incomplete, as smaller explosions (< ML 1.5) may not have been detected by the seismic networks or have been detected but discarded, due to past routine practice.

Propellants, primers, and explosives are inherently unstable, and managing them requires comprehensive physical and chemical surveillance.[60] A failure to institute these necessary management practices can cause the ammunition to become unstable, and it may ignite or explode, and its constituents may contaminate the environment. It has been known for over a century that, during the storage of some types of explosives (e.g., propellants), a slow but continuous deterioration occurs.[61] Deterioration may be due to chemical instability (i.e., a natural tendency to decompose slowly, frequently accelerated by impurities or the products of decomposition). For some explosives, the effect of chemical deterioration is decreased sensitivity and/or a loss of efficiency. For others, it may be the opposite. This will be dependent on its unique characteristics, and the presence of various factors such as moisture, metals, temperature, pressure, etc.[62] With propellants, the decomposition may proceed so rapidly as to lead eventually to the formation of sufficient heat to cause spontaneous ignition. Such deterioration can also be caused by changes in the physical condition of the ammunition, brought about

[58] Ibid.

[59] G. Ford, L. Ottemöller, and B. Bapite, *Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004* (British Geological Survey, 2005), https://webarchive.nationalarchives.gov.uk/20121203195642/http://www.mod.uk/NR/rdonlyres/712B6133-E353-4030-9DD0-F677DC3B6F38/0/bgs_beauforts.pdf.

[60] James Bevan, "Introduction," in *Conventional Ammunition in Surplus*, ed. James Bevan (Geneva: Small Arms Survey, 2008).

[61] Small Arms Survey, *Unplanned explosions at munitions sites, excess stockpiles as liabilities rather than assets* (Geneva: Small Arms Survey, 2015); US Army, *Prediction of Safe Life of Propellants, Technical Report 4505,* Picatinny Arsenal, 1973, https://semspub.epa.gov/work/06/9530612.pdf.

[62] FFI, *Pikrinsyre og metallpikrater – dannelse av metallpikrater i dumpet ammunisjon [Picric acid and metal picrates – formation of metal picrates in dumped ammunition] FFI-Rapport 17/00818,* Norwegian Defence Research Establishment, 2017.

by unstable temperatures, ingress of moisture, etc.[63] Physical changes include the melting, freezing or crystalline change of the explosive or any of its components, the absorption of water from damp atmospheres and the loss of volatile constituents.[64]

The probability of self-detonation occurring in ammunition will of course be dependent on several factors, such as type, quantity, structure, material, chemical composition, external milieu, etc. And, although the risk of self-detonation in most cases is considered unlikely, the potential consequences could be extreme. Research indicates that explosive ordnance both can become increasingly sensitive to external stress[65] and is frequently found to explode spontaneously without any human interaction.[66] The risk of self-detonation in ammunition should therefor always be assessed.

Risk of Pollution/Contamination

Up until the end of WWII, the dumping of ammunition was strictly regulated with respect to requirements regarding the dumping site (e.g. depth and distance from the shoreline) and prohibitions as to where and when ammunition was allowed to be dumped. For example, the dumping of explosives or ammunition into waste places, pits, wells, marshes, shallow streams or inland waterways was absolutely prohibited.[67]

[63] Tony DiGiulian, "Naval Propellants - A Brief Overview," *NavWeaps*, 26 March 2022, http://navweaps.com/index_tech/tech-100.php

[64] Naval Ordnance Department [UK], *Handbook on Ammunition 1945. B.R. 932 (1945)*, Naval Ordnance Department, 1945.

[65] Richard Albright, *Cleanup of Chemical and Explosive Munitions: Location, Identification and Environmental Remediation,* 2nd ed. (Massachusetts, United States: William Andrew, 2012); Mick Hamer, "The doomsday wreck," *New Scientist*, 21 August 2004.

