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Synthesizing stakeholder knowledge on submerged munitions in the Baltic Sea: Insights from World Café and Mentimeter engagements

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ABSTRACT

A legacy of submerged munitions remains in European seas decades after the World Wars. This poses significant ecological, security, safety and socio-economic risks to marine biota and humans. This underscores the need for immediate remediation. To synthesize current knowledge, identify gaps and challenges in the risk assessment, and legal frameworks for marine munitions; a stakeholder workshop was held during the Kiel Munition Clearance Week conference (Germany). We used two approaches: the World Café method and Mentimeter – a digital responses tool. Our findings indicate that most stakeholders were concerned about the impacts of marine munitions on the environment, as well as critical infrastructure, security, and safety. Consequently, they indicated that the key criteria for prioritizing remediation should be environmental impacts, presence of critical infrastructure, social well-being, security, and munition casing corrosion. Although the stakeholders indicated that environmental impacts should ideally drive remediation actions, they noted that actions are likely more feasible when justified by the risk to critical infrastructure and security, as these impacts are immediate and visible than ecological impacts. Additionally, the stakeholders identified critical knowledge gaps in national and EU legislative frameworks, environmental impact assessment, and remediation cost. The gaps, knowledge, and stakeholder perspectives synthesized in this study could provide lines of evidence to guide responsible authorities and agencies on what to prioritize and address for effective remediation of munitions in European marine waters. These insights are also relevant to the EU Oceans Pact, 2025, aiming to provide a unified framework for remediating munitions.

1. Introduction

The World Wars left behind a legacy of large quantities of munitions, including conventional explosives and chemical warfare agents, in European seas, causing environmental and safety concerns (Beck et al., 2025; Greenberg et al., 2016; Strehse et al., 2023). The Baltic Sea alone is estimated to contain 40,000 t of chemical warfare agents, including mustard gas and arsenic compounds (HELCOM, 2013).

These submerged munitions pose critical ecological challenges, such as the release of toxic compounds that are harmful to marine organisms, leading to biodiversity loss and degradation of the health of the ecosystem (Barbosa et al., 2023; Maser et al., 2024; Schuster et al., 2021; Strehse et al., 2020). The presence of munitions also presents significant security, safety, socio-economic, and cyber threats, as the potential for explosions can disrupt fishing and shipping activities, as well as destroy underwater and offshore infrastructures (Barbosa et al., 2023; Bueger and Liebetrau, 2023; Mai et al., 2025). The presence of munition-dumping grounds next to critical infrastructure creates additional risk in case of sabotage, as demonstrated by Nordstream explosion (Sanderson et al., 2023). Compounding these challenges, climate-induced changes such as ocean warming and elongated vegetative season are expected to accelerate the corrosion of munition casings, the

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spread of their contents or their transformation to more toxic compounds, thereby increasing the risk of toxic substances leaking into marine ecosystems (Beck et al., 2025; Beck et al., 2018; Popiel et al., 2018; Scharsack et al., 2021). To protect biodiversity, support sustainable marine-based infrastructure, and ensure maritime security and defense, there is a broad consensus among stakeholders to address the impact of submerged munitions.

In response to the challenges posed by submerged munitions, various stakeholder engagements and policy interventions have been initiated at both national and EU levels. A key milestone was the second edition of the "Our Baltic Conference", organized by the EU Commission in Palanga, Lithuania, on 29 September 2023, which had representatives from the eight EU countries bordering the Baltic Sea, except Russia. The conference assessed the progress on the first edition in reducing overfishing and pollution in the Baltic Sea, in line with the EU's biodiversity strategy and zero pollution targets under the European Green Deal. The special focus of the "Our Baltic Conference" was to address threats posed by submerged munitions in the Baltic Sea. Participants expressed concern about the scale of submerged munitions, the associated environmental risks, and the urgent need to address these risks in line with the 2021 Baltic Sea Action Plan (BSAP) developed by HELCOM. A direct outcome of the Palanga conference is the launch of three EU co-funded projects: MUNI-RISK,[1] MUNIMAP,[2] and MMinE-SwEEPER,[3] aimed at assessing risks, mapping and prioritizing sites for munition clearance and remediation, and developing remediation strategies and techniques for submerged munitions. These projects are implemented within the principle of "triple bottom line" and tenets of sustainable marine management (Elliott et al., 2025; Molina and Rajagopal, 2023). Further, to address threats from submerged munitions, particularly on maritime security and safety, the European Ocean Pact (2025) proposed the development of a comprehensive Unexploded Ordnance (UXO) strategy to remove UXO from European waters, starting in the Baltic and North Seas.[4] Broadly, the Ocean Pact aims to bring together EU ocean policies under one single and coordinated framework (European Commission, 2025b). The first pilot project regarding planned large-scale removal of dumped munitions is currently being conducted in Germany.[5]

In assessing the current remediation efforts of submerged marine munitions, MMinE-SwEEPER, MUNI-RISK, and MUNIMAP, EU-cofunded projects, jointly organized a two-day stakeholder workshop to dialogue with stakeholders during the Kiel Munition Clearance Week conference (KMCW; 18–20 June 2025, Germany), a leading platform for stakeholders, innovators, and decision-makers in the field of munition clearance. The goal of the stakeholders' dialogues was to gather current knowledge, identify gaps and challenges in the risk assessment and governance of submerged marine munitions, and to identify lines of evidence to support decision-making on remediation actions. Based on the goal, we focused on the following questions for the dialogues: 1) what are the criteria for prioritizing remediation sites? 2) how should remediation actions be initiated i.e., identifying appropriate methods and activities? and 3) who is responsible for remediation i.e., clarifying legal mandates and responsible entities for remediating submerged marine munitions?

In this paper, we describe the methods used in the workshop, present the results in a structured manner, and discuss the results and their broader implications. Lastly, we conclude with recommendations for future research.

