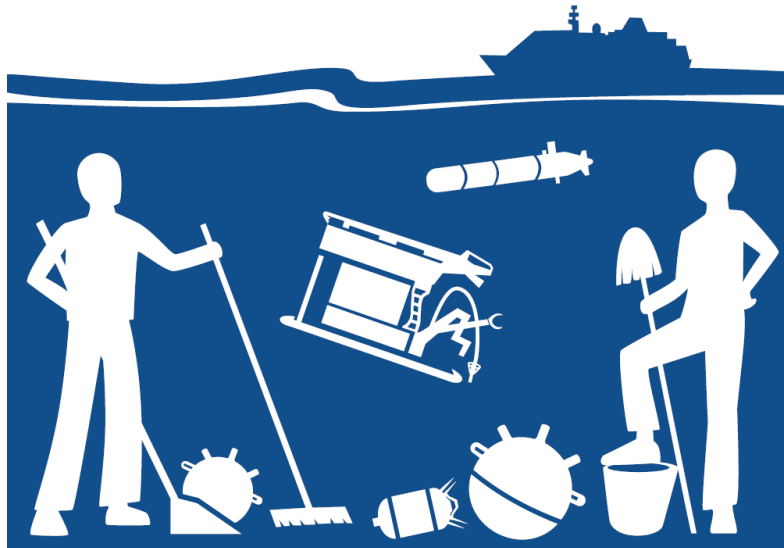




MMinE-SwEEPER

Deliverable Report

Deliverable No. 13.4: Project Report 1



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TECHNICAL REPORT (PART B)

COVER PAGE

PROJECT	
Project number:	101167839
Project name:	Marine Munition in Europe - Solutions with Economic and Ecological Profits for Efficient Remediation
Project acronym:	MMinE-SwEEPER

REPORTING PERIOD	
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Annex: Compilation of Milestone Reports First Interim Reporting Period

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1. EXPLANATION OF THE WORK CARRIED OUT AND OVERVIEW OF THE PROGRESS

Chapter 1 presents the work carried out during the first 18 months of the project. Sub-Chapter 1.1 describes the activities linked to the project objectives, providing brief summaries and references to the relevant deliverables. Sub-Chapter 1.2 presents the work undertaken by the different work packages in more general terms. In several cases, multiple work packages contributed to the same objective. The level of detail is intended to ensure that the reader gains a clear understanding of the work performed, while omitting excessive detail that is provided in the respective deliverables, all of which were submitted on time. In addition, a comprehensive annex of completed milestone reports is included. Some of these interim milestone results already contain substantial content that we considered relevant to include in this report, even though the corresponding final deliverables are due at a later stage. Chapter 1 concludes with the impact we have achieved so far in Sub-Chapter 1.3.

1.1 Objectives

MMinE-SwEEPER has a broad range of objectives aimed at advancing knowledge on marine munitions, their environmental impact, and potential solutions in a comprehensive manner. A total of five objectives have been proposed with each of them having several sub-objectives. These are described briefly below, always starting with a table showing the dedicated milestones or deliverables addressing the respective sub-objective. The following table provides an overview of the deliverables and milestones due for the month 18 report. It also shows to which objective the respective outputs belong and how they are linked to the **12 Examples** of project impacts

Table 1. Overview of the deliverables due for the 18-month interim report.

WP	No	Deliverable Name	Lead	Objectives	Examples
1	D1.1	Stakeholder community	HELCOM	A, D, E	-
	D1.2	Identified needs	AU	A, E	-
3	D3.3	Acoustic camera applications	IOPAN	A, B	6
5	D5.1	Data Management Plan	NORTH.IO	B	9
	D5.2	First data sets collected	NORTH.IO	B, C	9
	D5.4	AI approaches compiled	RMA	A	10
6	D6.2	Magnetics on AUVs	GEOMAR	A	11
8	D8.1	Environmental risk review	AU	A	12
	D8.3	Explosives analysis technologies	GEOMAR	A, B	4
	D8.5	CWA analyses through NAA	IOPAN	A	4
9	D9.1	Onsite LOD and HOD	FFI	A	12
11	D11.1	Report on Historical Data Analyses	KRD-SH	A	1
12	D12.1	Plan for diss. and exploitation	JPIO	E	1
13	D13.1	SAB establishment	GEOMAR	D	-
	D13.3	Project Website	GEOMAR	A, D	2
	D13.4	Project Report 1	GEOMAR	-	-
14	D14.1	NEC - Requirement No. 1	GEOMAR	-	-
	D14.2	EPQ - Requirement No. 2	GEOMAR	-	-
	D14.3	AI - Requirement No. 3	GEOMAR	B	10

Table 2, Overview of the milestones achieved during the first 18 months of the project and their related objectives.

WP	No	Milestone Name	Lead	Objectives	Examples
1	M1	Stakeholders enrolled	HELCOM	D	2
1	M2	Stakeholder Workshop 1	AU	A, D	2
2	M4	Workshop on „responsibilities and legal framework”	HELCOM	A, D	2
2	M6	Workshop on ‘assessment and decision-making’	AU	A, D	2
3	M7	First compilation on best practices of hydroacoustic spatial mapping	FFI	A	6
3	M8	First compilation of best practices of optical studies and photogrammetric reconstructions	GEOMAR	A	6
5	M11	Initial data platform is set up	North.io	B	9
5	M12	First AI-models and code for detection on spatial data	RMA	B	6
5	M13	First AI-models and code for detection on optical/acoustic camera data	IOPAN	B	6
7	M16	Mission control report	SeaTerra	B	5
8	M18	Samples for baseline chemical analysis collected from project stakeholders	AU	A	3
10	M19	Planning of trials in “artificial mine gardens”	GEOMAR	C	2
10	M20	Application for ship time and cruise planning	GEOMAR	C	2
11	M21	First training materials (munition detection/remediation and environmental studies)	IOPAN	D	2
13	M22	Digital news, newsletter and social media	GEOMAR	D	2
13	M23	Project flyer	GEOMAR	D	2
13	M29	Project Kick-Off meeting	GEOMAR	-	-

Objective A: Compile existing knowledge and management approaches

Objective		Deliverables during reporting period	Milestones during reporting period
A1	Compilation of country-specific management of marine munitions	(D2.1, not part of this reporting period but work started).	
A2	Compilation of stakeholder needs	D1.1; D1.2	M2; M4; M6
A3	Compilation of state-of-the-art and newly generated knowledge	D3.3; D5.4; D6.2; D8.1; D8.3; D8.5; D9.1; D11.1	M7; M8; M18
A4	Gather information from other national and international projects	D13.3	

A1. Compilation of country-specific management of marine munitions (main contributing WPs: 1, 2)

Although there are no deliverables yet that directly address this objective, work towards D2.1 “Responsibilities” was already initiated during this reporting period by cooperating with the parallel running MUNIMAP¹ project. The objective of D2.1 is to compile the management procedures, responsible bodies, and policy frameworks used across Europe for addressing sea-dumped munitions. The MUNIMAP policy report collects, among other things, information on regulations and responsible authorities from the Baltic Sea Member States, including the Skagerrak area. Building on the main outcomes of MUNIMAP’s report, MMinE-SwEEPER has developed a follow-up survey

¹ <https://interreg-baltic.eu/project/munimap/>

and distributed it to countries in the North Sea, the Mediterranean and the Black Sea. The survey closed at the end of April 2026, and its results will be incorporated into D2.1 to be submitted at month 24 (end of September 2026) and shown in the second interim report.

A2. Compilation of stakeholder needs (main contributing WPs: 1, 2)

Three milestones and one deliverable were added to this subobjective.

Deliverable 1.2 “Identified Needs” (Lead AU): The needs assessment was co-created with activities within the MUNIMAP and MUNI-RISK² projects. The needs underpinning this deliverable were identified through stakeholder consultations conducted via an online survey (with results summarized in a manuscript currently under review), online workshops, and in-person meetings with stakeholders during the United Nations Ocean Conference (UNOC; Nice, June 2025), and the BANOS Conference (April 2025). Additional input was gathered through workshops held during the Kiel Munition Clearance Week (June 18-20, 2025), as well as through a review of published literature and policy reports (e.g., the ICF 2022 final report on underwater unexploded munition). The results of these interactions are summarized in Dugasseh et al. (2026)³ and will also be compiled in D1.3, to be delivered in month 26. During these engagements, the primary concerns and needs of stakeholders were expressed in three thematic areas: (1) environment, (2) economy, and (3) security and safety. The paper by Dugasseh et al. (2026) synthesized current knowledge, gaps, and challenges in risk assessment and legal frameworks for marine munitions from 109 stakeholders and concluded that environmental protection emerged as the foremost priority in remediation efforts, with particular emphasis on safeguarding sensitive ecosystems and biodiversity hotspots. The second paper, titled *“Remediation of Submerged Marine Munitions in European Seas: Stakeholder Priorities, Requirements, and Constraints”* has been submitted to *Marine Policy* (Asiedu et al.) and is currently in review. The paper, based on responses from 52 stakeholders, identified stakeholders’ needs, constraints, and priorities for remediating submerged marine munitions across Europe. The task is on time and has reached its defined achievements for the period.

Milestone 2 “Stakeholder workshop 1” (lead AU): The workshop was held physically at the Kiel Munition Clearance Week (June 18-20, 2025). It was a two-day workshop consisting of: i) a “World Café” with three thematic tables – the “Legal aspects”-table was organized in coordination with MUNIMAP to compile inputs for Milestone 4 – and ii) a “Mentimeter” with general questions asked in the plenary session. Results of these two-day sessions are compiled especially in Deliverable 1.3, Synthesis of findings (DL month 26), and in the scientific publication Dugasseh et al. (2026).

Milestone 4 “Workshop on Responsibilities and Legal Framework” (lead HELCOM): This workshop was organized in close coordination with the MUNIMAP project and conducted through two activities: i) a thematic island on “Legal Aspects” during the side event titled “No Time to Waste: Tackling Submerged Munitions in European Seas” on 11 June 2025 at the United Nations Ocean Conference (UNOC); and ii) the “Legal Table” of the World Café at KMCW. At the UNOC side event, MUNIMAP and MMinE-SwEEPER jointly prepared a thematic island and a factsheet on the “Legal Framework for Marine Munition Remediation”⁴. The event featured a high-level panel of scientists, policymakers, regional coordinators, and EU leaders, followed by thematic discussions. With more than 80 participants from around the world, it offered an excellent opportunity to present and discuss initial findings on the limitations of the current regulatory framework for addressing marine munitions in an environmentally sound and secure manner in the Baltic Sea region.

Milestone 6 “Workshop on ‘assessment and decision-making’ (lead AU): The workshop was held online on 24 February 2026 under the title “Why and how should we remediate sea-dumped munitions – and how does/should the EU Ocean Pact impact this?”. It marked the midpoint of the ongoing stakeholder dialogue on key concerns and needs related to the remediation of submerged marine munitions, initiated by MMinE-SwEEPER in 2025. Building on previous stakeholder activities and findings (D1.1 Stakeholder community, D1.2 Identified needs, Dugasseh et al. 2026), participants discussed and further refined key lines of evidence from earlier dialogues and identified additional evidence gaps. The workshop also addressed stakeholder perceptions of the implications of the EU Ocean Pact for decision-making needs, concerns, and funding priorities for remediation activities.

² <https://muni-risk.eu/>

³ <https://www.sciencedirect.com/science/article/pii/S0025326X2600216X>

⁴ https://mminesweeper-munition.eu/02_resources/downloads/factsheet-unoc-6LegalAspects.pdf

A3. Compilation of state-of-the-art and newly generated knowledge (main contributing WPs: 3, 4, 5, 6, 9)

This sub-objective has a great number of deliverables that add to the envisioned compilation of knowledge. Deliverables from five work packages are briefly explained.

Deliverable 3.3 “Acoustic camera applications” (lead IOPAN): The first achievement of the related Task 3.3 was the compilation of best practices for hydroacoustic camera data acquisition, especially for 2D mapping in low-visibility environments. The deliverable report translates the physical constraints of forward-looking sonar into practical survey guidance, including recommended grazing angles, maintaining constant altitude where possible, using short operating ranges, avoiding roll, maximizing frame rate for the selected range, and planning smooth single-track or overlapping multi-transect trajectories. It also defines a measurable track-spacing rule based on range and field of view, making the guidance directly applicable in field operations. Identification workflows were established based on example datasets. The deliverable documents a complete 2D acoustic mosaicing workflow, from frame-to-frame registration and sequential alignment to global optimization and image blending. As a result, four example datasets acquired in 2025 were processed into acoustic mosaics. The documented datasets were collected using the Blueprint Oculus 1200d at 1.2 MHz and 2.1 MHz, providing a concrete and measurable basis for further algorithm development.

Deliverable 5.4 “AI approaches compiled” (lead RMA): The latest advancement in Machine Learning (ML), Deep Learning (DL) approaches, and the development of Artificial Intelligence (AI), used for maritime applications were presented in D5.4. The deliverable report includes the latest literature published in papers describing how the object detection, and classification are performed using acoustic and optical data. The objective of this deliverable is to provide a knowledge base that supports the development of robust, and reliable AI systems within the project. The presented methods are expressed in details and compared with each other. That will support the selection of the approach that will give the best results, and achieve high precision.

Deliverable 6.2 “Magnetics on AUVs” (lead GEOMAR): We compiled knowledge about the use of AUVs for magnetic surveys. Particularly we focus on a recent development at GEOMAR where AUVs with hiver capability were used with four flux-gate magnetic sensors in a gradiometer-like assembly. The results build on the started developments in the EU funded BASTA project and the further development of SMART AUVs within the SAM project. In MMinE-SwEEPER we will use the development stage to further advance AUV autonomy including hydroacoustic, optical and magnetic sensors for munition detection up to munition identification.

Deliverable 8.1 “Environmental Risk Review” (lead AU): Essential for evaluating environmental risks for future assessments in European waters is a compilation of what is known from previous studies. Particularly recently ended or still ongoing projects are continuing to generate data on toxicity levels of explosives or enhance the data set about concentration levels in European waters. Increasing the number of European-wide concentrations of explosives is also a task in work package 8 of MMinE-SwEEPER. Deliverable 8.1 gives a fundamental understanding of the state-of-the-art and contains a longer reference list that can be used for further reading.