[66] G. Ford, L. Ottemöller, and B. Bapite, *Analysis of Explosions in the BGS Seismic Database in the Area of Beaufort's Dyke, 1992-2004* (British Geological Survey, 2005) https://webarchive.nationalarchives.gov.uk/20121203195642/http://www.mod.uk/NR/rdonlyres/712B6133-E353-4030-9DD0-F677DC3B6F38/0/bgs_beauforts.pdf.; M.T K. Nordaas, "Ammunisjonen kan bli brukt til bomber i tilsiktede handlinger [The ammunition can be used for bombs in intentional acts]," *Nærnett,* 13 October 2019, https://www.nernett.no/artikler/nyhende/sjodumpet-ammunisjonukjente-konsekvenser.

[67] US War Department, Miscellaneous Ammunition, Ammunition General, TR 1370-A, Washington: War Department, 1930; US War Department, *Technical Manual - Ammunition, General, TM 9-1900*, Washington: War Department, 1942; US War Department, *Technical Manual - Ammunition, General, TM 9-1900*, Washington: War Department, 1945

This must be viewed in the context of the fact that most of the high-explosive compounds found in ammunition were known to be poisonous.[68]

History shows us that leaking and the bioaccumulation of toxic chemicals from corrosive munitions could pose a threat to the ecosystem.[69] It has been known for over a century that several chemicals used in ammunition are poisonous to humans; in addition, new knowledge shows that chemicals from ammunition dumped in the sea may also enter the marine food chain and by that means directly affect human health. The hazard potential of these chemicals still has to be determined and the exposure to be estimated, e.g. the nature and extent to which animals or humans are exposed to the chemicals. From the combined assessment of the hazard potential and exposure, the actual risk is derived.[70]

Whilst some toxicity studies suggest that chemical components of munitions are unlikely to cause acute toxicity to marine organisms,[71] there is increasing evidence that they can have sub-lethal and chronic effects in aquatic biota, especially in organisms that live directly on the sea floor or in subsurface substrates. These chemicals may also enter the marine food chain and directly affect human health upon the consumption of contaminated seafood.[72] The latter could prove to be of special concern to the

[68] Naval Ordnance Department [UK], *Handbook on Ammunition 1945, B.R. 932 (1945)*, Naval Ordnance Department, 1945.

[69] FFI, *Påvirkes fisk og skalldyr av dumpet ammunisjon? – en undersøkelse i fire dumpefelt for krigsetterlatenskaper [Does dumped munitions harm fish and shellfish? – an assessment in four dumping grounds], FFI-Rapport 21/01396*, Norwegian Defence Research Establishment, 2021, https://publications.ffi.no/nb/item/asset/dspace:7168/21-01396.pdf; Jacek Bełdowski et al., "Sea-dumped ammunition as a possible source of mercury to the Baltic Sea sediments," *Science of The Total Environment*, no. 674 (2019): pp. 363-373, https://doi.org/10.1016/j.scitotenv.2019.04.058; US Army, *Summary Review of the Aquatic Toxicology of Munitions Constituents, ERDC/EL TR-13-8,* US Army Engineer Research and Development Center, 2013, https://apps.dtic.mil/sti/pdfs/ADA583083.pdf.

[70] Edmund Maser and Jennifer S. Strehse," Can seafood from marine sites of dumped World War relicts be eaten?" *Archives of Toxicology*, no. 95 (2021): pp. 2255–2261, https://doi.org/10.1007/s00204-021-03045-9.

[71] Edmund Maser and Jennifer S. Strehse," Can seafood from marine sites of dumped World War relicts be eaten?" *Archives of Toxicology*, no. 95 (2021): pp. 2255–2261, https://doi.org/10.1007/s00204-021-03045-9; FFI, *Påvirkes fisk og skalldyr av dumpet ammunisjon? – en undersøkelse i fire dumpefelt for krigsetterlatenskaper [Does dumped munitions harm fish and shellfish? – an assessment in four dumping grounds], FFI-Rapport 21/01396*. Norwegian Defence Research Establishment, 2021. https://publications.ffi.no/nb/item/asset/dspace:7168/21-01396.pdf.