2. Materials and methods

The two-day stakeholder workshop was conducted using two approaches: the World Café method and Mentimeter to capture the views of stakeholders on submerged munitions. World Café is a flexible participatory method used to explore relevant issues or concerns in a conducive, informal and relaxed environment where participants can communicate constructively through collective intelligence for innovative actions (Brown and Isaacs, 2005; McGrath et al., 2023). World Café is structured to ignite collaborative thinking and knowledge sharing among participants (Brown and Isaacs, 2005). Participants are usually divided into small groups for an evolving round of dialogues, switching tables or groups after each discussion session to cross-pollinate ideas and perspectives. This structure encourages active participation from every member, rather than relying solely on individual lived experiences and experimental knowledge (Brown and Isaacs, 2005; McGrath et al., 2023). This method has been used to investigate stakeholder perspectives on social care professionals (Cassarino et al., 2020), assess complex security environments and adaptable solutions (Raisio et al., 2020) and examine key factors that influence the sustainable development of marine-based tourism economy (Prasetiyo et al., 2025; Rania et al., 2025).

Mentimeter, a freely accessible web-based interactive presentation and polling software, enables real-time audience engagement and responses (Khan, 2025). The interactive usability of Mentimeter, including its anonymous response features, enhances engagement and boosts participation, making it a valuable tool for both in-person and online engagement (Khan, 2025). By characterizing responses via voting and ranking, it clearly highlights the priorities of the focus groups, stimulating further discussion (Best et al., 2020). Mentimeter has been used in many studies, including measuring students' satisfaction within groups and across multiple disciplines (Mayhew et al., 2020), assessing teaching strategies (Deshmukh et al., 2025), public acceptance of autonomous vehicles (Loukea et al., 2023) and stakeholder perception on clinical genomic testing (Best et al., 2020).

While most studies use either only the World Café or Mentimeter alongside tools such as interviews, their combined use to explore participant perceptions and knowledge is emerging. The present studies integrate Mentimeter and World Café to provide a comprehensive overview of submerged munitions and deep insights into site prioritization, risk assessment and remediation and the legal and policy regimes, respectively. The preceding sections outline the participant selection, pre-session questionnaire design and the procedures during the World Café and Mentimeter sessions.

2.1. Selection of participants

The World Café and Mentimeter sessions were organized for international stakeholders in marine munitions who attended the KMCW in Kiel, Germany. The stakeholders were invited through multiple channels, including direct invitations to the project's stakeholders, social media channels of the three munition projects, the KMCW website, announcements during KMCW sessions, and the official KMCW program of activities.

2.2. Design of questions for the World Café and Mentimeter

The questions for the World Café and Mentimeter were co-created by partners from the three projects. They were developed based on the project's objective, a comprehensive literature review, and consultations with stakeholders in the field of marine munitions. The questions were thematically structured around three core pillars: 1) identifying and prioritizing sites for remediation, 2) addressing the remediation of identified submerged munitions sites, and 3) the legal and governance

[1] Mitigation of risks Due to submerged munitions for a sustainable development of the Baltic Sea.

[2] Baltic Sea Munitions Remediation Roadmap

[3] Marine Munition in Europe - Solutions with Economic and Ecological Profits for Efficient Remediation

[4] https://oceans-and-fisheries.ec.europa.eu/european-ocean-pact_en#enhancing-maritime-security-and-defence

[5] https://www.bundesumweltministerium.de/en/topics/marine-conservation/unexploded-munitions-in-the-sea

regimes associated with remediation.

Questions (See Appendix 1) posed to stakeholders during the World Café session related to key requirements, protection needs or limitations they face in implementing remediation activities, or important risks to understand and protect before, during and after remediating marine munitions. During the Mentimeter session, questions participants answered included 'For which reason should we clear or remediate munitions in the sea?' See Appendix 2 for the list of questions. Discussions during the Mentimeter sessions were more general and less detailed than those during the World Café sessions, due to the limited interaction of the online platform.

2.3. Conduct of the World Café and Mentimeter sessions

2.3.1. The World Café session

At the start of the World Café session, the leader welcomed stakeholders, shared the objectives of the World Café, emphasizing how participants' contributions can enrich the dialogue on submerged marine munitions and explained the procedures for the World Café. The World Café took place in a private room at the KMCW venue, where we set up three Café Tables, each for one of the discussion topics, i.e., 1) prioritization criteria for remediation and Environmental Impact Assessment (EIA) needs, 2) key considerations, risks, and responsibilities in the remediation of dumped munitions, and 3) legal challenges and the need for regulatory frameworks in munition removal. At each table, two main questions (see Appendix 1) were discussed, facilitated by a Table Host and supported by a Note Taker. The facilitators and note takers were partners from the three projects. At the start of each session, the Table Host welcomed the stakeholders (a maximum of 10 per table), presented the topic for that table and asked the first question (also written on the flip chart). For the first minute, the participants were encouraged to reflect quietly on their responses and write them down on the sticky notes. The responses were then grouped by related ideas and attached to a flip chart by the note taker.

Subsequently, the stakeholders were given 9 min for oral discussions. This was repeated twice, and after 20 min on one table, the stakeholders rotated between tables, creating a dynamic flow of dialogue and enabling engagement with a diverse range of stakeholders. Participants switching tables (while the "Table Host" stays) ensure that ideas from one conversation are carried to the next, enriching the discussion and building on previous insights for deeper exploration. This process was iterative until all participants were at all tables. After three rounds of discussions at each Table Café, the Table Hosts and Note Takers convened and shared the key findings from the World Café with the stakeholders.

2.3.2. Mentimeter

The survey was conducted using the Mentimeter software and facilitated by the Host, a partner of the three projects, in the venue's plenary room. Conference participants responded via their smartphones by scanning a QR code. At the beginning of the session, the Host invited the three project leaders (MMinE-SwEEPER, MUNI-RISK, and MUNI-MAP) to provide a 5-min overview of each project before beginning the interactions with the participants, progressing from broad questions to more specific items. The survey was anonymous; participation implied consent and no personal data was collected. The Mentimeter was configured to one response per device. The Host informed participants that their aggregate inputs will be used for further research and reporting. The questions asked by the Host were visible in the room monitors and, on the participants' phones. Participants had less than two minutes to respond, and the graphic representation of the responses was immediately displayed on the monitors, allowing both participants and the project leaders to discuss and comment.

Using the Mentimeter analytics dashboard, the information collected from the stakeholders was transformed into visual charts, including word clouds, ranking scales, and multiple-choice graphs. The raw data was exported in real time. Some Mentimeter graphics shown on the screens were converted into usable form for publication while preserving the original data.