Deliverable 8.3 “Explosives analysis technologies” (lead GEOMAR): For evaluating the environmental impact of marine munition it is vital to analyse in a reasonable short time, concentrations of typical explosive substances like TNT, RDX, DNB or metabolites of TNT as 2- or 4-ADNT. The Deliverable gives an overview of used technologies and where MMinE-SwEEPER is going to increase technical capabilities through the extension of the Xplotector Lab-in-a-Box System and the Fraunhofer ICT electrochemical sensor. The Xplotector now being advanced in MMinE-SwEEPER was originally started as a development as part of the EU-funded ExPloTect project.

Deliverable 8.5 “CWA analyses through NAA” (lead IOPAN): During the reporting period, significant progress was made under Task 8.3 towards Deliverable D8.5, focusing on advancing Neutron Activation Analysis (NAA) for the non-invasive, in-situ identification and classification of chemical warfare agents (CWAs) versus conventional munitions. The work included comprehensive Monte Carlo simulations to design and optimize an NAA-based sensor comprising a neutron generator and a gamma quantum detector mounted on a Remotely Operated Vehicle (ROV). Researchers evaluated the sensor's performance based on the detector-to-target distance and the varying thicknesses of munition shells and ship hulls. Following theoretical modeling, experimental trials were conducted in a simulated aquatic environment. These trials utilized surrogate materials, including melamine (to simulate explosives) and NaCl (to simulate the chlorine signal present in CWAs like mustard gas and

Adamsite), assessing elemental signals through a layer of water. To achieve the highly specialized nuclear physics testing, IOPAN successfully prepared and executed the entire tender procedure. Through this procurement process, IOPAN engaged experts from the Jagiellonian University, who executed the theoretical Monte Carlo simulations and laboratory irradiation experiments using fast neutron generators.

Deliverable 9.1 “Onsite LOD and HOD” (lead FFI): The clearance of munition is often done by detonating the respective munition object in place (blast in place operations = BIP) either as high order detonation (HOD) or low order detonation (LOD). The deliverable of work package 9 describes the environmental problems related to these two methods; HOD creates high pressure waves that endanger sea life, including mammals; LOD distributes much toxic explosive substances into the environment. This deliverable summarizes relevant information, gives a longer reference list and will be used later in work package 9 to also discuss mitigation measures e.g. for HOD operations.

Deliverable 11.1 “Report on Historical Data Analyses” (lead KRD-SH): Historical data analyses are one of the very first steps when aiming at investigating marine areas for developments as part of Blue Growth ambitions (e.g. off shore wind) and other infrastructure activities. They are the main task in the first phase of the four-phase marine EOD process. The deliverable gives an overview of classical “manual” analyses and shows an AI-supported approach from two partners of the MMinE-SwEEPER consortium (KRD-SH and north.io).

Milestone 7 “First compilation on best practices of hydroacoustic spatial mapping” (lead FFI): Milestone 7 represents a draft report on methods and best practices for Multibeam Echosounder (MBES), Side-scan sonar (SSS) and Synthetic Aperture Sonar (SAS) approaches. The final version of this report is Deliverable 3.1 which is due in Month 40 of the project. The aim of this report is to provide stakeholders with comprehensive and complete background information about underwater munition mapping techniques using sonar. That information should enable them to weigh up the options and make the right decisions on sonar-based survey technology for detecting, localizing and classifying marine munitions on the seabed.

Milestone 8 “First compilation of best practices of optical studies and photogrammetric reconstructions” (lead GEOMAR): This milestone provides the initial update on Deliverable D3.2. It reports on the deliverable’s status, summarizes the content prepared so far, and outlines the next steps. The aim of Deliverable D3.2 is to equip stakeholders with comprehensive background information on optical underwater munition mapping and processing techniques. This information is intended to support informed decision-making by presenting the advantages and limitations of the different methods.

Milestone 18 “Samples for baseline chemical analysis collected from project stakeholders” (lead AU & GEOMAR) describes in short, the success in establishing contacts with different stakeholders, who are willing to sample water from different sea basins around Europe. The number of supporters is constantly increasing and we hope to generate a much better scientifically sound data base by the end of the project.

A4. Gather information from other national and international projects (main contributing WP2: 12 & 13)

To gather information from other national and international projects partner JPI Oceans has established a Communication Coordination Group between the various European and national research projects working on the topic of munitions in the sea. Through this group, which meets bi-monthly, summaries of the various projects were collected and compiled in the Munitions in the Sea booklet⁵, which can be downloaded from the project website as well as on the JPI Oceans Munitions Portal.

Objective B: Advance robotic applications, 3D imaging and AI-supported data analyses

Objective		Deliverables during reporting period	Milestones during reporting period
B1	Secure exchange of sensitive data and cloud-based analyses	D5.1; D5.2	M11
B2	AI-supported munitions detection and classification in acoustic seafloor data	D14.3	M12;

⁵ https://mminesweeper-munition.eu/02_resources/downloads/Munitions_booklet_October_2025.pdf

B3	3D munition-object reconstructions from optical and acoustic data	D3.3	
B4	AI-supported image-based object classification and identification		M13
B5	Smart-AUVs through optic and acoustic sensing		
B6	Cooperative operation of several robotic vehicles		
B7	Grabbing System		M16
B8	Establishing the state of corrosion of munition		
B9	Faster and more precise chemical analyses of explosive compounds	D8.3	

Several of the deliverables and milestones for these objectives first compile the state-of-the art with respect to the different sub-topics

B1. Secure exchange of sensitive data and cloud-based analyses (main contributing WP: 5)

In addition to the hardware and software developments ongoing for the different sub-objectives in objective B, a secure exchange of data is essential. Already during the project phase, we decided to use the north.io TrueOcean platform for this. As part of the setup and development of this platform, some deliverables and milestones were reached within the first 18 months of the project.

Deliverable 5.1 “Data Management Plan” (lead north.io): To establish a common basis for secure data handling, a dedicated data management plan (DMP) has been developed under Task 5.1 with input from project partners and SEB members. This deliverable outlines, based on the FAIR principle (Findability, Accessibility, Interoperability, and Reusability), how data is being handled, what kind of data is being used and on what platforms. Within the MMinE-SwEEPER project three platforms are used for different purposes: the GEOMAR Cloud for secure internal communication and document management, the JPI Oceans Knowledge Portal Munitions in the Sea as a public repository for references and information, and north.io’s TrueOcean Data Platform for the storage, processing, and collaborative analysis of sensitive geospatial marine survey data.

Deliverable 5.2 “First Data Sets collected” (lead north.io): Deliverable 5.2 documents the compilation of the first consolidated datasets within Work Package 5 and contributes primarily to Objective B1 – secure exchange of sensitive data and cloud-based analyses. Building on the previously deployed TrueOcean data platform, the consortium has now operationalised the environment for collaborative data management and exchange of sensitive marine munition information. The platform supports structured storage, controlled sharing, and geospatial visualization while ensuring that data sovereignty remains with the respective partners and that access rights are clearly managed. A major outcome of this deliverable is the successful compilation of a substantial and heterogeneous dataset. To date, more than 22,000 files with a total volume of approximately 275 GB have been collected within the platform. The data inventory includes raw and processed hydroacoustic survey data, raster and vector geodata, optical imagery, video material, and supporting documentation. These datasets originate from both historical partner repositories and newly generated project data, ensuring continuity between existing knowledge and current project activities.

Milestone 11 “Initial data platform is set up” (lead north.io): Milestone 11, embedded in Task 5.2, marks the first step toward achieving secure data exchange and cloud-based analysis capabilities within the project (Objective B1). The milestone was achieved through the deployment of an initial data platform, providing the consortium with a secure environment for storing and sharing project data. The dedicated TrueOcean instance was deployed on 9 October 2024 and is exclusively accessible to members of the MMinE-SwEEPER consortium. To support the operational use of the platform, three onboarding seminars were conducted in the fourth quarter of 2024, introducing partners to the platform’s functionalities, workflows, and data management procedures.

B2. AI-supported munitions detection and classification in acoustic seafloor data (main contributing WP: 5)

Milestone 12 “First AI-models and code for detection on spatial data” (lead RMA): Milestone report 12 presents the first results of Task 5.5, focusing on the development of artificial intelligence (AI) methods for detecting potential unexploded ordnance (UXO) in spatial

hydroacoustic data thereby addressing Objective B2. The work builds on datasets compiled in Task 5.2 and algorithmic developments from Task 5.4. Two complementary AI approaches were developed by RMA and north.io. The RMA approach applies supervised object detection to side-scan sonar imagery using a deep learning model based on the YOLOv11 Nano architecture. A dataset of annotated sonar images containing mine-like objects was used for training, including data pre-processing, augmentation, and model evaluation. The model achieved promising detection results, demonstrating the feasibility of automated UXO detection in sonar images.

The north.io approach follows an unsupervised anomaly detection strategy based on spatial point-cloud data derived from hydroacoustic measurements. A convolutional autoencoder combined with a Local Outlier Factor analysis identifies deviations from typical seabed patterns and produces spatial anomaly maps indicating potential objects of interest. Trials have been run on side scan sonar data sets and are currently being extended.

B3. 3D munition-object reconstructions from optical and acoustic data (main contributing WP: 3)

Deliverable 3.3 “Acoustic camera applications” (lead IOPAN): This deliverable has been assigned a sensitive status and is thus not public! It first describes general mapping approaches with FLS systems and gives examples of 2D reconstructions using data sets generated in WP10. Another important achievement is the development of an algorithm for 3D reconstruction from 2D acoustic imagery. The report presents a coherent reconstruction concept based on synchronizing sonar pings from the acoustic camera with the vehicle position and gimbal orientation, and it defines the complete transformation chain required to map local sonar measurements into a global coordinate system. The resulting transformations will enable the generation of a point cloud in which each point is assigned X, Y, and Z coordinates, as well as the intensity of the backscattered acoustic energy. Data processed in this way should enable 3D reconstruction from acoustic camera data. The required example sensor set was also specified to support this subtask. The planned software architecture covers synchronization, transformation, accumulation, export, and visualization. The planned use of the BlueView SDK 4.8 and a Python-based post-processing pipeline is a significant enabling factor. The deliverable presents the 3D approach as conceptual and offline, it demonstrates a strong methodology that needs to be improved in subsequent work packages.

B4. AI-supported image-based object classification and identification (main contributing WP: 5)

Milestone 13 “First AI-models and code classification on optical/acoustic camera data” (lead IQUA): This deliverable has been assigned a sensitive status and is thus not public! It presents the first results of Task 5.6, focusing on the development of artificial intelligence (AI) methods for classifying and potentially identifying potential munition objects in optical and acoustic camera data. The work builds on datasets compiled in Task 5.2 and the literature review from Task 5.4. Task 5.6 has established an initial AI pipeline for UXO classification by developing specialized workflows for acoustic and optical camera data. Pre-processing steps were established to standardize resolution and apply grayscale and Cartesian conversions to ensure consistent model input. Using the CVAT annotation tool, five distinct classes were defined for optical data while a single UXO class was adopted for preliminary acoustic detection. YOLOv8 has been selected as the initial core architecture for both sensor modalities due to its optimal balance of detection accuracy and the fast inference speeds required for operational use in WP6. Initial training of the two YOLOv8n models achieved a mAP@50 of 0.713 for the optical case and 0.79 for the acoustic images, showing good performance for common class instances but highlighting the need for more diverse data to improve detection of less frequent UXO classes.

Another model based on YOLOv8, targeted to orthomosaics only, is in preparation, but is still not ready. The idea is to integrate the visual information with DEM-derivative geometric features coming from the photogrammetric process. This approach could improve detection and identification performance in some cases, for example when many objects are overlapped on the seafloor. Preliminary results are encouraging. Ongoing efforts are focused on expanding the volume and diversity of training datasets and conducting peer reviews of annotations to ensure high ground-truth reliability. To account for this problem, an initial investigation to generate a synthetic dataset using 3D modelling software is ongoing. This work is the precursor

to the upcoming "online" phase in T6.3 and T6.4, where these models will be integrated directly onto the AUV hardware for real-time inference.

B5. Smart-AUVs through optic and acoustic sensing (main contributing WP: 6)

This sub-objective does not have a finished milestone or deliverable. However, work in the related Task 6.6 has started. Task 6.6 has advanced the AUV's software architecture to support truly adaptive missions, enabling the vehicle to dynamically adjust its behaviour based on real-time perception events. Key developments include event-triggered survey pre-emption, which allows the AUV to break away from a standard survey pattern the moment a target is detected, and configurable inspection patterns designed to optimize data collection for identification once a target of interest is detected. These integrated capabilities combining survey and inspection logic were successfully validated by IQUA Robotics during the REPMUS 25 exercise. In 2026, these architectural enhancements will be trialled in combination with the online AI models developed in Task 5.6 to demonstrate fully autonomous UXO detection and inspection in real munition dumping sites.

B6. Cooperative operation of several robotic vehicles (main contributing WP: 6)

This sub-objective does not have a finished milestone or deliverable. A literature review and initial work on a mission-planning framework for autonomous marine vehicles in seabed survey missions, focused on cooperation between an unmanned surface vessel (USV) and autonomous underwater vehicles (AUVs) has been conducted and published as a conference paper. It proposes a layered, auditable architecture in which a Remote Operations Centre supervises the USV, a behaviour-tree executive manages mission phases and recovery actions, a global planner generates coverage paths with limited adaptive edits, and a safety layer enforces collision avoidance and COLREG compliance. Learning-based methods are included only in an advisory role, helping suggest when local plan updates may be useful without directly controlling the vessel. The study also explains how the framework supports weak or intermittent communications, structured task handoff from the USV to AUVs, and detailed logging for validation in sea trials. It will be implemented on the UiT research vessel Ymir together with a Remote Operation Centre with selected AUVs, with the goal of enabling transparent, safe, and practical autonomous seabed surveying under limited human supervision.

B7. Grabbing System (main contributing WP: 7)

Sub-Objective B7 focuses on the pre-sorting and grabbing of munitions from robotic platforms such as underwater crawlers; but also links to Objective A "Compile existing knowledge and management approaches" and does work towards Objective C "Perform trials and use-case surveys around Europe". WP7 is guided by two intentions. The first is to develop software for conducting the operation, with the second focused on determining a technical solution for the guidance of munition grabbing. One milestone has been reached.