[72] Edmund Maser and Jennifer S. Strehse," Can seafood from marine sites of dumped World War relicts be eaten?" *Archives of Toxicology*, no. 95 (2021): pp. 2255–2261, https://doi.org/10.1007/s00204-021-03045-9.

Norwegian fish farm industry, as many fish farm sites in Norway are located in the immediate vicinity of ammunition dumping areas.

Many studies of ammunition dumping sites at sea show that several types of munitions are already perforated by water,[73] and whilst some studies at some dumping sites do not yet show any significant ecological effects generated from leakage in dumped ammunition,[74] harmful constituents will, eventually, leak into the environment as ammunition casings continue to deteriorate.[75] Both differences in individual ordnance and local environmental conditions will strongly affect the rate of deterioration. The different chemicals break down and react differently in different environments, and metals corrode at different rates, depending on water depth, salinity, and temperature, as well as on the quality, thickness, and metallurgical composition of the casings. Each type of ammunition and each dumping site, therefore, needs to be considered on an individual basis, and it is not possible to make general assumptions about the properties of a dumping area that have not been thoroughly studied. As the individual properties vary to such an extent, and the rate of degradation of the munition components is heavily dependent on a number of technical- and environmental factors,[76] some ordnance could start leaking after a relatively short time, whilst others can remain intact for centuries[77]. It is therefore virtually impossible to estimate when a peak in the release of munition components will be reached. The explosives within the ammunition will in turn have different properties, which can result in continuous leakage of potentially deadly chemicals from a dumping site for

[73] J. Beddington, and A. J. Kinloch, "Munitions dumped at sea: A litterature reiew," IC Consultants Ltd., Imperial College London, 2005, http://www.environet.eu/pub/pubwis/rura/000ic_munitions_seabed_rep.pdf.
[74] J. Beddington, and A. J. Kinloch, "Munitions dumped at sea: A litterature reiew," IC Consultants Ltd., Imperial College London, 2005, http://www.environet.eu/pub/pubwis/rura/000ic_munitions_seabed_rep.pdf.
[75] OSPAR Commission, *Assessment of the impact of dumped conventional and chemical munitions (update 2009),* OSPAR Commission, 2009, https://www.ospar.org/documents?v=7110.
[76] Jörn Peter Scharsack et al., "Effects of climate change on marine dumped munitions and possible consequence for inhabiting biota," *Environmental Sciences Europe 33,* no. 102 (2021) https://doi.org/10.1186/s12302-021-00537-4
[77] J. Beddington, and A. J. Kinloch, "Munitions dumped at sea: A literature reiew," IC Consultants Ltd., Imperial College London, 2005, http://www.environet.eu/pub/pubwis/rura/000ic_munitions_seabed_rep.pdf.

hundreds of years. The important point to note is that the effect these processes will have on the environment is dependent on their precise location.[78]

This results in the fact that the only way to gain adequate knowledge on the leakage of harmful constituents is to continuously monitor not only the extent at those sites where leakage has already been confirmed but also the sites in which the leakage is expected to occur sometime in the future.

There is an undisputable direct link between the occurrence of dumped munitions and increased concentrations of toxic substances, with implications for the edibility of fish, mussels, and other seafood.[79] Explosives such as TNT and its derivatives are known for their toxicity and carcinogenicity, thereby posing a direct threat to both marine and human life. Furthermore, where it was previously thought that ammunition dumped in deep waters at sea would not affect human life, recent reports now suggest that the metal shells of the ammunition are corroding, such that harmful chemicals are leaking out and being distributed in the marine environment.[80]

A lack of studies conducted on ammunition dump sites makes it difficult to accurately determine the potential environmental consequences of the harmful constituents in dumped ammunition.