2.4. Data analysis

In the analysis of the data and insights from the stakeholders' dialogues, we used a thematic analysis approach (Braun and Clarke, 2006). In the first step of the analysis, we used the three research questions to provide a structure for weaving a narrative around the insights, opinions, perspectives, and knowledge shared by the stakeholders. We identified and extracted keywords and phrases used by the stakeholders during the dialogues, notes taken by the Hosts during the interactions, and information captured on the Mentimeter analytics dashboard. The items (words and phrases) identified in the dialogues included: "prioritization criteria", "risk", "remediation", "corrosion and leakages", "legal challenges", "regulatory frameworks", "key needs", "responsibilities in remediation", and "EIA". Subsequently, the items were coded according to the three research questions and then grouped based on emerging patterns, repetitions, and similarities within each question. We stringed related patterns to generate these broad themes and after three reviews: "Concerns of Participants on the Impact of Submerged Marine Munitions", "Remediation of Marine Submerged Munitions" and "Opinions on Legal Challenges Encountered in the Removal of Submerged Munitions".

3. Results

A total of 109 stakeholders participated in both the World Café (n = 16) and Mentimeter (n = 93) sessions. Participants in the World Café session were also included in the Mentimeter session. The organizations the stakeholders represented were from EU countries, except for one, which was based in the USA (Fig. 1). The stakeholders were from diverse sectors, including international government agencies, NGOs, and business and research institutions, focused on addressing the challenges associated with marine munitions.

4. Concerns of stakeholders on the impact of submerged marine munitions

Stakeholders expressed different levels of concern regarding the impacts of submerged marine munitions. The majority of respondents were either extremely (n = 31) or moderately (n = 38) concerned about the risks posed by submerged munitions, while only 2 indicated no concern (Fig. 2).

The primary concern of the stakeholders was linked to the potential negative impact of submerged munitions on the environment (Fig. 3). This was demonstrated through the repeated use of terms such as

Fig. 1. List of host countries of participating organizations.

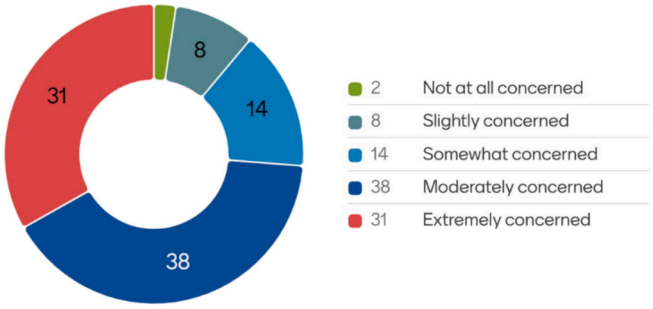

Fig. 2. Stakeholders' concern about the presence of munitions in the sea.

'environmental impacts', 'environmental health', 'pollution', 'environmental contamination' and 'environmental risk' during the World Café and Mentimeter sessions. In addition to environmental concerns, security risks, food chains and construction challenges were also highlighted as major concerns.

4.1. Considerations for the prioritization of sites for remediation action

During the dialogue with the stakeholders, they indicated that the key criteria for prioritizing the remediation of marine munitions were environmental impacts, presence of critical infrastructure, social well-being, security and the extent of casing corrosion.

4.1.1. Environmental consideration

Regarding environmental considerations for remediation, the top priority for the stakeholders was areas near critical habitats, such as fish spawning grounds and marine protected areas (MPAs), due to the high risk of biodiversity loss. Munition sites that pose risks to vulnerable or endangered species were highlighted as requiring urgent action.

4.1.2. Proximity to critical infrastructure

The proximity of the submerged munitions to critical infrastructure was also a key consideration for their remediation. This infrastructure includes both existing and planned offshore energy and telecommunication systems, such as wind farms, underwater cables, and pipelines. Remediating munitions in areas of existing and planned offshore infrastructure is crucial to ensure its safety and stability. Proximity to major shipping lanes and ports was also considered as a key criterion for prioritizing remediation, as munitions may pose significant risks to maritime safety and shipping activities. According to the stakeholders who participated in KMCW, effective spatial planning is crucial for determining the proximity of munitions to critical infrastructure.

4.1.3. Social considerations

Social factors, particularly those related to tourism and recreational use, are a significant consideration for remediation action. Sites near beaches and recreational areas, which are vital to tourism, should be prioritized for remediation. This will ensure public safety and facilitate tourism activities. Public perception and acceptance will also influence remediation efforts, especially in regions where tourism and recreational activities are central to the local economy. This also includes concerns about the impact of munition constituents on local seafood quality. Minimizing disruption and maintaining public confidence will be essential for successful remediation.

4.1.4. Security concerns

The stakeholders also identified security issues related to the potential weaponization of abandoned munitions as a priority for remediation. A key security concern was the potential recovery and exploitation of submerged marine munitions by terrorist groups or rogue states, thereby threatening both national and international security.

4.1.5. Corrosion state and remediation feasibility

The degree of corrosion of munitions casings was highlighted as a consideration for remediation. Munitions that have corroded to the point of being unstable or difficult to remove were given lower priority by the stakeholders.

The ease of remediation was considered as a factor in prioritization, i.e., simpler and more feasible remediation tasks should be prioritized to make initial progress, while more complex sites can be addressed later. As shown in Fig. 4, participants indicated that remediation driven by environmental concerns is considered the most important but the least feasible. In contrast, remediation aimed at protecting infrastructure is viewed as the most feasible, though slightly less important than environmental motivations. Finally, remediation for security reasons is regarded as less important than the other two drivers, yet more feasible than environmental remediation and less feasible than infrastructure protection.

Fig. 3. Main concerns of stakeholders about the presence of munitions.