Milestone 16 "Mission Control Report" (lead SeaTerra): SeaTerra completed a broad survey and evaluation of existing technology for a mission control architecture that later will be implemented. The basic software which will natively integrate into the existing setup for operating the grabber has been prepared for initial testing.

B8. Establishing the state of corrosion of munition (main contributing WP: 8)

No specific milestones and deliverables were due in the first 18 month. However, during several expeditions we successfully tested an ROV-deployable ultrasonic sensor to measure metal thicknesses. In addition, repeated visual observations of certain munition objects show the rather fast decay of munition objects with thin metal hulls. Explicitly F103 rocket war heads have been investigated in Lübeck Bay. Further KC250 casings in the Bornholm Deep and Little Belt showed strongly increased stages of corrosion and disintegration. More quantitative assessments are currently being done.

B9. Faster and more precise chemical analyses of explosive compounds (main contributing WP: 8)

Within MMinE-SwEEPER we anticipate to develop better and faster methods for onboard and in-situ measurements. The current state-of-art has been compiled as part of Deliverable 8.3, and GEOMAR as well as Fraunhofer ICT are currently working on updating their systems and advancing their technologies in Task 8.2 and 8.3. We foresee first field tests with the improved Fraunhofer ICT sensor for July 2026.

Objective C: Perform trials and use-case surveys around Europe

Objective		Deliverables during reporting period	Milestones during reporting period
C1	Test new technologies under real conditions		M19; M20
C2	Learn about new munitions dump sites	D5.2	M20
C3	Increase the knowledge of the munition compound contamination in European waters		M20

C1. Test new technologies under real conditions (main contributing WP: 10)

Milestone 19 “Trials in artificial mine gardens” (lead GEOMAR): Some partners joined tests in La Spezia (Italy) using AUVs with magnetic sensors and sub-bottom profiling to find artificially buried mine objects in a harbour setting. VLIZ and GEOMAR are currently preparing a paper about the results. The milestone report gives an overview about cruise application procedures in different countries (Belgium, Germany, Poland and France). Since the milestone report was due, several updates on cruises occurred and are described in the work package 10 description in Sub-Chapter 1.2.

Milestone 20 “Application for ship time and cruise planning” (lead GEOMAR): GEOMAR, IOPAN and RMA all submitted successfully cruise proposals or cruise requests for 2026 and 2027. The cruise in 2027 to Norwegian water has been granted although with some time cuts.

C2. Learn about new munitions dump sites (main contributing WP: 10)

The cruises undertaken in the Baltic Sea (RV ALKOR AL628 & AL642, RV Oceania 2025, 2026) investigated dump sites for which no or only little data have been available before. Results are being presented in the cruise reports which at the time of this report were not finally published/openly accessible. Some more details are explained in the work package 10 description. A recent cruise with RV ALKOR (AL648) also investigated unknown wreck sites as part of the BaltWreck project and took water samples along the transit (Sub-Objective C3).

C3. Increase the knowledge of the munition compound contamination in European waters (main contributing WPs: 8 & 10)

During the undertaken cruises, we enhanced the number of samples in the Baltic Sea much further to the east. The next cruise with RV ALKOR in October 2026 will sample up to Estonia. In the reporting period, GEOMAR engaged with several stakeholders from Europe who did sampling in other sea basins. Among them was the Mediterranean around Greece as well as locations around Great Britain. Some more details are given in the work package 10 description.

Objective D: Strengthen cooperation and capacity building

Objective		Deliverables during reporting period	Milestones during reporting period
D1	Establish a well-connected and diverse community of experts	D1.1; D13.1, D13.3	M1, M22, M23
D2	Design and execute webinars and hands-on workshops		M2, M4, M6
D3	Compile training materials and datasets		M21
D4	Use tests and cruises to train people for capacity building		
D5	Strengthening the JPI Oceans Action ‘Munition in the Sea’		M22

D1. Establish a well-connected and diverse community of experts (main contributing WP: 1, 2, 12)

Deliverable 1.1 “Stakeholder Community” (lead HELCOM): The D1.1 Stakeholder Community deliverable has been submitted and uploaded to the consortium portal. The document outlines the process and objectives of MMinE-SwEEPER in engaging a wide range of experts and other

marine actors who are directly or indirectly involved in submerged marine munitions issues or in related remediation activities. The aim of creating this international and cross-sectoral community is to gather as many perspectives on the topic as possible, thereby collaboratively supporting an effective assessment of submerged marine munitions. Because the stakeholder roster is a living document, D1.1 reports those contacts who were actively involved as of February 2026. All partners have contributed to the process of engaging new stakeholders. We began with the existing networks of JPI Oceans and HELCOM and expanded through the broader networks of the consortium partners. Through collaboration with other projects (such as MUNIMAP, MUNI-RISK, REMARCO⁶, and CAMMera⁷) and by hosting and participating in various workshops and events, the stakeholder community has continued to grow—and is expected to expand further over the course of the project.

In March 2025, MMinE-SwEEPER enrolled several entities research institutions, private-sector actors and NGOs from across Europe as part of the Milestone 1 Stakeholders enrolled. We also invited stakeholders working at the governmental bodies, like environmental, safety and security related public institutions, however most of them were from outside the Baltic Sea region because the method used for approaching them required a different strategy than for the other groups. On the one hand, we expect governmental stakeholders to especially collaborate in the compilation and assessment of the current approaches, regulations and responsibility bodies addressing marine munitions and their inherent safety and security risks (tasks of WP2, D2.1. Responsibility, D2.2. Assessment of security risks, and D2.3. Risk assessment & decision). Because of the sensitivity of the topic, we decided to reach out this group through official channels. On the other hand, our colleagues from MUNIMAP were already collaborating with these institutions in the Baltic Sea region for their policy report. To avoid duplicating effort and the stakeholder overload we prioritised reaching out to governmental stakeholders from outside the Baltic Sea Region.

Deliverable 13.1 “Establishing the SAB and ESAB” (lead GEOMAR): The coordinating centre GEOMAR successfully established the SAB and ESAB members. ESAB members are now invited regularly to the management board meeting, during which all WPs report on their progress.

Milestone 22 “Digital news, newsletter and social media” (lead GEOMAR): Rather early in the project we setup a digital newsletter which is distributed regularly to signed up users.

D2. Design and execute webinars and hands-on workshops (main contributing WP: 11)

As part of WP1&2 organized workshops we identified key needs and concerns of stakeholders to initiate remediation (M2), to identify regulation concerns (M4) and to discuss key aspects of the decision-making process (M6). This has been summarized in D1.2. and D2.1 as well as Task 2.2 also started with a series of workshops to compile and discuss security aspects of marine munition with various experts (M5), the conclusion will be summarized in report D2.2 Assessment of security risks. All these stakeholder interactions will guide us in designing webinars and compiling training material. Partly, many of our stakeholder engagement activities do have a strong ‘educational’ focus, which we will enhance with proper webinars and hands-on workshops with non-partner stakeholders. Internally, we held several hands-on workshops as part of our research cruises, where we trained e.g. a new established underwater reconnaissance group from BPOL (see D4).

D3. Compile training materials and datasets (main contributing WP: 3, 4, 9, 11, 12)

Milestone 21 “First training materials (munition detection/remediation and environmental studies)” (lead IOPAN): A first version of a training/webinar presentation on munitions detection and environmental studies has been successfully prepared and structured into two main modules covering geophysical detection methods and environmental chemical screening. The material presents a complete workflow from wide-area detection to object identification and environmental risk assessment, including side-scan sonar, multibeam echosounders, magnetometry, LF SAS, ROV verification, and environmental sampling strategies. The presentation integrates case studies from the Baltic Sea to support practical understanding and improve knowledge transfer for project partners and stakeholders. Significant activities included the development of a structured training workflow from detection to confirmation and environmental screening, preparation of educational slides describing major detection

⁶ <https://www.dsm.museum/forschung/forschungsprojekte/remarco>

⁷ <https://cammera-munition.eu/>

technologies and their applications, compilation of environmental screening methodologies including sampling matrices such as sediment, pore water, and biota, and integration of case-based examples to support practical learning. Summary slides and key takeaways were also prepared to facilitate knowledge transfer and training effectiveness.

D4. Use tests and cruises to train people for capacity building (main contributing WP: 10 & 11)

Internally we held several hands-on workshops as part of our research cruises, where we trained e.g. a new established underwater reconnaissance group from BPOL during RV ALKOR cruises (GEOMAR). At the same time, three cruises with RV Oceania (IOPAN) conducted research in the Baltic Sea but also in the Black Sea. During all cruises we explained to participants how systems work, how samples need to be taken and they got hands-on experience by operating ROVs and AUVs themselves. We will continue this work, in which also students and interns are involved, during the upcoming cruises.

D5. Strengthening the JPI Oceans Action ‘Munition in the Sea’ (main contributing WP: 12)

To achieve this objective, JPI Oceans took up a leading role as a connector among the various ongoing research initiatives in this field and established an interproject coordination group on communications to promote the “Munitions in the Sea” brand. In doing so, MMinE-SwEEPER has been consolidating outreach efforts under a unified LinkedIn account and producing shared materials such as the *Munitions in the Sea* booklet and roll-ups. Beyond this, the Munitions Portal and, in particular, the Zotero database *Resources: Munitions in the Sea*⁸ has been developed. In doing so, MMinE-SwEEPER has been centralising knowledge to improve visibility of ongoing efforts. By having been invited to participate in numerous events as speakers (GICHD Innovation Conference, Marine UXO Survey & Clearance Symposium, Kiel Munition Clearance Week,...) and as coordinators for joint conference contributions (Blue Economy Baltic Forum 2025 & Arena 4 Blue Mission BANOS Meeting, Danish EU Presidency Conference for the Restoration and Sustainability of Europe’s Ocean and Waters, ...) and by co-convening the *Munitions in the Sea* sessions at the Fraunhofer ICT Annual Conference 2026, partner JPI Oceans has been reinforcing its position as a facilitator for knowledge exchange and discourse.

Engagement with UN agencies, including UNDP, UNIDIR, and UNMAS, further raised awareness of the wider European scientific expertise on this topic at global level. This will become evident in discussions at the 29th International Meeting of Mine Action National Directors and UN Advisers in Geneva in April 2026. The co-organisation with GEOMAR of a side event at the European Maritime Day 2026, alongside an exhibition stand, underscores the commitment to sustaining the Joint Action’s legacy.

Objective E: Promote European collaboration, management strategies and solutions

Objective		Deliverables during reporting period	Milestones during reporting period
E1	Strengthen European cooperation on marine munition aspects	D1.1, D1.2, D12.1	
E2	Present and promote management strategies and solutions		

E1. Strengthen European cooperation on marine munition aspects (main contributing WPs: 1, 12, 13)

To achieve this objective, especially WP1 and WP2, through the development of the stakeholder roster (D1.1 Stakeholder community) and close coordination with the sister projects MUNI-RISK and MUNIMAP in synergising efforts to identify stakeholder needs related to munitions in the sea (D1.2 Identified Needs), have contributed extensively (see above). Regarding the Communication Coordination Group: This group brings together leads on communication and outreach from all EU-funded and co-funded projects, as well as a range of regionally and nationally funded research projects working on the topic. Through these efforts, MMinE-SwEEPER has been central from its start to establishing the “Munitions in the Sea Community,” which promotes collaborative fieldwork,

⁸ https://www.zotero.org/groups/5983093/resources_munitions_in_the_sea/library

coordinated event contributions, joint media interactions, and unified communication materials. The latter include the Munitions in the Sea roll-up, a common Munitions in the Sea poster, the Munitions in the Sea booklet, and information factsheets.

Deliverable 12.1 “Plan for dissemination and exploitation” (lead JPIO): MMinE-SWEEPERS WP12 has made the promotion of wider European collaboration on the topic central to its Plan for Dissemination and Exploitation. Through this, it has especially advanced European interproject research cooperation by establishing a Communication Coordination Group and initiating what is intended to become a regular exchange between project coordinators.

E2. Present and promote management strategies and solutions (main contributing WPs: 12, 13)

Although the presentation and promotion of management strategies and solutions is foreseen to take place especially through the Knowledge Transfer Workshops later in the project, activities in relation to that have already been conducted in various ways. On the one hand, this has been for example done by active contribution to the public consultation on the European Ocean Act with a coordinated response by MMinE-SWEEPER and CAMMera to the Call for Evidence. Besides the numerous participations in conferences, workshops and dialogue events, especially the contribution of the project coordinator GEOMAR, but also by project partner HELCOM to the EU Member States Expert Group on Maritime Security in February 2026 gives evidence of active dissemination efforts undertaken already in the first half of the project.

#@WRK-PLA-WP@#

1.2 Explanation of the work carried out per WP

1.2.1 Work Package 1 “Stakeholder dialog and project co-design”

WP1 mainly worked on Objectives A2 and D1 as outlined above. HELCOM led the efforts in WP1, especially in contacting and coordinating the engagement with new stakeholders, worked closely with AU which led tasks 1.2. “Dialog requirements” and has initiated the compilation of lines of evidence for **Task 1.3** Synthesis of stakeholder discussion outcomes that will be summarised in D1.3. Synthesis of findings in the next reporting period. HELCOM helped AU in design the stakeholder surveys, supporting the organization of workshops, and facilitating invitations to participants. HELCOM also hosted several online workshops through their platform and co-authored the two papers led by AU. IOPAN co-authored one of the papers and supported the moderation of the workshops. SHOM contributed to organizing the online evaluation workshop and co-authored one of the papers. UiT and JPI Oceans helped organized and moderate the online evaluation workshop.