Risk of Misuse

Conventional ammunition is in high demand on the illicit market. It is a commodity that has many applications, ranging from misuse of bombs and illegal firearms to unlawful mining and fishing. The use of conventional ammunition, such as

[78] NATO, *Environmental Impact of Munition and Propellant Disposal*. NATO, 2010. https://www.sto.nato.int/publications/pages/results.aspx?k=RTO-TR-AVT-115&s=Search%20All%20STO%20Reports.

[79] Edmund Maser and Jennifer S. Strehse," Can seafood from marine sites of dumped World War relicts be eaten?" *Archives of Toxicology*, no. 95 (2021): pp. 2255–2261, https://doi.org/10.1007/s00204-021-03045-9.

[80] FFI, *Vurdering av følsomhet til dumpet ammunisjon som inneholder TNT [Sensitivity assessment of dumped ammunition containing TNT] FFI-Rapport 18/02521*, Norwegian Defence Research Establishment, 2018, https://www.ffi.no/publikasjoner/arkiv/vurdering-av-folsomhet-til-dumpet-ammunisjon-som-inneholder-tnt; Mareike Kampmeier et al., "Exploration of the munition dumpsite Kolberger Heide in Kiel Bay, Germany: Example for a standardised hydroacoustic and optic monitoring approach," *Continental Shelf Research* 198 , no. 104108 (2020) doi:http://dx.doi.org/10.1016/j.csr.2020.104108.

explosive remnants of war, in homemade bombs (IEDs) is well documented. A significant majority of IEDs in conflict areas are manufactured from conventional ammunition and military explosives,[81] but, although the challenges involving the use of explosive remnants of war are substantially greater in conflict areas like Iraq, Afghanistan, and the Occupied Palestinian Territories, illicit use even in peaceful societies is more common than one would expect. Explosive ordnance is regularly retrieved unlawfully from former battlefields, shipwrecks, or dumping sites, and in many cases, this ammunition is found to be unlawfully trafficked or used in criminal activity.[82] Bombs used in a number of terrorist acts and criminal activities have been found to contain explosives recovered from sunken mines, torpedoes, aerial bombs, or unexploded ordnance left over from World War II.[83] Several governments and international organisations, such as NATO and the UN have also raised concerns regarding WWII ordnance being salvaged for illegal fishing or the construction of homemade weapons.[84] There is an expressed concern that the explosives represent a clear threat to public safety if illegitimately recovered by criminals.[85]

There is also the risk of a deliberate act of sabotage or terrorism, where an explosive object is deliberately detonated in an area heavily contaminated with other pieces of ammunition, such as a dumping site or a shipwreck. Another scenario could involve one or several explosive objects being purposely detonated within a critical range of vital infrastructure (ferries, harbours, gas, oil, power main lines, etc.). Such

[81] Adrian Wilkinson, James Bevan, and Ian Biddle, "Improvised Explosive Devices (IEDs): An Introduction," in *Conventional Ammunition in Surplus*, edited by James Bevan (Geneva: Small Arms Survey, 2008).
[82] Small Arms Survey, *Unplanned explosions at munitions sites, excess stockpiles as liabilities rather than assets* (Geneva: Small Arms Survey, 2015).
[83] Monica Massari, "Guns in the family, Mafia violence in Italy," in *Small Arms Survey 2013: Everyday Dangers*, edited by G. M. Emile LeBrun, et al., (Cambridge: Cambridge University Press, 2013), pp. 75-101; The Scotsman, "Fisherman's WWII bomb find helped Mafia kill 21," *The Scotsman,* 13 November 2012, https://www.scotsman.com/news/world/fishermans-wwii-bomb-find-helped-mafia-kill-21-2468018.
[84] NATO, *Environmental Impact of Munition and Propellant Disposal*, NATO, 2010, https://www.sto.nato.int/publications/pages/results.aspx?k=RTO-TR-AVT-115&s=Search%20All%20STO%20Reports; Rean Monfils. "The global risk of marine pollution from WWII shipwrecks: Examples from the seven seas," International Oil Spill Conference Proceedings, (2005): 1049–1054, https://doi.org/10.7901/2169-3358-2005-1-1049.
[85] M.T K. Nordaas, "Ammunisjonen kan bli brukt til bomber i tilsiktede handlinger [The ammunition can be used for bombs in intentional acts]," *Nærnett,* 13 October 2019, https://www.nernett.no/artikler/nyhende/sjodumpet-ammunisjonukjente-konsekvenser.

scenarios could potentially lead to a severe loss of life or infrastructure and the potential loss of vital military or civilian capacity.