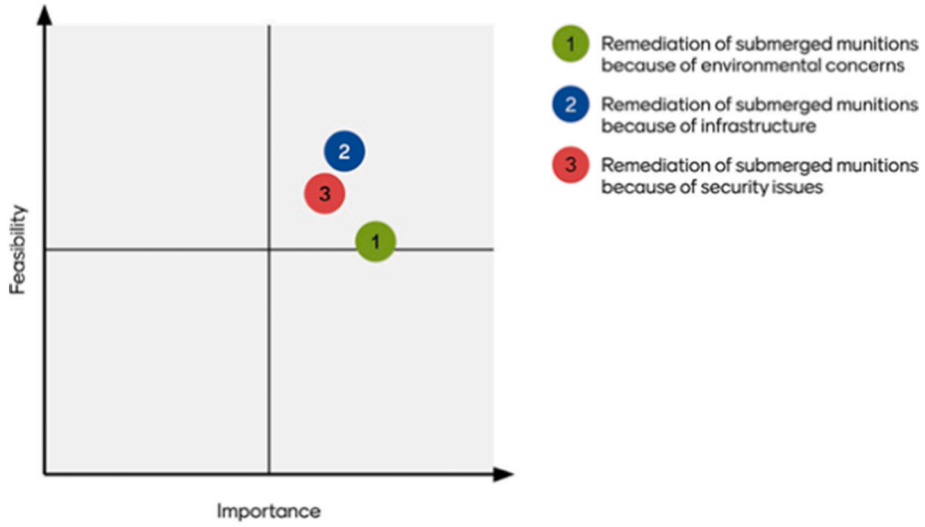

Fig. 4. Ease of remediation actions.

4.2. Environmental impact assessment (EIA) for submerged marine munitions

The need for a comprehensive EIA for marine munitions was highlighted within the context of identifying critical information for understanding the environmental impacts of remediation. The following elements were identified by stakeholders as key to the process:

4.2.1. Direct environmental impact data

An essential component of EIA is the evaluation of the impacts of submerged munitions on marine biodiversity. This includes impacts on species abundance, richness and diversity, vulnerable species and habitats, as well as ecosystem functions and services. Additionally, information on the degree of contamination, both chemical and physical, at munition dumping sites is critical for remediation, as underscored by the stakeholders. Hence, it is important to measure contaminant levels before, during, and after remediation activities.

4.2.2. Munition characteristics

Information on the condition of munitions (e.g., corrosion levels, intactness) is crucial for assessing the risk of detonation and potential leakage of hazardous substances during remediation action. Different types and sizes of munitions present varying challenges and risks. The stakeholders opined that knowing the specific types of munitions involved (e.g., conventional or chemical) helps select the most suitable remediation methods and specialized handling and disposal techniques.

4.2.3. Site-specific environmental characteristics

Characterizing sites for remediation, e.g., sediment type in the area, provides essential context for choosing remediation methods. Sediment composition can influence the spread of contaminants and the methods used to mitigate risks. Additionally, the stakeholders suggested that factors such as dissolved oxygen levels, water temperature, salinity, and other environmental parameters should be included in the EIA to better understand the local conditions that may influence the spread of contamination and the effectiveness of remediation techniques.

4.2.4. Safety risks during and after remediation

The EIA should include safety risks associated with the remediation process as well as the potential contamination from remediation activities, e.g., risks to workers, the public, and marine life. A concern for the stakeholders is underwater noise generated during remediation, particularly during blasting or excavation. It was recommended that the level of underwater noise be documented in any EIA. This is important for understanding the impact of underwater noise on marine fauna, such as fish and marine mammals, which rely on sound for navigation and communication. Another concern was the resuspension of contaminated sediments and their potential transport to other areas.

4.2.5. Cross-cutting aspects and data collection

Several cross-cutting aspects were mentioned as important for a comprehensive EIA: They included 1) retrieving all existing data, such as historical records from the security agencies e.g., the Navy regarding known dumping sites or previous environmental impact studies in the vicinity, which can provide valuable insights into the risks and extent of contamination, 2) reviewing EIAs from nearby infrastructure projects (e.g., offshore energy or shipping lanes), which can provide additional context and identify potential synergies or conflicts with ongoing or planned remediation efforts, and 3) defining the most suitable local disposal methods and assessing local expertise and technologies. These cross-cutting activities are critical for effective remediation, ensuring that the methods chosen are feasible and appropriate for the specific site conditions.

4.2.6. Unified planning and collaboration

The stakeholders were of the view that EIA plans for sites containing unexploded ordnance (UXO) and munitions should be unified across projects, ensuring consistency in data collection, risk assessment, and decision-making processes. Collaborative planning can help streamline the process and align multiple stakeholders, including local authorities, environmental agencies, and contractors.

5. Remediation of submerged marine munitions

5.1. Reasons for remediation

Stakeholders ranked environmental protection as the primary consideration for remediation, followed by security and cost. They suggested that environmental concerns should be central to decision-making in remediation efforts to prevent the release of toxic compounds leaking from the submerged munitions. The reasons provided by stakeholders in support of remediation actions are shown in Fig. 5. Risks to infrastructure and public safety also emerged as prominent motivations for remediation actions. The stakeholders agreed that identified munitions should be removed and managed on land or secured in situ (e.g., cover up only diffuse, wet storage in overpacks) rather than blast in place.

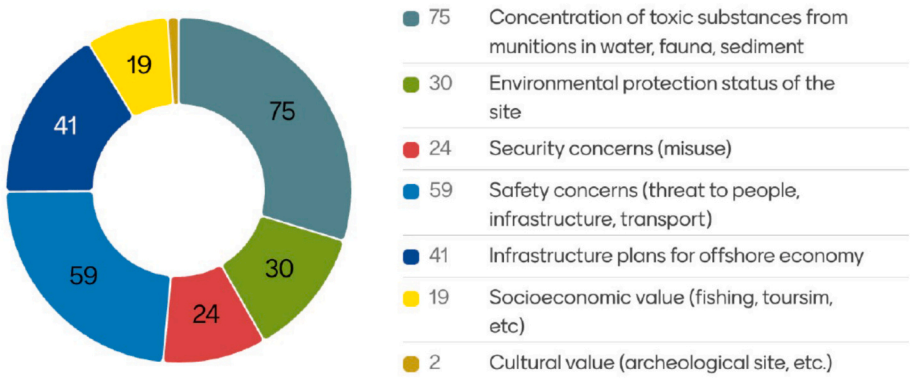

Fig. 5. Reasons given by stakeholders in support of the remediation of submerged marine munitions.