As part of **Task 1.1** “Identification and invitation of relevant stakeholders” (lead HELCOM) the current roster is reported in D1.1. This deliverable summarizes all stakeholders enrolled as of the end of February 2026, although it remains a living document that will be continuously updated. HELCOM led and coordinated the engagement process of new stakeholders. However, all partners contributed to creating a preliminary list of relevant stakeholders and to engaging with specific ones, always informing HELCOM to avoid duplication of efforts. By February 2025 was enrolled the first stakeholders (M1 Stakeholders enrolled) that mainly contained MMinE-SWEEPER partners’ network from research and some private companies in the Baltic Sea Region. HELCOM, together with AU, established periodical meetings of WP1 and WP2 to evaluate the evolution of the tasks in these two WPs, and it was decided to share the tasks of involving new stakeholders from governmental institutions allocated beyond the Baltic Sea. For that HELCOM and AU organized several bilateral meetings with partners especially allocated outside the Baltic Sea region. In this sense SHOM, Iqua, CranU, FFI, VLZ and CNR have been instrumental in contacting stakeholders in France, Spain, the UK, Norway, Belgium and Italy respectively. JPIOceans has actively reached out to EU-level stakeholders especially connected with security, as well as reaching some countries based in the North Sea and Mediterranean. HELCOM has also participated in OSPAR internal meetings to promote the project and engage new stakeholders from the North Sea and NE Atlantic. In addition, HELCOM contacted the other countries outside the consortia. Finally, collaboration with other projects—such as MUNIMAP, MUNI-RISK, REMARCO, and CAMMera—has further supported the inclusion of new stakeholders outside the consortium. Additionally, HELCOM in close collaboration

with AU and BPOL, initiated the development of the privacy policy⁹ document used for stakeholder engagement, ensuring alignment with GDPR requirements. The document was circulated and commented by all partners in the consortium, especially by GEOMAR, the project leader.

Task 1.2. “Dialog of requirements” (lead AU) related to the stakeholder dialogue have been led by AU in collaboration with HELCOM. AU and HELCOM initiated drafting a survey on key concerns of stakeholders, and it was circulated within all partners involved in WP1 and 2 and also to our collaborative projects MUNI-RISK and MUNIMAP. The results of the survey are reported in Deliverable 1.2. D1.2 Identify needs was the first step for the stakeholder dialogue, and outcomes were developed in further and extensive stakeholder engagement, including in-person workshops in UNOC side event (M4), Kiel in June 2025 (M2), multiple online and in-person workshops within the project and the sister initiatives MUNIMAP, MUNI-RISK, and CAMMera. Additional insights gathered through literature and policy document reviews, as well as participation in conferences such as the United Nations Ocean Conference and the BANOS Conference. All these lines of evidence have been compiled and summarized in a scientific publication [Dugasseh et. al \(2026\)](#), led by AU and with the collaborations of other partners (HELCOM, IOPAN, UBA, CBSS) working in MMinE-SwEEPER, MUNI-RISK and MUNIMAP.



MMinE-SwEEPER, MUNI-RISK and MUNIMAP interproject physical meeting previous to the joint stakeholder workshop at Kiel Munitions Clearance Week (June 2025).



Stakeholder dialogue first workshop. Kiel Munitions Clearance Week (18 June 2025)

1.2.2 Work Package 2 “Responsibilities assessments and decision-making”

WP2 mainly worked on Objectives A1, A2, A4 and D1 as outlined above. AU led the efforts in WP2 and worked closely with HELCOM. The WP2 deliverables will be reported in the next period, but work on D2.1 (Responsibilities) has already begun, including workshops on security aspects (M5). The workshop on assessment and decision-making processes (M6) has already been accomplished and is reported.

⁹ <https://mminesweeper-munition.eu/privacy-policy/>

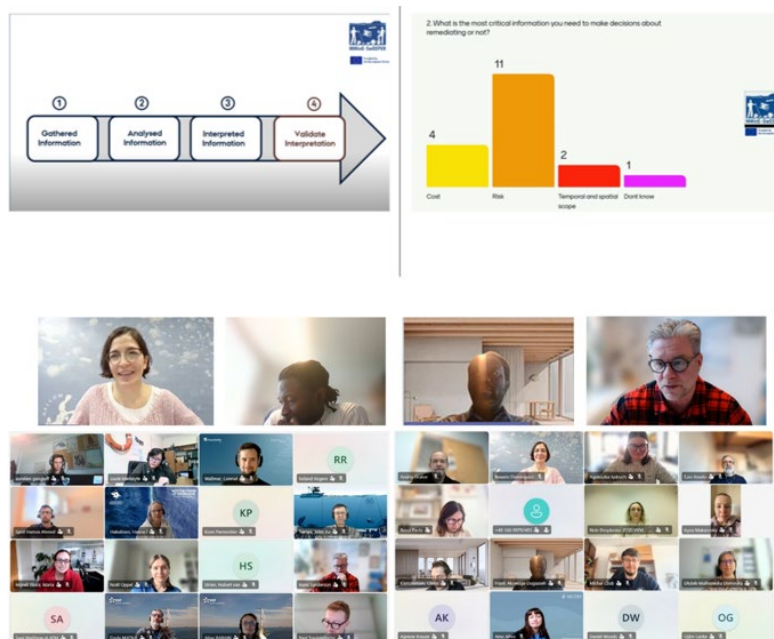
In **Task 2.1** “Analysis of responsibilities and legal frameworks regarding munition remediation” (lead: HELCOM), HELCOM organized together with MUNIMAP partners leading the tasks of the policy report (UBA) a thematic island and a factsheet on “Legal Framework for Marine Munition Remediation.” This was presented in UNOC-side event organized in June 2025. In addition, both UBA and HELCOM also collaborate in the legal thematic table of the World Café workshop arranged in Kiel Munitions Clearance Week also in June 2025. Both insides of the two workshops were compiled in Milestone 4 Workshop on responsibilities, and conclusions will be further summarised in D2.1. Responsibility (month 24). HELCOM in collaboration with AU has initiated the compilation of current procedures used across European countries for managing submerged munitions outside the Baltic Sea region, drafting the survey questionnaire, and ensuring that stakeholder interactions from WP1 feed into WP2 tasks. HELCOM contributed by drafting the survey on responsibilities—drawing on the MUNIMAP report—and distributing it to governmental stakeholders outside the Baltic Sea region. HELCOM has also engaged new stakeholders by participating in external meetings, including the Stockholm meeting with MUNIMAP, MUNI-RISK, and the HELCOM Expert Group on Environmental Risks of Submerged Objects (EG Submerged), where the MUNIMAP policy report was discussed, and by joining the CAMMera workshop to engage stakeholders from the North Sea. Further support came from partners: SHOM distributed the survey in France, and JPI Oceans facilitated contacts with respondents in Malta and the UK. Outcomes will be reported in D2.1. Responsibilities (month 24) and in the next reporting period.

In **Task 2.2** “Security aspects of marine munition and related security risk assessment” (Lead BPOL and KDR-SH), KRD-SH, GEOMAR, and BPOL initiated a series of smaller online workshops. Experts from various institutes dealing with security aspects related to explosive ordnance on and offshore were invited to contribute to a collective assessment of the topic “security risks of munitions in the sea”. The first three workshops (27.Feb., 06. and 09. March 2026) were conducted with German institutions. Future sessions will involve European experts in order to broaden and complete the overall perspective. During these online workshops, participants are guided through a structured questionnaire organized into broader topics. The questions are posed to the experts, and their responses are discussed collectively in the group. The overall objective for these workshops are:

- Learn if the participants see a security issue with old marine munition when it is laying on/in the sea bed, sorted in wet storages, or during clearance and transport.
- Learn if and why participants see a security issue if munition is being recovered and disposed of at sea (platform or vessels)
- Learn whether participants see the security risks greater than the human, environmental, and economic risks of the munitions or not. And how these security concerns should play a role in prioritizing munitions for clearance.
- Learn where the participants see a security issue of exchanging data on marine munition for 1) environmental questions, 2) security questions, 3) remediation questions

The conclusions will be summarized in the deliverable report D2.2. “Assessment of security risks” (month 36). Some of the initial results of the German expert assessment show that, although some security aspects have been identified, there is general agreement that, under the current geopolitical situation, environmental risks are considered far more critical. Security risks, however, are expected to change once clearance activities begin, particularly when munitions are sorted and stored in interim storage (e.g. wet storage) or destroyed on land or at sea (e.g. destruction platform at sea). Another key finding concerns is the limited extend of security screening procedures for personnel, for example within clearance companies or scientific research institutions.

In **Task 2.3** “Analysis of assessment and decision-making processes for munition remediation (Lead AU) the M6 online workshop on “assessment and decision making”, took place online workshop on 24 February 2026. It brought together 32 stakeholders from research, government, industry, civil society, and the security sector. The workshop focused on validating findings from earlier stakeholder engagements (see Section 1.2.1, WP1) and gathering additional perspectives relevant to the decision-making process. The outcomes will be compiled in D 2.3. Risk assessment & decision (month 36).



Online workshop (M6) on decision making (February 2026).

1.2.3 Work Package 3 “Seafloor munition detection and identification”

WP3 mainly worked on Objectives A3, B2, C1, C2, D3, and D4 as outlined above. FFI led the efforts in WP3 and worked closely with GEOMAR, IOPAN, RMA, IQUA, SeaTerra and WTD71. WP3 generally compiles knowledge and best practices for mapping larger survey areas using sonar for detection, localization and classification of marine munitions on the seabed (Task 3.1). In addition, the WP will advance technologies for optical and acoustic camera for object identification in Task 3.2 and 3.3. All partners of WP3 are actively involved in acquiring new data that are used in WP5 for testing the setup of the data management system as well as supporting the needed data for AI training. WP3 links closely with WP4 as at the end seafloor and sub-seafloor methodologies need to go hand in hand for final munition identification. Partners of WP3 have regular meetings with WP4 and WP5 to secure data flow and streamlining of deliverables. The series of deliverables from all WP3 tasks will be merged and complementary to each other. They will also build the base for training material in WP11 and as long-term information for the knowledge compilation for WP12.

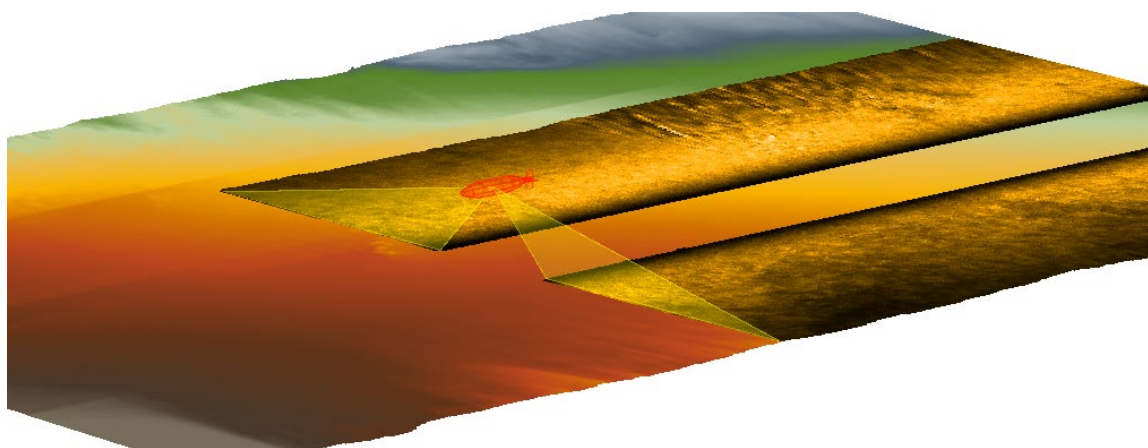


Image showing an AUV scanning the seafloor with an SSS system draped over a bathymetric map.

Specifically, in **Tasks 3.1** “Compilation of methods and best practices of MBES, SSS, and SAS approaches” (led FF), we compiled information about all these systems in a first compendium as part of Milestone 7 (see appendix). The consortium is working on a well-structured series of different deliverables including D3.1 that will not only present the acoustic systems as such, but also specifics for different platforms or general navigational issues.

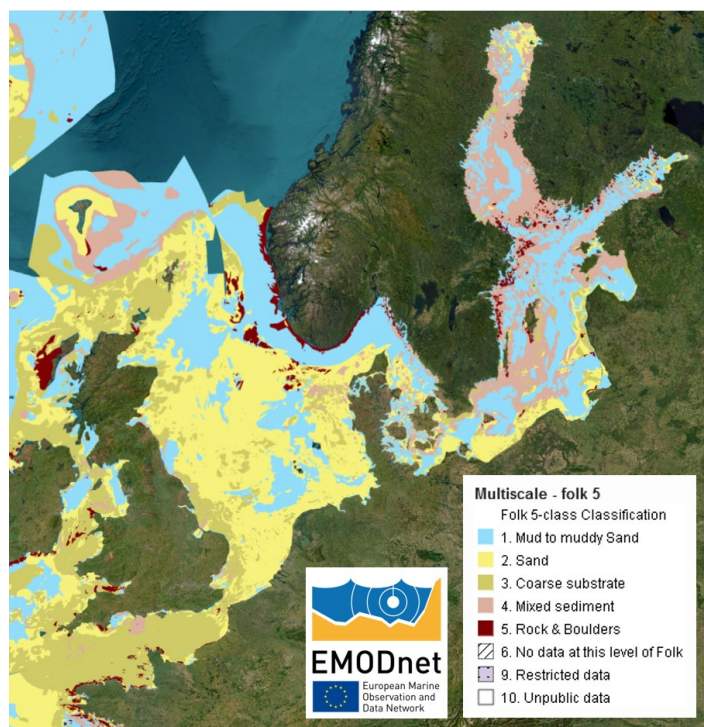
In **Task 3.2** “Acquisition of optical data and photogrammetric reconstruction” (led GEOMAR) the partners acquired new optical data as part of the WP10 run cruises and uploaded subsets of this to the TrueOcean Platform of WP5. The short Milestone 8 report highlights some introductory papers for marine optical image acquisition, data management and photogrammetric processing. Processed photomosaics have been also uploaded into the TrueOcean platform and are used to train AI methodologies to e.g. count the number of munition boxes in a large munition pile.

Similarly, in **Task 3.3** “Acquisition of hydroacoustic camera data for object identification and 3D reconstruction (led IOPAN) also used cruises of WP10 for data acquisition. The classified text of D3.3 has been send to the EU project office in Brussels.

1.2.4 Work Package 4 Subseafloor munition detection and classification

WP4 mainly worked on Objective A3, C and C2 and supports D3 equally as WP3 does. In WP 4 the partners (RMA, SHOM, VLIZ, SeaTerra, GEOMAR, WTD71, IOPAN, KRD-SH) investigate the possibilities of detection and classification of subseafloor munitions. Each task looks into different aspect of the problem of finding buried and partially buried munition objects.