Concerns are raised that dumped munitions are open to terrorist access.[86] Many areas containing huge quantities of highly attractive explosive ordnance are readily available to the public; in some places, large calibre ammunition can even be found openly, next to inhabited areas, at the shoreline, or in shallow waters. Buried ammunition and ammunition located in deeper waters have for many years remained undiscovered and unrecoverable to the public, as the available technology for the most part has been too ineffectual in use or too expensive to obtain. However, in recent years, this has changed considerably, and ammunition that was previously practically unrecoverable is now readily available for anyone with access to a strong magnet, a metal detector, or a relatively cheap underwater ROV.

Whilst it could also be argued in the past that it was an easier alternative for criminals and terrorists to make their own explosives (especially since, traditionally, they had not been too concerned with safety, security or performance), access to many of the required precursor materials is now becoming progressively controlled. High explosive large calibre ordnance is, therefore, increasingly desirable to such actors, and the illicit recovery, proliferation, and misuse of explosive remnants of war, therefore, represents a noteworthy and increasingly important threat to societal safety and security.

Risk of Political, Economic and Societal Consequences

Many factors determine the consequences of an unplanned explosion in dumped ammunition or of explosive remnants of war. Key factors include the proximity to exposed personnel and populated areas, the amount of explosive detonating, the typography of the area, the surrounding environment, and the effectiveness of the emergency response. The impacts may be both direct and indirect, and there may be long-term consequences, like ongoing clearance of unexploded objects, investigations,

[86] NATO, *Environmental Impact of Munition and Propellant Disposal*, NATO, 2010, https://www.sto.nato.int/publications/pages/results.aspx?k=RTO-TR-AVT-115&s=Search%20All%20STO%20Reports.

and the cordoning off of potentially large areas for several years. It is only possible to fully understand and illustrate the risk represented by dumped ammunition and explosive remnants of war with adequate knowledge of these various effects. Unplanned explosions can have a direct and indiscriminate potential to kill and injure, but they can also result in political, economic, and social consequences. Because accumulations of explosive remnants of war often run into hundreds of tons of explosives, if a detonation of any of the explosive objects occurs, it can lead to a mass detonation, with large-scale loss of life, major environmental damage, drastic impacts on local economies and the destruction of important infrastructure.

The effects of such a large-scale explosion would be wide-ranging and long-lasting. Large numbers of unexploded ordnance are likely to be jettisoned from the explosion site, often many kilometres, and people may encounter such ordnance accidentally, or they may seek them out of inquisitiveness or deliberately to harvest the explosives or metals for either commercial or nefarious purposes. It seems that the unexploded ordnance poses an especially great risk to the personnel tasked with the subsequent clearing operation but also to children who may be unaware of the dangers related to them.[87] Casualties could therefore accrue for months and even years after an explosion. In their study on unplanned explosions at munition sites, the Small Arms Survey[88] has found that, although culpability often goes undetermined or unpublished, the political repercussions of some incidents may mean that high-ranking officials do, at times, face sanctions for their role in the incident. They further suggest that, although the political impact may become apparent relatively quickly, information about the underlying criminal and political responsibility is not likely to emerge until an investigation is complete. Regardless of the ownership of the munitions involved, the government has the overall responsibility for upholding public- and national security, and their civil authorities and agencies are responsible for ensuring public safety.[89]

[87] Jacqueline MacDonald Gibson and Carmen Mendez, *Unexploded ordnance cleanup costs: implications of alternative protocols,* (RAND Corporation, 2005) https://www.rand.org/pubs/monographs/MG244.html.
[88] Small Arms Survey, *Unplanned explosions at munitions sites, excess stockpiles as liabilities rather than assets* (Geneva: Small Arms Survey, 2015).
[89] Norwegian Government, *Support and Cooperation, A description of the total defence in Norway*, Oslo: The Norwegian Government, 2018, https://www.regjeringen.no/contentassets/5a9bd774183b4d548e33da101e7f7d43/support-and-cooperation.pdf.