5.2. Feasibility of remediation actions

The stakeholders considered environmental concerns as the most important but least feasible motivation for remediation actions. In contrast, protection of infrastructure was considered the most feasible motivation but slightly less important than environmental concerns. Remediation due to security concerns was also considered less important but highly feasible, compared to environmental and infrastructure concerns (Fig. 5).

5.3. Barriers to remediation action

The major barriers to remediation action relate to cost and who covers the cost (62%), gaps in national legislation (38%) and unclear decision-making on remediation activities (36%). The highly ranked barriers fall within the governance aspects of remediation, i.e., legal regime, regulation and policy frameworks. These barriers hinder remediation action and enable unregulated activities in the sector. Fig. 6 shows the major barriers to remediation action as communicated by the stakeholders.

5.4. Factors to consider in remediation of submerged marine munitions

The remediation of submerged marine munitions, including both conventional and chemical types, requires careful consideration of a variety of factors to ensure operational safety, minimize environmental impacts, and effectively manage associated risks. Responses from the stakeholders highlighted several critical aspects to address during the planning and execution phases of remediation. The responses are organized into categories in Table 1.

Successful remediation hinges on a deep understanding of site conditions and the nature of the munitions present. The stakeholders highlighted the critical role of comprehensive analysis and local knowledge in guiding the selection of appropriate technologies and strategies tailored to specific environmental and logistical contexts. Economic considerations, such as remediation cost and socio-economic effects, were also underscored. Stakeholders stressed the need to balance financial feasibility with long-term environmental stewardship and adhere to legal frameworks to ensure that all activities remain compliant and accountable throughout the remediation process.

5.5. Key risks in remediation of submerged munitions and responsibilities for protection

5.5.1. Key risks to address

The stakeholders at KMCW emphasized that the remediation of marine submerged munitions involves a range of critical risks. These risks fall into three main categories: safety, environmental, and operational concerns.

Safety risks: The stakeholders identified safety risks as a critical concern associated with remediation activities. This is against the backdrop of accidental detonations and the release or leakage of hazardous chemicals, e.g., TNT, during recovery and clearance. It can result in physical injuries and pose short- and long-term health risks to the personnel directly involved in remediation, as well as the immediate communities. According to the stakeholders, accidental detonations may occur via operational errors, such as mishandling munitions, underscoring the need for expert oversight and strict safety protocols during the remediation process.

Environmental risks: These include chemical pollution from disturbed materials, which can contaminate surrounding marine ecosystems. Stakeholders highlighted concerns about habitat destruction and

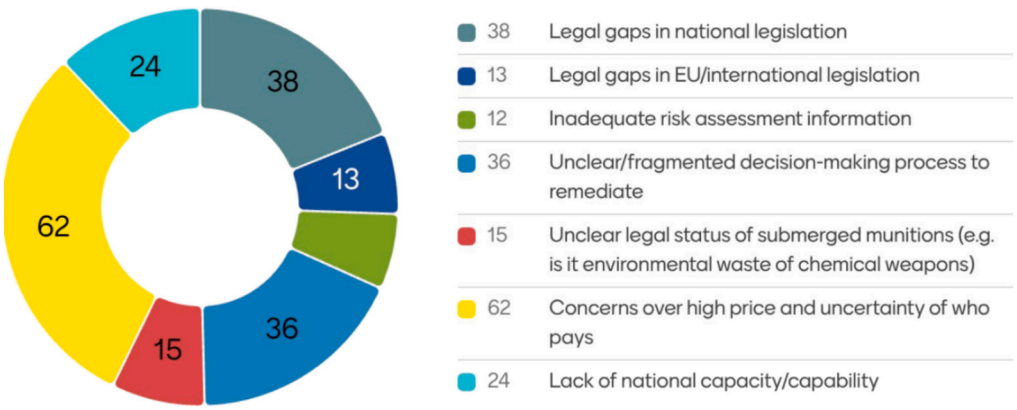

Fig. 6. Barriers to remediation actions.

Table 1
Key considerations for remediation of submerged munitions.

Critical aspects	Key considerations
Ensuring Safety and Minimizing Environmental Impacts	*Environmental safety:* Safeguarding marine and terrestrial ecosystems during remediation is paramount. The use of methods that minimize sediment resuspension, disturbance of spawning grounds, and potential noise pollution from blasting is encouraged. The broader ecological impacts relate to the risk of disturbing ecosystems, such as food webs, which are crucial for the health of marine environments *Human safety:* Protection of workers, as well as local communities, from the risks associated with explosive ordnance disposal and contamination release, is a core consideration. *Operational safety:* Safety procedures and measures to prevent accidental detonation or release of harmful chemicals during the remediation process. *Methodological safety:* Methods for remediation are environmentally safe and minimize significant ecological damage. *Maritime safety:* The specific challenges related to underwater operations, such as dealing with currents, varying sediment types, and ensuring proper safety measures in the marine environment.
Knowledge of Appropriate Methodology and Technology	*Knowledge of the site and contaminants*: Precise knowledge of the location and condition of submerged munitions and surrounding habitat is necessary for prioritization. The identification of high-risk items and their specific removal requirements should be prioritized. *Technological readiness:* The availability of suitable technology to address specific types of contamination (e.g., chemical munitions, unexploded ordnance) and environmental conditions (e.g., underwater ecosystems) must be assessed. *Risk assessment:* A clear understanding of the risks posed to both human health and the environment is crucial. This includes the contamination during disassembly, the spread of pollutants, and the disturbance of local ecosystems. *Success criteria:* Setting measurable, achievable targets throughout the remediation process to monitor progress and evaluate success.
Economic Considerations	*Cost efficiency:* Remediation efforts should be cost-effective while ensuring minimal environmental and human safety risks. *Long-term economic benefits:* While the direct costs of remediation are significant, there is an opportunity for economic growth through job creation, infrastructure development, and the creation of a market for remediation services. *Socio-economic impacts:* The remediation process can have positive or negative socio-economic effects on local communities, including job creation or disruption to local industries. *Costs of inaction:* Failure to address contamination can have long-term economic consequences, including the loss of fishing or tourism industries, and increased health-related costs.
Regulatory and Legal Considerations	*Regulatory awareness:* Understanding which activities are permitted and prohibited in different jurisdictions is essential. Regulations may vary by country, and remediation methods must align with national laws. *Legal flexibility:* A flexible legal framework is necessary to accommodate the challenges of specific remediation projects, which may require adjustments in response to new findings or changing conditions during the process. *Local acceptance:* Gaining approval and acceptance from local stakeholders, including the public and environmental organizations, is important for the success of remediation projects.
Other considerations	*Efficiency and effectiveness:* Remediation methods should be both efficient and effective, achieving the desired results with minimal cost, time, and environmental impact. *Priority setting:* The prioritization of remediation efforts should consider the most dangerous objects first, based on the risk they pose to human and environmental safety.

disruption of food webs, particularly in ecologically sensitive areas. Additionally, underwater noise and shock waves from blasting operations were identified as harmful to marine life and require careful management.