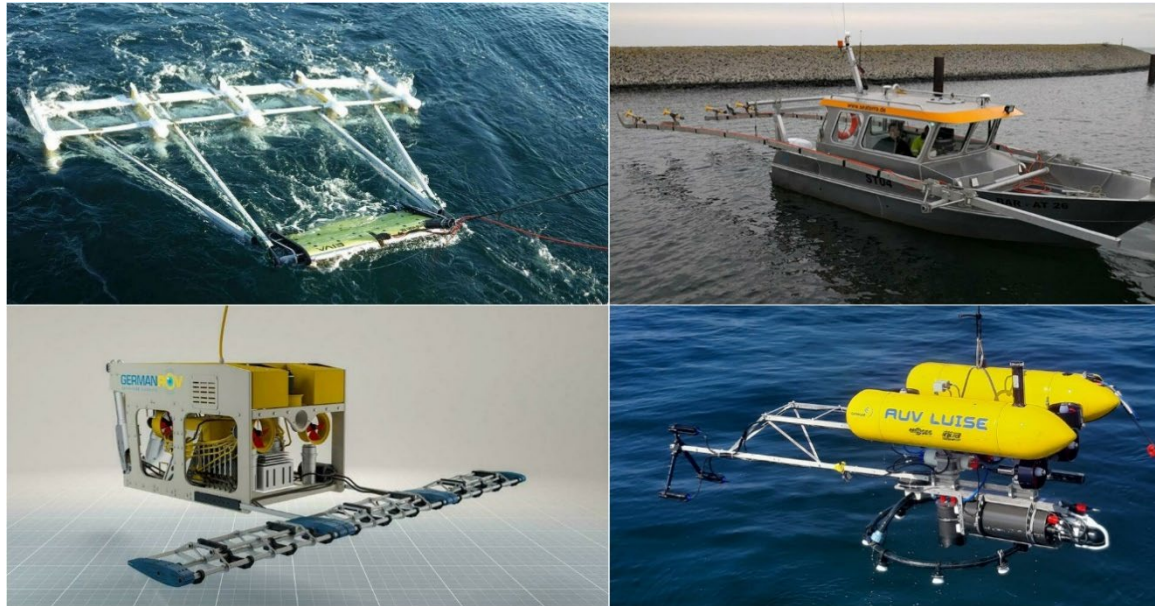
For **Task 4.1** “Sedimentological assessment & simulations of potential buried munition” (led SHOM) SHOW use data collected from EMODnet and Copernicus. The datasets include seabed substrate map, bathymetry, currents in lowest vertical level and wave data. They will be processed, analysed, and combined to make the final dataset, which will be used for modelling of potential buried munition places. The input dataset for the model will are presented in Milestone 9, together with the first generated maps. The finalised version will be a map with around 1 km resolution. The work is well advanced and first results have been presented in WP4 online meetings.



Available EMODnet seabed substrates data using Folk-5-class classification at a scale of 1:1 million in the area of interest

The other four Tasks, **Task 4.2 to 4.5**, are looking into the different approaches for finding subseafloor munitions: magnetic detection, electromagnetic techniques, 3D Sub bottom profiler detection, and detection using Low Frequency Synthetic Aperture Sonar. A number of detailed reports explaining the methods have been prepared and filled by each partner. It is summarised in the milestone 10 and reflects Objective A of the project. Each partner looked into the method, connected to the task they are involved in, and presented the working principle, the resolution, and

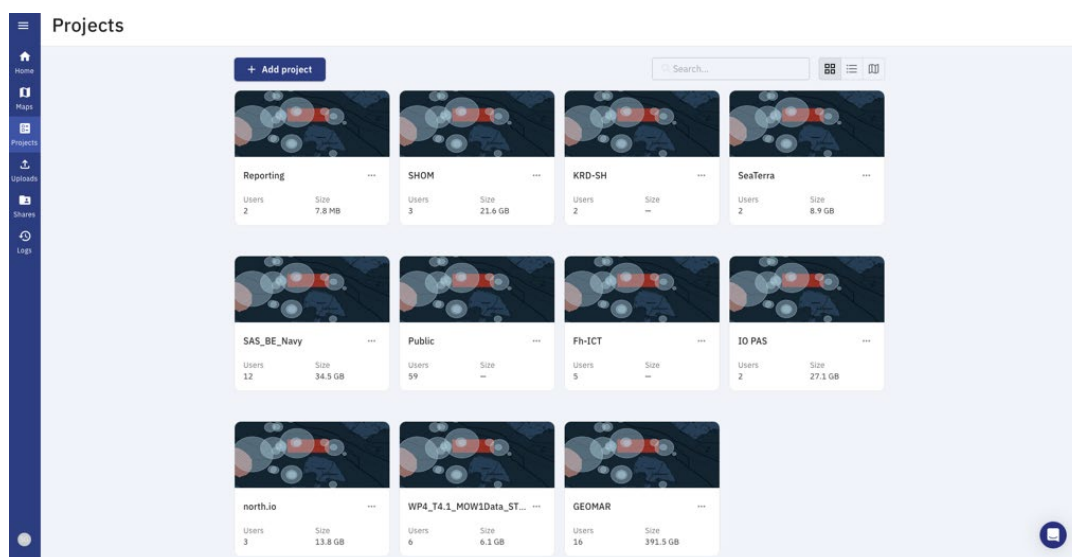
the restrictions and the limitations of each approach. Substantial text has been compiled already and will be submitted as planned as Milestone 10 in month 20.



Various carrier systems for the use of magnetometers in marine environments. Top left: Towed GEOWING system (© FGLG). Top right: Lowerable sensor array permanently installed on an aluminium boat (© SeaTerra GmbH). Bottom left: Multiple magnetometers on an ROV (concept graphic, © SENSYS GmbH). Bottom right: Magnetometer installation on an AUV (© GEOMAR Helmholtz Centre for Ocean Research Kiel). Image taken from Frey et al. (2022).

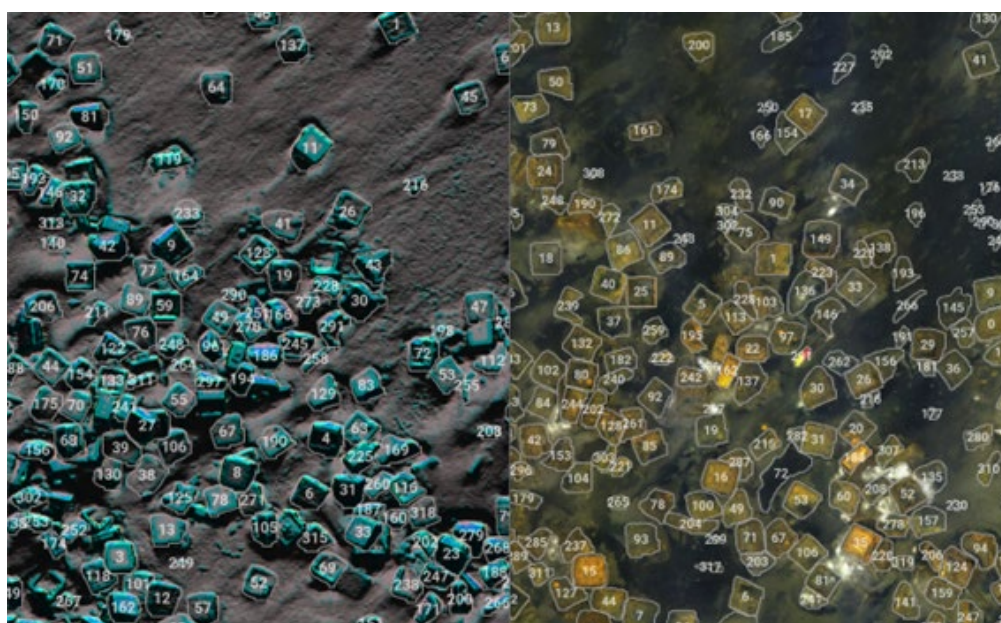
1.2.5 Work Package 5 “Secure data management & automated munition detection/classification/identification”

WP5 mainly works on Objective A3, B1, B2, B4, and supports C1, C2 and D3. WP5 focuses on establishing secure data management and advancing automated, AI-supported detection, classification, and identification of munition objects on the seafloor. Multiple partners contribute to this work package including north.io, GEOMAR, RMA, CNR, IQUA, and the WTP71. This work package organizes and streamlines project-wide data management while supporting the development of AI-based analysis methods for acoustic and optical datasets. In **Task 5.1**, a key element was the development of a data management plan (DMP) in May 2025 and the deployment of a secure data platform by north.io in October 2024, which enabled controlled data exchange among international partners while preserving data sovereignty and complying with security regulations. The platform, deployed as part of **Task 5.2**, allows partners to upload, manage, and share sensitive survey data and currently hosts several hundred gigabytes of hydroacoustic and optical datasets contributed by consortium partners (including GEOMAR, RMA, IQUA, WTD71, SeaTerra). The operational use of the platform marks the first step in achieving Objective B1 and implementing **Example 9**.

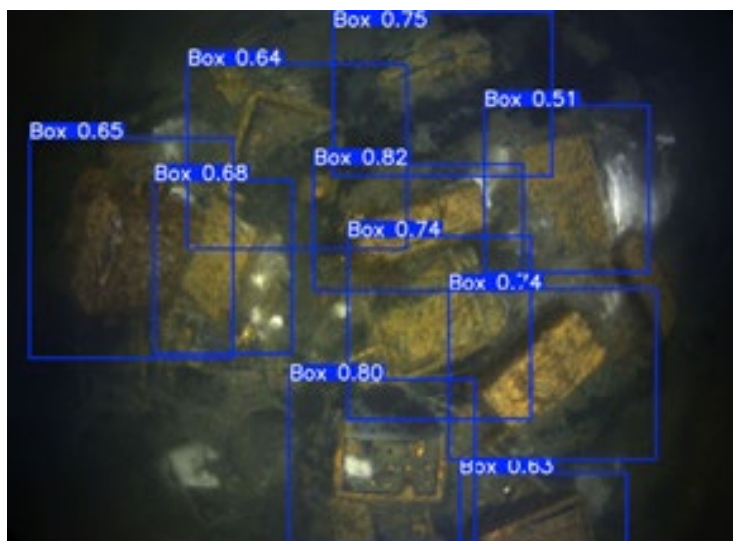


Project overview in the TrueOcean data platform. Each individual project partner has a dedicated project folder for secure data sharing.

In **Task 5.4** Based on a shared compilation of scientific and grey literature a literature review was conducted lead by RMA of existing AI approaches for munition detection and classification, including methods applicable to both acoustic as well as optical data sets. Building on these insights, RMA, GEOMAR, WTD71 and north.io developed in **Task 5.5** prototypic AI-based detection workflows using hydroacoustic data such as side-scan sonar, synthetic aperture sonar, and multibeam datasets. RMA focuses on supervised detection models for mine-like contacts, while north.io developed a more generic anomaly detection approaches for point cloud data. The work on spatial hydroacoustic datasets directly contributes to Objective B2 and reflects the work on **Example 10**. In parallel, IQUA and CNR investigate AI-based classification methods for optical and acoustic camera data, including photogrammetric orthomosaics, with the goal of identifying and counting munition objects. These approaches explore different annotation strategies, model architectures, and pre-processing workflows to handle complex underwater scenes including partially buried or obscured objects therefore addressing Objective B4 as well as contributing to **Example 6**.



Results of the AI-assisted annotation of munition boxes based on the DEM-derivative geometric information (left) and the orthomosaic that has been generated using seafloor images (right). Note that the id of the objects are different



Example of inference results on optical images achieved by the preliminary model.

In summary, WP5 establishes the technical and data-driven foundation for AI-assisted munition detection, combining secure data management with the development of machine learning models that can ultimately be integrated into autonomous underwater vehicles (AUVs) in later project stages.

1.2.6 Work Package 6 “Smart and cooperative applications for autonomous and remotely controlled vehicle”

WP6 mainly works on Objective A3, B2 to B6, and C1. WP6 focuses on advancing the autonomy of underwater and surface vehicles (AUVs and USVs) through onboard data processing, inter-vehicle communication, and adaptive mission planning. The main partners are UiT, GEOMAR and IQUA Robotics.

With regards to **Task 6.1**, GEOMAR set up a processing pipeline of onboard MBES data processing using MB-Systems as open source software. The advantage of this approach is the wide support of many different MBES and SSS data formats and a full suite of correction possibilities as sound velocity, static offsets, and time latencies. MB-Systems is widely used in the academic world and can be scripted with a final export of a georeferenced grid that can be used for object detection. The software is running on GEOMARs GIRONES 500 and SPARUS AUVs. During AL644, this setup was used to process sidescan data during several SPARUS dives.

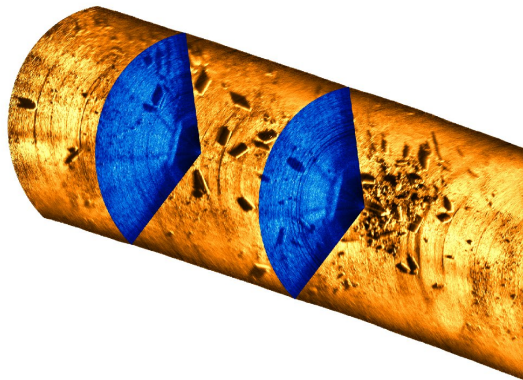


*SSS Data from AUV Sparus II
Albert automatically processed
using side-scan tools during AL644.*

For **Task 6.2** GEOMAR used existing developments of the previous BASTA project and build on developments of the parallel running (now finished) SAM project. Next to the capability of acquiring good quality magnetic data, the AUVs intelligence was advanced to perform first a low-resolution lawn-mowing pattern, identify magnetic hotspots and reinvestigate these magnetic hotspots by

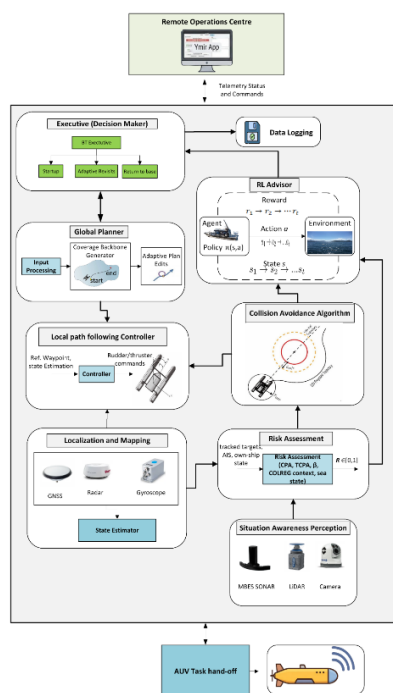
accounting for the current direction, cluster nearby magnetic anomalies where feasible and finally generate the shortest path mapping each of the magnetic objects/clusters with a 1m line spacing lawn-mowing pattern. Tests in Lübeck Bay showed that the algorithms are working properly and the AUV can execute the missions successfully. The respective Deliverable 6.2 has been submitted.