Neglecting or failing in these responsibilities can, however, have severe political implications, even without a large-scale explosion. Even minor explosions or the detection of harmful chemicals in food or in nature will raise the question of whether the authorities did enough to protect their people or simply neglected their duties as elected representatives.

Risk Approach

The Norwegian White Paper on societal safety[90] states that the population shall rest assured that their life, health, and important values are well protected, yet other official governmental reports[91] specify that there is reason to believe that ordnance may, in fact, constitute a potential explosion and contamination hazard and that it is of vital importance that the government removes the explosives as soon as possible so that the public is not exposed to any danger and can feel safe. However, our current risk management strategy is still based on the erroneous assumption that if the ammunition is left alone, it will slowly become harmless over time.

In addition, any assessments made regarding the risk surrounding dumped ammunition and explosive remnants of war must also reflect the uncertainty related to the fact that (some) assumptions are based on incorrect or incomplete information (e.g. cases of insufficient research and overgeneralization). In addition to the strength of knowledge perspective, surprises may also occur relative to the knowledge of the analysts or experts conducting the assessment. When assessing risk, it is therefore imperative to explore the type of situations and events that are of interest and importance to us when discussing unforeseen and surprising events and to

[90] Justis- og beredskapsdepartementet, *Risiko i et trygt samfunn. Samfunnssikkerhet [Societal safety] (Meld. St. 10 (2016-2017))*, Oslo: Ministry of Justice and Public Security, 2017.

[91] Justis- og politidepartementet, *Brannsikkerhet [Fire safety] (St.meld. nr 35 (2008-2009).* Oslo: Ministry of Justice and Police 2009; Justis- og politidepartementet og Forsvarsdepartementet, *Ansvarsforhold og håndtering ved funn av eksplosive varer [Responsibilities and handling of explosive goods]*, Oslo: Ministry of Justice and Police and the Ministry of Defence, 2012, https://www.regjeringen.no/globalassets/upload/jd/vedlegg/rapporter/rapport_eksplosiver_2012.pdf?id=2327852.

conceptualize them, link them to risk, and confront them.[92] A failure to assess and describe the risk relative to the strength of knowledge and potential surprises/black swans will inevitably lead to an inadequately described risk and, in turn, to incorrect conclusions and distorted decision-making biases.

Proposed Solutions

Based on this study, it seems obvious that the essential risks posed by conventional ammunition include a safety risk to the public, a significant security risk to states and societies, and a severe political, environmental, and economic risk. Dumped ammunition and explosive remnants of war will always represent a latent threat, from any perspective.[93]

To enable us to evaluate these threats, we must start by acknowledging the fact that we do not have sufficient knowledge at this time to perform a proper risk assessment. We must then, to the greatest possible extent, establish knowledge of exactly what has been dumped, where it is located, its inherent risks, and possible risk-mitigating measures. The next step would be to carry out individual risk assessments of the various dumping sites and, based on the relevance and feasibility of available mitigating actions, develop a prioritized action plan.