Other risks: The risk to underwater infrastructure, such as pipelines and communication cables, is a critical concern for remediation actions. Security threats, especially the theft or unauthorized handling of explosive ordnance disposal (EOD) materials, were also flagged as concerns requiring vigilant control measures.

5.5.2. Responsibility for managing and mitigating risks

The responsibility for managing and mitigating risk is jointly held by the service provider and the relevant state agencies, says the stakeholders. However, they emphasized that the primary duty for managing risks during remediation lies with the executing company or contractor. They are expected to implement appropriate safety protocols, conduct thorough risk assessments, and apply effective mitigation strategies throughout the remediation process. At the same time, environmental agencies, local governments, and other regulatory bodies play a vital oversight role. Their responsibilities include ensuring compliance with applicable regulations, auditing the remediation process, and approving the proposed plans. The stakeholders emphasized that risk management is a shared, collaborative effort that ensures remediation is carried out safely and effectively.

5.6. Opinions on legal challenges encountered in the removal of submerged marine munitions

The remediation and removal of submerged marine munitions face several legal challenges across jurisdictions. These challenges can be broadly categorized into four main themes: 1) permit requisition, 2) institutional responsibility, 3) political commitment, and 4) the limitations of current regulations.

5.6.1. Permit requisition

The stakeholders at the KMCW reported that permit acquisition process posed significant challenges due to its complexity and inconsistency. They observed that delays in permit approvals, particularly in countries such as Germany, had obstructed timely remediation efforts. In several cases, jurisdictions lacked specific permits for remediation activities, which created regulatory gaps and uncertainty. Stakeholders also encountered difficulties when navigating the diverse legal frameworks across EU member states, which complicated cross-border remediation projects. A stakeholder from the United States stated that they frequently had to obtain multiple permits from various authorities, which introduced bureaucratic inefficiencies and slowed down project implementation.

5.6.2. Regulatory clarity and institutional responsibility

During the World Café, stakeholders highlighted the lack of regulatory clarity and institutional responsibility as a critical impediment to

effective remediation. They reported that existing regulations often contained ambiguities, and institutional responsibilities were not clearly delineated. In the Netherlands, for instance, municipalities with partial responsibility for remediation were described as "difficult to engage" due to administrative complexity. Implementation efforts were further hindered by overlapping governance structures at both the federal and state levels, as in the case of Germany. Stakeholders also noted the absence of a clear distinction between military and non-military remediation responsibilities, with the roles of national defense entities such as naval authorities remaining undefined in many jurisdictions.

5.6.3. Political commitment

Low levels of political commitment also surfaced as a major challenge for remediation actions. The lack of political will may partly be due to misconceptions that equate submerged marine munitions with chemical weapons, which tends to deprioritize the issue on political agendas. This observation was strongly canvassed by a stakeholder within an international governance institutition. There is also the issue of capacity, as not every country has a facility for the destruction of CWA when removed and reported to the Organization for the Prohibition of Chemical Weapons.

5.6.4. Limitations of current regulations

Many legal frameworks governing remediation have not kept pace with technological progress or evolving environmental challenges. This was a major sentiment expressed by the stakeholders. They suggested that existing laws often lag behind current practices, leaving risk assessment procedures either underdeveloped or entirely absent. Environmental risks associated with submerged munitions remain insufficiently addressed, while military restrictions on UXO surveys and the lack of EIAs for clearance operations continue to hinder proactive planning. Oftentimes, clearance operations occur when there is an immediate risk to human life, leaving no time for an EIA. However, in the case of remediation, which involves long-term planning, an EIA can be incorporated. According to the stakeholders, the absence of a uniform regulatory framework across Baltic countries limits the effectiveness of coordinated remediation efforts across borders. While the stakeholders identified that current regulations do not pose significant challenges, others advocated outsourcing remediation under ALARP (As Low As Reasonably Practicable) principles, indicating the need for pragmatic, risk-based legal approaches.

5.7. Opinions on national, european, or international legal frameworks

Opinions of stakeholders were varied on the scope, relevance, necessity and structure of the legal and regulatory frameworks governing marine submerged munition remediation activities. Four broad directions emerged:

5.7.1. Maintaining the status quo

Several stakeholders advocated for retaining national-level legal frameworks, citing the need for country-specific risk responses. They submit that legal diversity is essential for addressing the distinct types and scales of risk present across different regions. This group of stakeholders also expressed skepticism about the feasibility of harmonizing a unified European framework, citing the complexity of aligning diverse national contexts and regulatory traditions.

5.7.2. Developing new legal frameworks

A more forward-looking approach, as suggested by stakeholders, envisions the creation of entirely new legal instruments at the EU or international levels to address the evolving challenges of remediation. Broad support emerged for an EU directive focused specifically on submerged munitions, reflecting the urgency and scale of the issue. Some stakeholders proposed establishing a global legal framework under the auspices of the United Nations to ensure universal compliance and standardized protocols. New legislation is seen as essential not only for enforcing accountability and reducing regulatory ambiguity but also for harmonizing remediation practices across borders. Nonetheless, concerns remain about the slow pace of EU legislative processes, which could delay the timely implementation of such ambitious reforms.