For **Task 6.3 and 6.4**, IQUA Robotics is currently concentrating its AI recognition algorithm development within **WP5**, after which the focus will shift to online implementation on the AUV. In parallel, they are actively developing an enhanced AUV software architecture that supports combined survey and inspection missions, including event-triggered survey preemption, configurable inspection patterns, and onboard generation of georeferenced maps. These capabilities are planned to be tested and used during the REPMUS 26 exercise and an upcoming RV ALKOR cruise (AL652 outside MMinE-SWEEPER objectives in May 2026).



Online generated side-scan like images based on forward looking sonar cameras, examples from AL644. Such data are used in WP to train AI-based detections and increase the navigational accuracy when the AUV is re-approaching and object for second more detailed imaging.

The work performed in **Task 6.5** by UiT focussed on the integration of an MBES in UiT's autonomous surface vehicle (installing a pole, updated GPS and data acquisition capabilities) as well as an update of the electrical propulsion system. Both of these activities used substantial amounts of own funding. Initial sea trials are expected to take place soon, during which seabed data will be collected under shallow-water conditions. In addition, UiT worked on the main goal of Tasks 6.5 which is to develop a mission planning framework for the surface and underwater vehicle.



Left: Detailed Architecture for Mission Planning of USV; right UiT research vessel with MBES unit.

A dedicated PhD, employed through the project, recently submitted a conference paper to this topic that describes and schematically depicts the general framework layout. Discussions are ongoing about the USV–AUV communication protocol are ongoing with Task 6.6.

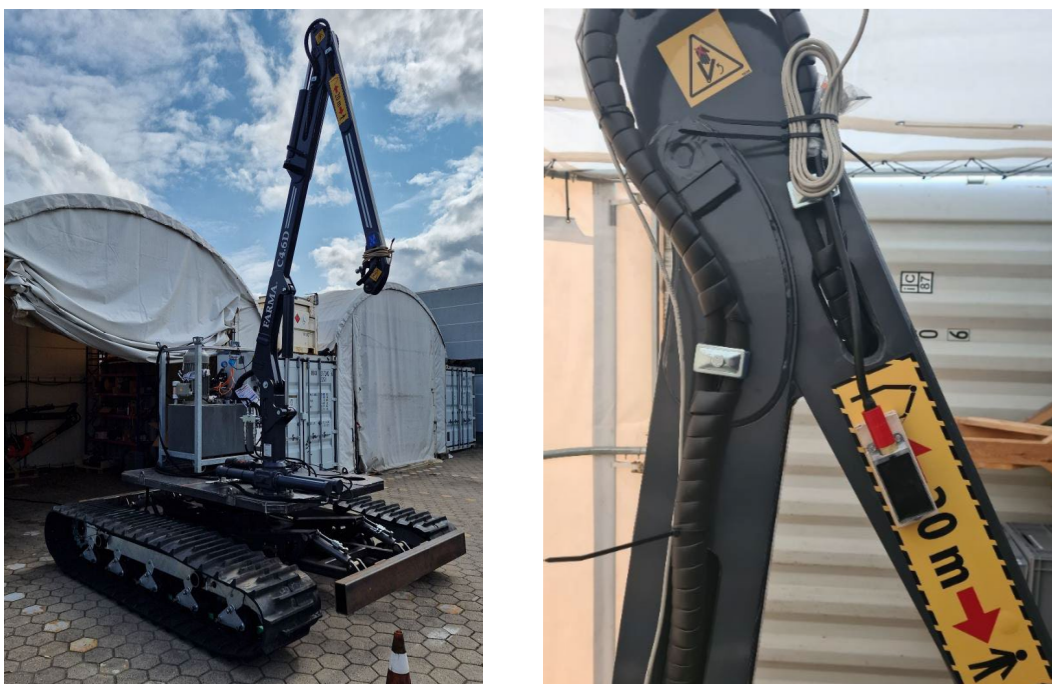
Task 6.6 is currently discussed between IQUA and GEOMAR and links to the successful Task 6.2, 6.3 and 6.4 as well as 6.7. For **Task 6.7**, IQUA in cooperation with GEOMAR has drafted a communication protocol proposal for USV–AUV interaction and AUV–AUV communication. Planning for **Task 6.8** is ongoing.

Looking ahead, WP6 work is currently focusing on getting a working set-up ready for the interims report review in Kiel (July 2026). A live demonstration of automated detection of munition-like objects in MBES data (data acquired with RV LITTORINA and not an USV) and automated transfer of data to an AUV with automated mission execution is planned. Further field trials in Tromsø with both AUV and USV, and developing mission scenarios for cooperative multi-vehicle operations are ongoing.

1.2.7 Work Package 7 “Munition removal by grabbing”

The work of WP7 exclusively targets Sub-Objective B7 but also contributes to Objective C, as well as cooperatively uses results of other B Objectives (3D reconstruction and AI). WP7 efforts are focused on methods for robotic grabbing of munition and the development and implementation of mission control software for use in crawler and AUV guidance and operation. Contributing partners which have supported the progress include GEOMAR, CNR, BPOL and KRD-SH. The completed mission control software will be functional for robotic vehicles such as ROVs and crawlers, including SeaTerra’s NORPPA (codeveloped within the REMARCO project), and the UXTractor, which was codeveloped in MMinE-SwEEPER.

As part of **Task 7.1** the selection and apt implementation of the mission control software for multi-vehicle control has been concluded with Milestone 16. In early 2025 the general status and availability of open-source ROS2 and mission control software were assessed (Task 7.1 & M16). From this initial evaluation it was determined which features and directions are necessary to improve and advance current ROS2 software, and evolve what exists to create a mission control framework. The assessment of commercial and public software is ongoing. AGSTrack is a navigational software developed for SeaTerra for use in geophysical surveys and munition clearance, however not specifically multi-agent robotic operation. Considering the basics, that is single-vehicle driving, targeted crawler arm movement, as well as spatial and visual data collection, the AGSTrack software is sufficient.



The UXTractor with grabber arm (left) and sensors to know the exact position of the arm (right).

Ongoing developments of sorting and grabbing different types of munitions currently undertaken in **Task 7.2**. SeaTerra has finalized the hardware design of the grabbing system and is progressing with its construction and development. At present all the time-critical components have been ordered, and most of the hardware is on premise. This includes a 5T “UXTractor” crawler system, the manipulator arms, and a first version of the grabber and control systems. Furthermore, ‘dummy’ targets of various weights and dimensions have been obtained to support testing. Design and construction of the “UXTractor” crawler system far exceeds the original scope of the project. But overall co-developing the grabber in conjunction with the crawler provides a broader base for operation as well as more practical testing. Results of WP3 and WP4 will be incorporated since information of visible and buried munitions will be used in mission control software and grabber development and workflow design. Further development in Task 7.2 will separately continue on software features which optimize the operators’ ability to identify patterns and sort and grab individual munitions

Crawler and smart grabbing arm will be finally tested during real-world tests in Task 7.3 where WP7 is joining forces with cruises applied for and led in WP10. Overall there has been good progress in the creation and development of grabbing technology in addition to the mission control software for multi-vehicle management. One point of hindrance was delivery delays with the ‘smart valve pack’, an essential part to efficiently control the crawler, arm and grabber hardware from the software. During the interim, work continued on building both hardware and software components. The valve packs finally arrived on May 15th. Grabber testing will begin as soon as the smart valve pack has been mounted and wired.

1.2.8 Work Package 8 “Environmental monitoring for chemical contamination using sensor systems”

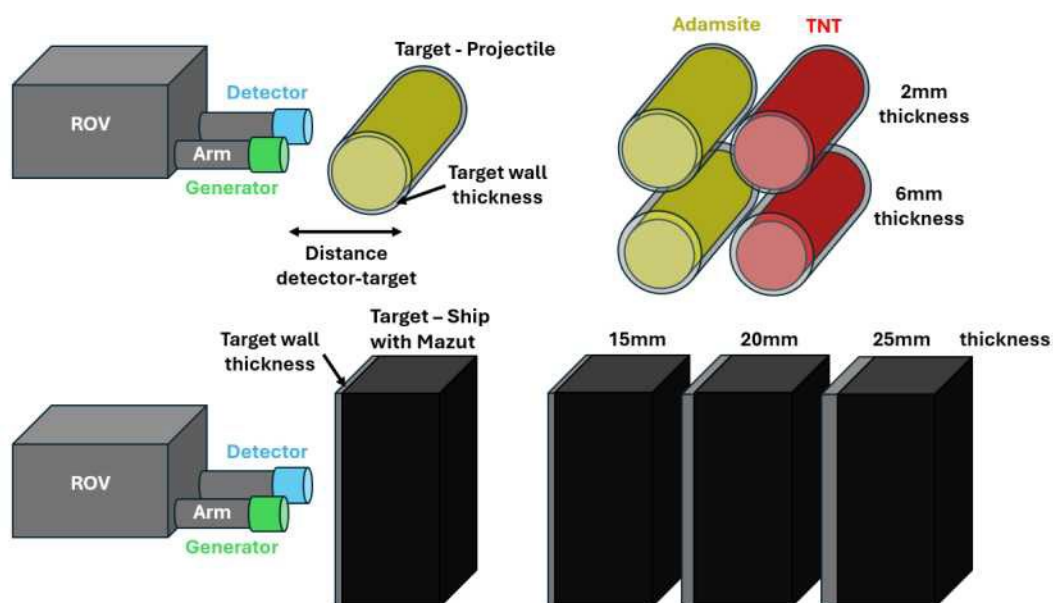
The work of WP8 targets Sub-Objective A3 but specifically B8 and B9. Through field tests the WP contributes/makes use of Sub-Objective C1 and substantially moves Sub-Objective C3 forward.

As part of **Task 8.1**, the deliverable 8.1 has been submitted in time. The deliverable provides a comprehensive compilation of the state of knowledge regarding munition-related contamination in EU waters and toxicological thresholds required for environmental risk assessment. Similarly, for **Task 8.2** the deliverable 8.3 has been submitted. The deliverable details an overview of the state-of-the-art regarding explosive chemical detection in aqueous samples. A focus on field-deployable technologies linked directly to the planned MMinE-SwEEPER integration and advancements of the Xplotector and the sensor system for explosives compound detection developed by Fraunhofer ICT.

For **Task 8.3**. Deliverable D8.5, focusing on advancing Neutron Activation Analysis (NAA) for the non-invasive, in-situ identification and classification of chemical warfare agents (CWAs) versus conventional munitions. The work included comprehensive Monte Carlo simulations to design and optimize an NAA-based sensor comprising a neutron generator and a gamma quantum detector mounted on a Remotely Operated Vehicle (ROV). Researchers evaluated the sensor’s performance based on the detector-to-target distance and the varying thicknesses of munition shells and ship hulls. Following theoretical modeling, experimental trials were conducted in a simulated aquatic environment. These trials utilized surrogate materials, including melamine (to simulate explosives) and NaCl (to simulate the chlorine signal present in CWAs like mustard gas and Adamsite), assessing elemental signals through a layer of water. To achieve the highly specialized nuclear physics testing, IOPAN successfully prepared and executed the entire tender procedure. Through this procurement process, IOPAN engaged experts from the Jagiellonian University, who executed the theoretical Monte Carlo simulations and laboratory irradiation experiments using fast neutron generators.

Within **Task 8.4** GEOMAR performed many visual observations during the past research cruises and did first tests with an ROV-based ultrasonic sonar head. This is to establish a qualitative standard for evaluation munition corrosion. This is work in progress which will link to a recently published work by the Center for International Stabilization and Recovery about the “Effects of

Biofouling and Corrosion on Underwater Munitions”¹⁰. Optical investigations using photogrammetric reconstructions are covered by Task 3.4. and will be used as ground truth of corrosion states of marine munition and as catalogue to classify these stages in a standard like way.



Scheme of the simulation setup with two different types of the target - projectile (cylinder) and ship (cu-boid) (source: Final Report on Commissioned Research No. K/KDU/000990: Research on the Suitability of Neutron Activation Analysis for the Identification of Chemical Warfare Agents," authored by M. Silarski, M. Kaczmarek, K. Dulski, and W. Zantowicz)

1.2.9 Work Package 9 “Assessment of munitions remediation methods”

The work of WP9 targets Sub-Objective A3 and particularly E2. WP9 investigates and compiles approaches and methods to deal with single munition objects or entire munition dump sites. Physical and chemical impacts on the environment and related mitigation and monitoring practices are considered by the different tasks. **Task 9.1** includes two aspects. First a comparison of low and high order approaches related to facts, impacts and cost issues (D9.1) has been performed by FFI. Second a simulative analysis to quantify the recently unknown degree of energy release has been performed by Fraunhofer ICT (D9.2). For Delivery 9.1, FFI conducted a literature review on high order disposal (HOD) and low order disposal (LOD) of explosive remnants of war, briefly covering different methods as blast in place, laser and waterjet methods. The delivery also includes national regulations and standards, with contributions from FFI, Fraunhofer ICT and GEOMAR. The main risk differences are acoustic impact and chemical contamination: HOD causes higher acoustic impact, while LOD leads to substantially higher explosive contamination. Few studies exist, so more research is needed for precise risk assessments. Laser and waterjet methods are not yet fully developed for underwater use but will be important future tools. Costs for ERW clearance range widely (850 to > 850,000 €) regardless of method, and unified international regulations and standards are still missing and have to be developed. For Deliverable 9.2 we are currently working on simulations of low order detonations, also called deflagration. Two processes were modelled: First the surface regression of the burning surface of the explosive and second the internal ballistics inside the casing. Due to its geometrical form the depth charge was chosen as basis. To model the surface regression, first the Signed-Distance-Function (SDF) for the starting burning surface is calculated for a mesh representing the inside of the casing. Results of different assumptions and calculations will be used in an internal ballistics model to calculate the pressure curve inside the casing. First prototypes of the two models have been written and tested. These prototypes are

¹⁰ <https://commons.lib.jmu.edu/cisr-globalcwd/1567>

further refinement to resolve the remaining issues with the models and to expand regarding towards high order detonations.