As accurate archives are, for the most part, missing or incomplete, this task could prove to be a mammoth one, probably continuing for years to come. Although the practice of dumping ammunition has now ceased, the damage has already been done. For one thing, there are no complete archives of what exactly has been dumped – or where – and those tasked with the dumping did not always adhere to the rules.[94]

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[92] Terje Aven, *Risk, Surprises and Black Swans. Fundamental Ideas and Concepts in Risk Assessment and Risk Management* (New York: Routledge, 2014).
[93] James Bevan, "Introduction," in *Conventional Ammunition in Surplus*, edited by James Bevan (Geneva: Small Arms Survey, 2008).
[94] Daniel Ross, "Government won't remove thousands of tons of potentially toxic chemical weapons dumped off US coast." *Truthout*, 3 October 2017, https://underwatermunitions.org/2017/10/17/government-wont-remove-thousands-of-tons-of-potentially-toxic-chemical-weapons-dumped-off-us-coasts/.

Several studies[95] have already attempted to identify and assess the extent of harmful constituents leaking from munitions, the possibility of bioaccumulation and whether it can be harmful to marine or human life. As can be expected, when individual properties vary to such an extent, the results are to some degree contradictory. Whilst certain studies do not yet show leakage of harmful constituents at some of the ammunition dumping sites, it is recognized that they will, eventually, leak into the environment as the ammunition casings deteriorate. Some explosives are known for their toxicity and carcinogenicity, and recent studies have shown an undisputable direct link between the occurrence of dumped munitions and increased concentrations of toxic substances, with implications for the edibility of fish, mussels and other seafood.[96] The only way to gain more knowledge on exactly how, and to what extent, harmful munitions' constituents affect human and marine life is to carry out additional research on this topic.

Key factors to determine whether munitions' constituents pose an environmental or human hazard are the quantity and dispersal of munitions within a disposal site, the depth of the disposal area, the effects of currents (e.g. direction, speed), and tidal flushing, and the quantity of munitions' constituents released in a given period of time.[97] These factors should also be registered and monitored regularly for individual dumping sites.

Based on the mapping and available research, individual risk assessments of the various dumping sites should be performed, taking into account the level of knowledge related to the identification and condition of the ordnance and the potential societal and

[95] Jacub Nawała et al., "Analysis of samples of explosives excavated from the Baltic Sea floor," *Science of The Total Environment* 708, no. 135198 (2020), https://doi.org/10.1016/j.scitotenv.2019.135198; FFI, *Påvirkes fisk og skalldyr av dumpet ammunisjon? – en undersøkelse i fire dumpefelt for krigsetterlatenskaper [Does dumped munitions harm fish and shellfish? – an assessment in four dumping grounds]. FFI-Rapport 21/01396*. Norwegian Defence Research Establishment, 2021, https://publications.ffi.no/nb/item/asset/dspace:7168/21-01396.pdf; Jacek Bełdowski et al., "Sea-dumped ammunition as a possible source of mercury to the Baltic Sea sediments," *Science of The Total Environment*, no. 674 (2019): pp. 363-373, doi:https://doi.org/10.1016/j.scitotenv.2019.04.058; US Army, *Summary Review of the Aquatic Toxicology of Munitions Constituents, ERDC/EL TR-13-8,* US Army Engineer Research and Development Center, 2013, https://apps.dtic.mil/sti/pdfs/ADA583083.pdf.

[96] Edmund Maser and Jennifer S. Strehse," Can seafood from marine sites of dumped World War relicts be eaten?" *Archives of Toxicology*, no. 95 (2021): pp. 2255–2261, https://doi.org/10.1007/s00204-021-03045-9.

[97] US Department of Defense, *Research Related to Effect of Ocean Disposal of Munitions in U.S. Coastal Waters* (Washington: US Department of Defense, 2016).

environmental threat the individual site represents.[98] As existing methodology (i.e. probability-based risk assessments) does not to a satisfactory extent consider complex risk and strength of knowledge, such assessments could be severely misleading to the decision-making. It is therefore essential to adapt or develop other methods to serve this purpose. Developing an improved method of risk assessments, by highlighting complex risks and the strength of knowledge concept, could make it possible to perform individual risk assessments of relevant sites and, based on the relevance and feasibility of available mitigating actions, to develop a prioritized action plan for reducing the total environmental and societal risk derived from ammunition dumping sites and explosive remnants of war.