5.7.3. Harmonizing and improving existing legal and regulatory frameworks

Rather than replacing national regulations entirely, contributors proposed a harmonization strategy that aligns existing legal systems under a broader EU or international framework. This approach was seen as a way to streamline remediation efforts and reduce administrative burdens while respecting national contexts. Aligning EU-level regulations with local practices was considered essential for ensuring cultural and operational compatibility. The establishment of a central supervisory authority within the EU was suggested to support implementation and monitor compliance. Importantly, any new legal instruments should be informed by emerging scientific and operational knowledge, tailored to national realities, and designed to foster regional cooperation.

6. Discussions

This study aimed to synthesize stakeholder perspectives on the impacts of submerged marine munitions, knowledge gaps and methodological challenges in risk assessment and remediation, as well as legal regimes governing the sector. Our findings revealed a high level of concern among stakeholders, particularly regarding the environmental impacts and remediation of submerged marine munitions, which Maser and Strehse (2020) described as a "new" source of pollution. These concerns align with public perceptions that the corrosion of submerged munitions would pose a significant risk to Baltic marine ecosystems (Demmler and Stoll-Kleemann, 2025). While stakeholder concerns were based on empirical evidence and their experience working on the topic, the similarity between public and stakeholder concerns could be due to the emerging public awareness of the environmental and health risks associated with submerged munitions. However, in a study commissioned by the EU secretariat on underwater unexploded munition (European Commission, 2022) safety was priotized against environmental concerns at the disposal stage.

The stakeholders' prioritization of environmental protection before, during, and after remediation may be due to growing concerns about exposing marine organisms to toxic chemicals such as 2,4,6-trinitrotoluene (TNT) and mustard gases, as well as to acoustic and pressure risks from accidental or intentional detonation. The prioritization of the environment also aligns with the criteria outlined in the U.S EPA's *Code of Federal Regulations* (40C.F.R. § 300.430, 2025), which states that remediation processes should be based on the overall protection of human health and the environment. The European Union Ocean Pact also recommends adopting precautionary and ecosystem-based approaches to address marine pollution in general. Environmental risk assessment for sites near ecologically sensitive areas, such as spawning grounds and MPAs, is critical for decision-making at the national and international levels (Wang and Pan, 2025). Beck et al. (2025) suggested that incorporating environmental considerations into decision-making can prevent the release of toxic compounds from corroding munitions, thereby protecting biodiversity. Such approach was also applied in the EU DAIMON project, aimed at creating a decision-support system for underwater munition management (Tengberg et al., 2017).

Despite environmental protection being the most important priority, the stakeholders noted that it is the least feasible objective for remediation actions. The limited feasibility may highlight the existing tension between environmental priorities and operational realities, as noted by Pechmann and Hinkel (2025), who suggested that cost, feasibility and policy often override environmental considerations in marine remediation actions. However, in Lübeck Bay (Germany), there are ongoing interventions to demonstrate how cost, feasibility studies, policy

frameworks and environmental concerns can be aligned to commence remediation activities (Bünning et al., 2025; Greinert et al., 2024). The outcome of the interventions in Lübeck Bay would provide options and operational standards for remediating submerged munitions across Europe.

The stakeholders' focus on prioritizing submerged munitions near critical infrastructure, such as offshore energy installations, telecommunication cables, and strategic shipping lanes, is evidently supported by the 2022 Nord Stream pipeline attack in the Baltic Sea. This incident not only caused the resuspension of highly contaminated sediments into the water column (Sanderson et al., 2023) but also triggered energy, economic, and geopolitical consequences across Europe (Virág and Tancsa, 2023). Despite actionable initiatives by the EU and NATO to safeguard critical marine infrastructure, challenges still remain, particularly in clearly defining and categorizing critical infrastructure, which is a political choice (Bueger and Liebetrau, 2023). It is anticipated that the EU Ocean Pact 2025 and the related Act will provide additional policy and regulatory protection for critical marine infrastructure while promoting ocean governance and sustainability.

Social well-being, especially in recreational and tourism zones, was also identified by stakeholders as a key priority for remediation. This is crucial, as coastal tourism represents the largest contributor to the EU blue economy, accounting for 53% of its workforce and 33% of the gross value in 2022 (European Commission, 2025a). However, the presence of explosive lumps, incendiary materials and white phosphorus along beaches poses serious risks to public safety and undermines socio-economic activities dependent on tourism and recreation (GEOMAR, 2025; Weslawski et al., 2006). Similar risks are faced by fishers and other actors in the blue economy value. It is estimated that around 900 munition encounters occur annually in European waters, with nearly half linked to fishing net entanglements (ECA, 2025). The entanglement of the nets affects fishing activities, endangers fishers and threatens coastal livelihoods. Integrating social and economic considerations into remediation planning and action is essential to safeguard blue economy actors and the sustainable use of marine resources.

The potential exploitation of submerged munitions by non-state actors for terrorist purposes, a major security concern identified by the stakeholders, aligns with findings from recent studies (Cumming, 2024; Novik et al., 2023). These studies highlight that weaponization of submerged munitions, whether through salvaging and repurposing components or targeted in situ detonation, threatens local, national and international security, especially when munitions are located near critical infrastructure and/or strategic maritime routes. These threats have become increasingly critical amid rising global geopolitical and socio-economic tensions, which continue to fuel military provocations and hybrid threats. This reinforces the need for remediation to prevent rogue states and individuals from accessing munitions stockpiles for nefarious purposes.

The corrosion state of the submerged munition was also indicated as a key criterion for prioritizing remediation actions. Beck et al. (2025) and Fabisiak et al. (2018) projected that the release of munitions chemicals in the Southwest Baltic Sea will increase as corrosion advances. Similarly, Scharsack et al. (2021) reported that climate change, including rising temperatures and heatwaves, is expected to accelerate the corrosion of munition casings, hence increasing leakage of hazardous compounds. Consequently, it is imperative to consider the corroding state of submerged munitions during remediation, with particular focus on those that have advanced corrosion.