A sea mine disposal by low-order deflagration. Left: Pluton™ deflagration charges placed on the mine shell. Right: After disposal, where large chunks of explosives are visible and no crater. Photo: Norwegian Naval EOD Command

Mitigation measures with regards to HOD and other disposal methods are addressed in **Task 9.2** and will cover methods like bubble curtains, relocation and movement to shallow areas (D9.3 in month 24). Procedures, techniques used and the relevant background information are explained and clearly outlined. To be able to evaluate the mitigation measures in use, a survey is currently exploring the relationship between disposal methods, mitigation measures, and environmental conditions. All conventional munitions are considered, but chemical munitions are currently excluded, as are clearance activities older than ten years. GEOMAR supported Fraunhofer ICT during the design and conceptualization of the questionnaire. To this end, it reviewed previous work from the ProBaNNt project to understand, which properties of and information on individual EOD activities were relevant to understand national and organizational operating procedures. A total of 24 questions were asked. In total 36 contacts were approached from 16 different countries. Feedback has already been received from Germany, Norway and Denmark. France and Switzerland have confirmed their participation by the end of April. Further enquiries are ongoing; the aim is to receive responses by September to ensure best possible comparability.

Cover-up and recovery disposal methods will be addressed in **Task 9.3** and **9.4** at later stage. Involved partners are FFI, WTD 71, ICT, SeaTerra, KRDSH and GEOMAR who all are active towards the task objectives outside of the MMinE-SwEEPER project.

In **Task 9.5** AU has searched for information and data regarding chemical contamination/dispersion during remediation/clearance activities. Both model and lab/field scale experiments are relevant. Cran-U has provided recent results on environmental impacts of low (LOD) and high order (HOD) detonations in water. LOD and HOD data will potentially be integrated in the exposure modelling that is carried out WP3 of the MUNI-RISK project.

1.2.10 Work Package 10 “Test, trials and demonstrator surveys”

The work of WP10 particularly contributes to Objective C but it also contributes to a large number of Sub-Objective of Objective B (B1, B2, B3, B4, B5, B6, B8, B9). Here it supports the acquisition of new data for AI training and provides the platform for AUV-based trials and sensor tests. WP10 also support objective D for compiling training data sets and for enabling training, so far only to project partners. With all its activities WP 10 directly influences on a number of Impact Examples (2, 3, 6, 7, 8, 10 and 11).

As part of **Task 10.1** and **10.2** we combine all efforts related to research cruises and field tests of the project. Partners who have been actively involved in seagoing operations and their planning include GEOMAR, FFI, IOPAN, RMA, SHOM, BPOL, WTD71 and VLIZ. So far, GEOMAR has performed field work was carried out in the Baltic Sea during several cruises (AL628, March 2025;

AL642, October 2025;). These cruises were also used for training and hands-on exchange between partners (BPOL, IOPAN, WTD71), to investigate new/less well-known munition dumpsites, to acquire new data for AI training, to test AUV autonomy, to advance equipment for onboard analyses of explosives and to evaluated technologies and approaches for evaluating the state of corrosion of munition objects. Here cruise AL628 e.g. went to the well-known Lübeck Bay area to use high-frequency sensors to measure the thickness shells and to continue a time series of decomposing munition objects (here F103 rocket war heads; link to WP8).

Parallel IOPAN performed three research cruises, two in the Baltic Sea and one in the Black Sea. The first cruise took place in the Lübeck Bay area in March 2025 just after the ALKOR cruise. During this campaign AUVs mapped sections of the seabed, sometimes simultaneously with side-scan sonar and a magnetometer. Around submerged munition sediment samples were collected for analyses in WP8. During the second Baltic Sea cruise in November 2025 within the Gulf of Riga research included side-scan sonar and magnetometer surveys followed by visual inspections during ROV dives and sediment sampling. Some of the sediment samples were analyzed onboard by partners from the Military University of Technology. During the Black Sea cruise in June 2025, visual inspections were performed at four locations containing submerged objects using the ROV. Throughout each cruise and at every stage of the work, early-career researchers from various institutions (including the University of Gdańsk and the Military University of Technology) as well as from the private sector took part. This allowed them not only to gain theoretical knowledge about methods used in studying areas with submerged munitions, but also to acquire practical, hands-on experience. As a result, capacity was built during each research cruise.



Four different AUVs onboard of RV ALKOR (AL628, March 2025). The AUV in the front left is from IOPAN. Next to AUV work, sediment samples at previously investigated locations were taken (image shows Jacek Beldowski, PI from partner IOPAN).

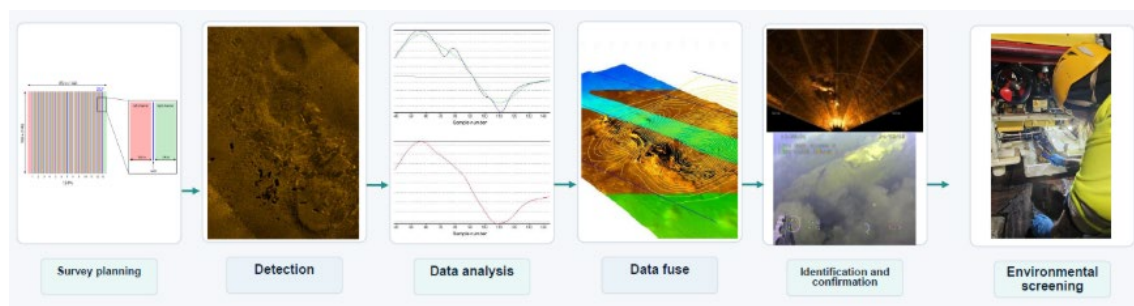
As part of **Task 10.3**, in early 2025 a cruise proposal for a larger cruise in 2027 to the North Sea and to Norwegian fjords was successfully submitted and approved through the German funding organisation. A number of granted cruises will happen in 2026 in July with RV LITTORINA (GEOMAR), in October with RV ALKOR (AL663, GEOMAR) and in April, July and September with RV BELGICA through RMA. Planning of all these cruises is ongoing and will involve several partners from the project. In summary, WP10 is well on track and the upcoming cruises with tests and the survey of new areas will enhance our knowledge about the munition contamination in European waters. During the rest of the project we plan to extend our seagoing activities within the Atlantic region, the eastern Mediterranean and the Black Sea (we are in the process of establishing a dedicated project in the Black Sea in cooperation with the CAMMera project).

1.2.11 Work Package 11 “Integrative compilation of best-practices & development of outreach/educational material”

WP11 works towards Objectives D2, D3 and upon implementation towards E2. Project partners from KRD-SH and north.io in **Task 11.1** recently submitted Deliverable 11.1 that presents a compilation about the needs and approaches for historical data analyses. The report also addresses automated identification of dumped munitions using AI-based tools and serves as a comprehensive reference for historical data compilation and analysis.

In parallel, work in **Task 11.2** focused on preparing training materials in the form of a scientific presentation on chemical screening and environmental assessment of submerged chemical warfare munitions. This activity involved literature review, compilation of analytical methodologies, and synthesis of knowledge generated in previous multidisciplinary projects, resulting in structured educational content covering contaminant classes, sampling strategies, safety considerations, and analytical approaches. Together, these tasks contributed to the objectives of the Work Package by strengthening knowledge transfer, supporting harmonized methodologies, and enhancing training capacity within the project.

For **Task 11.3**, we are cooperating with the MUNIMAP projects who are compiling a strategy for environmental monitoring for the Baltic Sea region. MMinE-SwEEPER and CAMMera partners are actively involved in the process and contribute with their knowledge about the physical investigations and strategies e.g. when and where to take samples, how to fuse data and where to find additional data and information for a conclusive monitoring strategy. All this uses existing information, e.g. the UDEMM report on Best-Practices¹¹.



A workflow diagram illustrating the process from detection and data fusion through ROV verification, sampling, laboratory analysis, and risk assessment

1.2.12 Work Package 12 “Communication and outreach”

WP12 works towards Objectives D and E specifically but supports Objective A through its international communication approach. All partners contribute to WP12 by delivering content about the project progress that is used for outreach or knowledge base and are repeatedly involved in personally joining/organising conferences, workshops and stakeholder interactions.

As a main output of **Task 12.1**, the DEC plan has been submitted in time (D12.1) and now also includes a video presentation about the project topic and goals. The DEC is constantly adjusted to the needs and opportunities that are emerging.

In this respect and as part of **Task 12.2**, WP12 has placed additional emphasis on engaging EU agencies in the project, successfully involving FRONTEX and the European Fisheries Control Agency in contributing to the survey on chemical munition contamination for WP8. While European cooperation has already been significantly strengthened, collaboration with entities outside the Baltic Sea still requires extra effort to be further strengthened over the remainder of the project lifetime. WP12 also coordinated a joint response to the Call for Evidence on the European Ocean Act, submitted together with CAMMera partners. In close cooperation with WP13, the content of the project website is regularly updated and the project newsletter is issued bi-monthly, sharing both project-specific updates and information on related research within the Munitions in the Sea

¹¹ http://oceanrep.geomar.de/48842/1/geomar_rep_ns_54_2019.pdf

community. WP12 has also coordinated the establishment of the LinkedIn channel “Munitions in the Sea”, supported by eight other projects, creating a central social media hub for the topic.

In parallel, WP12 has established an inter-project communication coordination group with EU- and nationally funded projects on Munitions in the Sea. Meetings are held bi-monthly to exchange information, coordinate joint activities, and support Task 12.4 by consolidating relevant knowledge to strengthen the JPI Oceans Munitions Portal as a central information hub. A booklet covering ongoing projects in the field has been developed, alongside factsheets disseminated via the project website and the Portal.

JPIO successfully applied to the Horizon Results Booster in July 2025. Support includes assessment of the dissemination and exploitation plan, go-to-market assistance, and audio-visual expertise. Go-to-market activities began in September 2025 and will continue throughout the project, supporting in particular Task 12.4 and the development of a long-term sustainability strategy for the Portal. A project video, to be finalized in April 2026, will further enhance dissemination.

As part of **Task 12.2 and 12.3**, WP12 has actively contributed (via posters, panels and workshops) to the following events:

- Dialogue Event: Munition Legacies at Sea and the European Perspective, 17 February 2025, Brussels, Belgium
- Blue Economy Baltic Forum 2025 & Arena 4 Blue Mission BANOS Meeting, 28–29 April 2025, Sopot, Poland
- UN Ocean Conference 3, 9–13 June 2025, Nice, France
- Kiel Munition Clearance Week 2025, 18–20 June 2025, Kiel, Germany
- Fehmarnbelt Days 2025, 14–16 June 2025, Lübeck, Germany
- Kieler Woche, 21–29 June 2025, Kiel, Germany
- Fraunhofer ICT Annual Conference, 23–26 June 2025, Karlsruhe, Germany
- Accelerating the Mission: A Danish EU Presidency Conference for the Restoration and Sustainability of Europe’s Ocean and Waters, 23–24 September 2025, Nyborg, Denmark
- Geneva International Centre for Humanitarian Demining (GICHD) Innovation Conference, 28–30 October 2025, Luxembourg
- EUSBSR Annual Forum 2025 “Securing the Future”, 30 October 2025, Sopot, Poland
- Austrian Maritime Conference, 14 November 2025, Graz, Austria
- Marine UXO Survey & Clearance Symposium, 3–5 February 2026, Manchester, United Kingdom

Upcoming events include:

- Side event at the 29th International Meeting of Mine Action National Directors & UN Advisers, 24 April 2026, Geneva, Switzerland (with Solomon Islands, UNDP and UNIDIR)
- Stand and side event at European Maritime Day 2026, 21–22 May 2026, Limassol, Cyprus (with ISPRA and UNEP/MAP)
- Application in preparation for the EU Macro-regional and Sea Basin Strategies Days, 1–2 July 2026, Brussels, Belgium

Additionally, ICT and JPI Oceans are co-convening three dedicated sessions on Munitions in the Sea at the Fraunhofer ICT Annual Conference 2026 (25–26 June 2026, Karlsruhe), with contributions from GEOMAR, SeaTerra and associated partner Cranfield University. The project has also been promoted through partner projects at external events. For example, MMinE-SwEEPER was presented by the IRAP project at the “Unexploded Ordnance: Mitigation in the Marine Environment” conference (7 October 2025, Blyth, UK). Beyond that, JPIO and GEOMAR have discussed MMinE-SwEEPER efforts also at the Black Sea and North Sea CAMMera Workshops in spring 2026. Project partners engaged repeatedly with media outlets. Through the Brussels-based magazine Revolve, JPIO is raising awareness through at least four journal editions, as well as podcasts and press briefings. One press briefing has already been conducted in December 2025 and published on YouTube¹².

¹² https://www.youtube.com/live/E-REcbNZu18?is=tl1gH0jkUMDA&_o



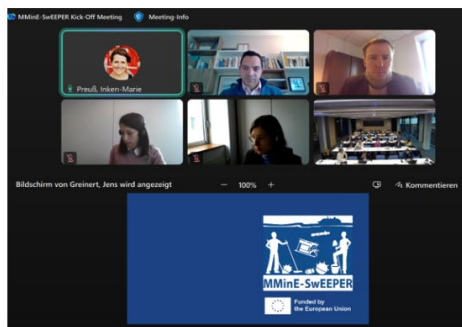
MMinE-SwEEPER consortium partners with representatives of their sister projects MUNIMAP, MUNI-RISK and REMARCO at the UN Ocean Conference in Nice (FR) in 2025 after successfully holding the side event “No Time to Waste: Tackling Submerged Munitions in European Seas”. Credits: Sara Uphoff (GEOMAR)

As part of **Task 12.4**, ICT and JPIO have held regular coordination meetings (at least quarterly, increasing to bi-weekly in spring 2026) to further develop the JPI Oceans Munitions Portal. The first annual editorial meeting with a broader expert group took place in spring 2025. A new feature of the Munitions Portal is a Zotero publication list, developed with GEOMAR and KRD-SH, providing a central repository of literature to support researchers, particularly early-career researchers, and to inform policymakers.