Any positive action on sea-disposed ammunition must of course be balanced against the potential harm to marine life, as well as the increased explosives safety risk to workers and the surrounding communities.[99] The final decision may nonetheless be that the ammunition should be left undisturbed. But it must be stressed that this is then an active policy choice, based on all available relevant facts, rather than a passive policy of ignorance/avoidance. A common mistake by decision-makers is to identify risk-taking exclusively and incorrectly with active policy choices. Passive policies may also entail risk-taking, by attempting to preserve the status quo and ignoring environmental signals that indicate a need for initiative and change. There are no risk-free decisions, including the decision not to decide.[100]

After a given period of time, any implemented actions should then be evaluated in terms of expected and achieved effect, and the risk assessments, action plans, and strategy they are founded on should be evaluated in light of achieved results, recent research, and the development of new knowledge and technology.[101]

[98] Jacqueline MacDonald et al., *Ordnance - A Critical Review of Risk Assessment Methods* (Santa Monica, CA: RAND, 2004).
[99] US Department of Defense, *Research Related to Effect of Ocean Disposal of Munitions in U.S. Coastal Waters* (Washington: US Department of Defense, 2016).
[100] Yaacov Y. I. Vertzberger, *Risk Taking and Decisionmaking - Foreign Military Intervention Decisions* (California: Stanford University Press, 1998).
[101] Terje Aven, *The Science of Risk Analysis* (Oxon: Routledge, 2020).

Conclusion

Research has proved that the complex risk related to explosive remnants of war is comprised of several factors and, whilst the most prominent is regarded as the risk of an explosion, we cannot neglect the potential risk of environmental contamination, the risk of the explosives being misused for criminal activity and the risk of political, economic and societal consequences. Even so, a tacit assumption by decision-makers is that, if left alone, the ammunition will slowly become harmless over time. It is therefore considered a safety measure to see to it that ammunition-contaminated areas, such as dumping areas and shipwrecks containing ammunition, remain undisturbed. This is also the basis of our main risk-mitigating strategy when it comes to large accumulations of dumped explosives and ammunition.

It is clear that dumped ammunition can remain in salt water fully intact and in pristine condition for over one hundred years, but it can also rust so thoroughly in a few decades that only non-soluble explosive filler and a few metal fragments remain.[102] As time passes, the objects will become less and less identifiable, and their chemical and technical condition will become increasingly indeterminate, thus dramatically limiting the number of potentially available risk-reducing actions.

Whilst some may go as far as to call the current risk-mitigating strategy a government-imposed "doctrine of denial,"[103] it may be safe to say at least that it is a strategy built on ignorance and wishful avoidance, and that the employed risk-mitigating action in itself could be acting as a risk accelerator.

There are several risks that the current risk-mitigating strategy does not seem to fully factor in. Likewise, the strategy does not sufficiently differentiate between different risks at various sites, nor does it provide us with sufficient knowledge to consider possible necessary risk-reducing actions or to prioritize where action is

[102] James V. Barton and Steven B. Pollack, "Assessment of Lethal Chemical and Conventional Munitions in the Nation's Waters," *CDC/NCEH*, 2017, https://truthout.org/wp-content/uploads/legacy/documents/2017_1002/CDC_report.pdf.
[103] James V. Barton and Steven B. Pollack, "Assessment of Lethal Chemical and Conventional Munitions in the Nation's Waters," *CDC/NCEH*, 2017, https://truthout.org/wp-content/uploads/legacy/documents/2017_1002/CDC_report.pdf.

needed. This leads to great uncertainty and concern that the current risk mitigation strategy desperately needs to be revised.

Such a revision should describe the need for: mapping, monitoring, and further research; developing an improved method of risk assessments, by highlighting complex risks and the strength of knowledge concept; performing individual risk assessments of relevant sites; and, based on the relevance and feasibility of available mitigating actions, developing a prioritized action plan in order to reduce the total environmental and societal risk derived from ammunition dumping sites and explosive remnants of war.

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