As emphasized by the stakeholders, the remediation of submerged munitions is not solely a technical or environmental challenge but a complex legal and institutional issue. Key issues include bureaucratic complexities with permit requisition, institutional ambiguity, weak political commitment, and obsolete regulations. These views are consistent with the findings of GEOMAR (2025); HELCOM (2024) and Novik et al. (2023), who reported that governance and legal responsibilities of sea-dumped munitions remain dispersed across various international and regional frameworks, with no single comprehensive treaty in place and clearance is only mandated when immediate threats to human safety or infrastructure exist. The weaknesses in these legal frameworks contribute to delays, cost overruns, and regulatory uncertainty in remediation activities (Frey and Kirchner, 2019). Given this, Carniel et al. (2019) suggested an integrated approach, potentially through an EU directive or UN-led framework.

Strengthening existing EU legal frameworks would require integrating an EIA framework and remediation process for submerged munitions. EIA is considered essential by the stakeholders for any remediation action since “it is a key regulatory tool for ensuring environmental protection while fulfilling international law obligations” (Wang and Pan, 2025). The absence of an EIA framework represents a significant gap and a weakness in the legal regime for the remediation of submerged munitions, particularly in areas of increased industrialization and ecosystem degradation (Schutter et al. (2025). EIA for submerged munitions remediation would promote transparency, public trust and ensure compliance with EU and international marine protection laws by selecting the least-harmful actions. Although the stakeholders highlighted the absence of a uniform regulatory framework across Baltic countries, this constraint could be addressed by adhering to the Convention on Environmental Impact Assessment in Transboundary context, ESPOO Convention, (UNECE, 2017). The ESPOO convention obliges parties to undertake EIA at the earliest planning stages and to notify and consult neighboring states regarding activities that may have significant adverse transboundary effects.

Effective remediation requires clarity of institutional responsibilities and accountability. Lack of clarity among actors in the remediation value chain can lead to avoidable conflicts and turf wars at the expense of environmental protection, human safety and security. The current legal framework in the EU reflects regulatory pluralism, where overlapping mandates and unclear jurisdictional boundaries impede decision-making. Defining the role of defense agencies in non-military remediation is therefore essential for improving coordination and operational effectiveness. Addressing submerged munitions would also require adaptive, multi-level cooperation linking environmental, defense, and maritime policy domains and relevant stakeholders.

While the stakeholder dialogues highlighted valuable insights into remediation strategies and the legal frameworks governing submerged munitions, not much was discussed about the impacts of climate change. Climate change, through rising temperatures and heatwaves, can influence the corrosion of munitions and accelerate the rate at which munition compounds are released (Scharsack et al., 2021). Cumming (2024) suggested that climate change may pose risks to munition sites and the marine food web, and Czub et al. (2024) demonstrated that climate change is the second most impactful factor on the accumulation rate and contamination transfer in the marine environment with munitions. It is therefore important that stakeholders in the munition space incorporate climate change mitigation measures in decision-making processes and policy development.

6.1. *Methodological limitations*

The use of Mentimeter during the dialogues did not provide the same depth of engagement and knowledge exchange as the World Café method. While the Mentimeter sessions allowed stakeholders to provide immediate and direct responses, these contributions often lacked detailed insights. In contrast, the World Café sessions facilitated direct face-to-face interaction and iterative discussion, generating deeper reflections on the topic. However, the World Café approach required smaller groups and was considerably more time-intensive and logistically demanding than Mentimeter. The World Café session was further constrained to 16 participants because other parallel sessions were taking place during the KMCW, which limited stakeholder availability. Despite these limitations, the combined use of both methods in this study proved methodologically complementary. Mentimeter broadened

participation and captured a wide range of perspectives efficiently, while the World Café enabled a more detailed exploration of stakeholder insights through sustained, interactive dialogue.

7. Conclusion

This study synthesized stakeholder knowledge and perspectives on the remediation of submerged munitions to establish criteria for prioritizing sites, identify appropriate methods, and clarify legal mandates and institutional responsibilities. Using both the World Café method and Mentimeter for the stakeholder dialogues, we captured the complex interplay among environmental, legal, social, economic, and security factors, providing valuable insights into the challenges associated with remediating submerged marine munitions. These insights may be directly relevant to the fifth strategic priority of the EU Oceans Pact, which aims to develop a comprehensive strategy for the removal of submerged munitions from European waters, starting in the Baltic and North Seas.

Environmental protection emerged as the foremost priority in remediation efforts, with particular emphasis on safeguarding sensitive ecosystems and biodiversity hotspots. This priority aligns with European Commission's objective of increasing the coverage of MPAs. Additional priorities included the presence of critical infrastructure near remediation sites, social well-being, security and the state of munition casing corrosion. While envionmental protection was prioritized by stakeholders for remediation, critical infrasture and security were observed to be more feasible. However, remediation efforts are hindered by fragmented legal frameworks, unclear institutional responsibilities, outdated regulations, limited political will, and financial and technological uncertainties. Moreover, the absence of a coherent EIA framework to guide the remediation of submerged munitions across EU member states is a critical policy gap that requires urgent attention to ensure environmental integrity, biodiversity conservation, and human safety and security in the marine environment.

Despite differing opinions on how remediation should be implemented, there was strong consensus on the need to modernize and harmonize existing legal and regulatory systems through coordinated national, EU, and international efforts. Ultimately, successful remediation depends on balancing safety, environmental stewardship, and technological innovation. It also requires a coordinated, science-based, and legally coherent approach that bridges environmental protection, security, and socio-economic resilience across the European marine space. It is expected that the EU Ocean Pact, 2025 and the Ocean Act by 2027, will provide a unified reference framework for all policies and strategies regarding the remediation of submerged marine munitions.

CRediT authorship contribution statement

Frank Akowuge Dugasseh: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Delove Abraham Asiedu:** Writing – review & editing, Formal analysis, Conceptualization. **Maria del Rosario Dominguez Carrasco:** Writing – review & editing, Investigation, Formal analysis. **Andriy Martynenko:** Visualization, Software, Methodology, Formal analysis. **Agnieszka Jędruch:** Writing – review & editing. **Anita Künitzer:** Writing – review & editing. **Jacek Bełdowski:** Writing – review & editing. **Hans Sanderson:** Supervision, Conceptualization, Funding acquisition.

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Declaration of competing interest

The authors declare that.

- The submitted manuscript has not been previously published and is not currently under consideration by another journal.
- They have no competing financial interests or personal relationships that could influence the findings of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2026.119429.

Data availability

Data will be made available on request.

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