1.2.13 Work Package 13 “Project coordination & management”

WP13 works towards Objectives A and D. During the reporting period, WP13 has successfully implemented the project's coordination and management framework, thereby directly supporting Objective E1, “Strengthen European cooperation on marine munition aspects,” primarily through communication with ESAB and via the project website.

Within **Task 13.1**, GEOMAR established the Project Management Office (PMO) with qualified project and financial managers, and formalized the External Stakeholder Advisory Board (ESAB; D13.1 SAB establishment) with six international members from non-consortium countries, including diverse expertise across science, military, industry, and governmental sectors. The in-person kick-off meeting of **Task 13.4**, was held in Kiel, Germany in November 2024 (M29 Project Kick-Off Meeting), during which the Executive Board (EB) was elected. One year later, in October 2025, the General Assembly was convened online. The PMO organized quarterly EB meetings in an online format. An ESAB online information session was conducted in April 2025, after which ESAB members were integrated into Executive Board progress update sessions to provide expert feedback. Ongoing communication with EU Project Officers was maintained throughout the reporting period. During EB meetings, issues of **Tasks 13.2** and **13.5** were discussed.



MMinE-SwEEPER Consortium partners at the project kick-off meeting in Kiel, Germany 13th & 14th Nov. 2024.

As part of **Task 13.3**, the project website “mminesweeper-munition.eu”¹³ was created and maintained as a central communication platform (D13.3 Project Website), with all consortium partners contributing text content for the website. The website hosts dissemination materials including the first project flyer. The PMO monitored project risks together with the Executive Board, and prepared the administrative amendment for the new Associated Partner Rheinmetall in summer 2025.

1.2.14 Work Package 14 “Ethics requirements”

WP14 does not directly work towards objectives, but relates to Objective B2, B4 and C2, C3. WP14 was implemented as planned during the reporting period, with all deliverables submitted on time. The WP has effectively fulfilled its role in ensuring the project's adherence to ethical standards and regulatory compliance. GEOMAR led the preparation and submission of D14.1 NEC - Requirement No.1, with contributions from NEC partners FFI, UiT and Cran-U. The deliverable demonstrates that all project activities involving non-EU countries are designed and implemented in full compliance with EU ethical standards. GEOMAR also managed the development and delivery of D14.2 EPQ - Requirement No.2, outlining measures to manage safety risks, minimize environmental impact, and ensure compliance with relevant health and safety procedures, thereby demonstrating that all project activities are conducted responsibly and ethically. RMA led the preparation and submission of D14.3 AI - Requirement No.3, working collaboratively with partners IQUA, CNR and GEOMAR, providing specialized expertise on ethical aspects of artificial intelligence within the project context.

#\$WRK-PLA-WP\$# #@\$IMP-ACT-IA@#

¹³ <https://mminesweeper-munition.eu/>

1.3 Impact

1.3.1 Projects pathway towards impact

Answering to the expected outcomes of the call on improving civilian capabilities with respect to a) enabling existing knowledge (WP1, 2, 9, 11, 13), b) detecting UXO and c) identifying, classifying, assessing UXO (WP 3 – 6, 8, 10), the project made great progress on compiling existing information and advancing technologies through new approaches, joint developments and tests in the field. Furthermore, we developed new technologies with respect to the expected outcome d) on inspecting and handling UXO (WP7). The contribution towards these targeted outcomes are described above as part of the Objective section (Page 2) and are further illustrated in the Work Package descriptions (Page 13). MMinE-SwEEPER runs for 42 months and in this first interim report, it is still expected that substantial progress will be made. We foresee impact even beyond the initial scope of MMinE-SwEEPER, as a number of other munition-related projects like REMARCO, MUNIRISK or MUNIMAP will finish before the end MMinE-SwEEPER. This makes MMinE-SwEEPER the project as the currently final project with dedicated tasks for compiling and distributing information.

Particularly through the work in WP1, 2, 12 and 13 the project gained wide recognition on European and international level between all levels of targeted stakeholder groups. Joining forces with the above-mentioned projects opened up an even wider group of stakeholders. MMinE-SwEEPER is seen as an accessible, visible and responsive project when it comes to the general topic of munitions in the sea.

Technical developments are currently entering a stage where tests have been and will be conducted, particularly when using USVs and AUVs in tandem. Summer and autumn of 2026 will be critical to make progress in this respect and advanced approaches will be shown by project partner IQUA Robotics during the REPMUS exercise in September. The October cruise with RV ALKOR will show how mature the advancements are.

1.3.2 Measures to maximise impact

Dissemination plan: AT the current stage, our dissemination plans are still in agreement with the ideas of the Description of the Action (DoA). We plan to use the Marine Munitions Knowledge Platform of JPI-Oceans for our long-term knowledge dissemination tool. During the project phase, we will continue using our established means of workshops, participation in international conferences and meetings, having our webpage and newsletters up-to-date and engaging proactively with a very diverse group of stakeholders on administrative, technical, societal and scientific level. We continue adapting our DEC plan based on upcoming opportunities (as the REVOLVE webinar, the Horizon Results Booster, or the EMD 2026).

Plans for commercial exploitation: Impact pathways and enablers for exploitation are outlined in the Plan for Dissemination, Exploitation and Communication (D12.1) and further discussed in the context of services provided by the Horizon Booster to the project. Companies as SeaTerra, north.io and IQUA-Robotics will use the gained knowledge to improve their products and services. In cooperation with the EOD Service Schleswig-Holstein (KRD-SH) and other German partners, the development of an “Advanced training course on the planning of Marine Munition UXO clearance” is ongoing with the goal of having a complete course planned by the end of 2026. How, and to what extent this will be commercialised, still needs to be seen.

Managing intellectual property: As written in the DoA and Consortium Agreement, knowledge generated by one partner belongs to this partner. At the moment we are still in the stage focusing on FAIR data and results publication. Should there be the need at a later stage to transfer IP from one partner to the other (for commercialisation), the conditions will mainly be discussed between the interested parties. The management board will support this process. With ongoing and successfully tested technologies we will see when and if such steps are needed. Sensitive or dual-use technologies are subject to additional scrutiny by the Security Advisory Board. The consortium does not foresee extensive patenting but recognises the commercial importance of certain outputs, especially software modules, robotic hardware, and data-sharing platforms. For these cases, IP arrangements

are explicitly set out, balancing partner interests with project-wide commitments to openness and knowledge transfer.

1.3.3 Summary

As part of the project application we defined 12 Examples that summarise the Impact of the project by linking to one or more of the targeted objectives. In the Description of the Action they are outlined in the Table of Chapter 2.3. All of these Examples made progress with eight of them having reached milestones or created deliverables already. All Examples and their progress are explained below.

Example 1: Compile knowledge on technology, strategies and management		Objectives: A & D
Activities Implemented: Many WPs worked on compiling and gathering information. WP 1 & 2 initiated the compilation of methods and strategies to remediate marine submerged munitions in EU countries. As part of this, a stakeholder dialogue was initiated to compile their needs and challenges for munition remediation. WPs 3, 4, 5, 6, 8, 9 and 11 compiled state of the art technical knowledge and generated first drafts of documents aimed at Best Available Technology reports. WP12 has established an inter-project coordination group on communication with other related EU and nationally funded projects. In addition, factsheets on the topic, as well as overviews of the various ongoing projects have been compiled and shared via a booklet, on the JPI Oceans Munitions Portal and on the project website. The new Zotero database “Resources Munitions in the Sea” compiled beyond that a list of more than 850 publications on the topic.	Outputs delivered: • WP1 & 2 reached Milestones 1 (Stakeholder list) and 2, 4, 5 and 6 as different stakeholder workshops. D1.1. and D1.2. • WP3 reached two milestones (M7 & M8) and produced D3.3. • WP5 reached M11, M12 and M13 and produced D5.1, D.5.2 and D5.4. • WP6 submitted D6.2 which is linked to WP4. • WP8 reached M18 and produced D8.1, D8.3 and D8.5. • WP9 produced D9.1 • WP11 produced D11.1	Target Groups Reached: National responsible entities; EU govern. bodies, EU agencies (Frontex, EFCA), UXO companies, maritime industry, environmental NGOs, science & academia, international organizations like GICHD and the UN.
Impact achieved so far: The compiled information so far opened up great opportunities for an EU-wide solid foundation for supporting governmental bodies and other decision makers with state-of-the-art knowledge. It strengthened cooperation with all EU-funded munition related projects and stimulated discussions related to integration of content from those projects on the JPI Oceans Munitions Portal. The work positioned the project and its consortium as go-to-experts on the topic of munitions in the sea at a European and truly international level (UN)	Changes to expected impact / adaptation: In light of ongoing developments related to the European Commission plans regarding the development of an UXO removal strategies for various European sea basins, as well as increased global discussions on maritime security, this will likely impact the scope and prioritization of knowledge compilation on specific aspects around the topic. Different UN-related organizations want to participate on that knowledge which will open up new opportunities.	Next steps: We will prepare additional workshops focused on technology used and on decision making. Deliverable 1.3. will synthesize all these needs, and deliverable 2.1 will compile the regulations and management approaches. Further developing and updating the JPI Oceans Munitions Portal. We are considering updating the IMAS Standards on marine munition detection and remediation (IMAS 09.69) in cooperation with GICHD.
Overall progress so far: ■ ■ □ □ □ = 40%		

Example 2: Distribute technical knowledge, train and build up capacities		Objectives: D
Activities Implemented: Through WP10 We are constantly transferring knowledge during research cruises but also during our scientific meetings, workshops and conferences among project partners and to their stakeholders. In WP 11 and through the knowledge compiled in Example 1, we are now stronger engaging in webinars. WP12 and WP13 are promoting the topic and the outcomes to all different stakeholder groups using social media, the webpage, fact sheets, and conferences.	Outputs delivered: • WP11: First training material compiled M21. • WP12: Project video generated, DEC document generated (D12.1) • WP13: Project webpage running and const. updated; we reached M22, M23 and produced D13.3	Target Groups Reached: International organizations; representatives of Environmental and Water Management Ministries; representatives of the offshore sector, and members of the marine munition scientific community.
Impact achieved so far: Cooperation has been established with other projects related to marine munitions. Great recognition of the project on an international level (EU and globally). Capacity building activities are underway, and the first webinars will start soon.	Changes to expected impact / adaptation: None	Next steps: We are currently organizing three webinars (next on 29. May 2026) and will be adaptive to needs and demands to come. The JPIO Munitions Portal will constantly be updated as will the webpage
Overall progress so far: ■ ■ □ □ = 40%		

Example 3: Establish status of munitions pollution in European water		Objectives: C
Activities Implemented: Partners who went at sea during our several cruises took water and sediment samples during these cruises, mainly in the Baltic Sea. As part of WP8, we initiated an EU-wide sampling approach through project partners and other stakeholders. We got in contact with FRONTEX and the European Fishing Control Agency, who agreed on taking additional water sampling. Through other partner projects, samples were taken in several places around European waters.	Outputs delivered: • Sample locations are shown online at https://marine-data.de/view-ers/da17ea0f-c994-4509-b47a-10e6eefbec63 • How to sample and treat water is described on the MMinE-SwEEPER webpage at https://mminesweeper-munition.eu/04_engage/ • M18 achieved	Target Groups Reached: Single persons, governmental bodies, scientific partners and other official entities
Impact achieved so far: We promoted the need for sampling water in European Seas and Oceans and got in contact with previously not considered stakeholders such as FRONTEX. We got in contact with authorities of the Solomon Islands and Palau.	Changes to expected impact / adaptation: -	Next steps: We will continue to send out sampling kits to perform analyses. Once we established a good data base we aim to write a scientific publication
Overall progress so far: ■ □ □ □ = 20%		

Example 4: Advance munitions compound analytical capabilities, MC and CWA		Objectives: B
Activities Implemented: GEOMAR is constantly advancing the Xplotector system to perform analyses of explosive compounds directly on board. The same system is used onshore to run samples from our EU-wide sampling. To carry out the specialized nuclear physics testing, IOPAN successfully prepared and completed the full tender procedure for testing neutron activation technologies for in-situ	Outputs delivered: • D8.3 and D8.5 produced	Target Groups Reached: So far project partners are informed.

CWA analyses. As a result, experts from Jagiellonian University were engaged to perform Monte Carlo simulations and laboratory irradiation experiments using fast neutron generators.		
Impact achieved so far: Limited to project partners	Changes to expected impact / adaptation: -	Next steps: We will continue advancing the systems and approaches and report on new progress as it comes.
Overall progress so far: ■ ■ □ □ □ = 40%		

Example 5: Develop grabbing system for semi-automated munitions clearance		Objective: B
Activities Implemented: in WP7, both software and hardware designs for the grabber have been completed. All components have been ordered, and the actual building has started.	Outputs delivered: • Background assessment of software has been completed (M16) • Grabber software developed • 'Dummy' targets have been gathered for testing	Target Groups Reached: Other UXO companies and EOD services. To them we will reach out once the grabber is operational.
Impact achieved so far: No direct impact yet.	Changes to expected impact / adaptation: The Grabber will be tested along with the large crawler to provide a more robust and realistic basis.	Next steps: Building will continue (both hardware and software). Testing will begin as soon as feasible.
Overall progress so far: ■ ■ □ □ □ = 40%		

Example 6: Enhance automated munitions identification methods in object-scale data		Objectives: B
Activities Implemented: WP3 was working on image acquisition in cooperation with WP10. WP3 partner IOPAN was working on acoustic camera applications and GEOMAR acquired forward looking sonar data for automated detection. Partners involved in WP5, in particular IQUA and CNR have started to develop first models individually with a focus on their area of expertise. So far emphasis was on the optical camera data, where an initial classification model has been trained. A multi-modal model which integrates geometric information derived from the photogrammetric process is in preparation but not ready yet. Furthermore, a model for acoustic camera data is in development.	Outputs delivered: • WP5 has so far generated first prototypic models that are being handed over to WP6 • M12 and M13 reached • D3.3 produced	Target Groups Reached: Partners from the project consortium so far.
Impact achieved so far: No impact has been achieved yet outside the project	Changes to expected impact / adaptation: -	Next steps: WP5 will hand over prototypic models to WP6, improve them based on feedback and develop additional approaches based on field tests in summer and autumn 2026. Work in WP3 and WP10 will continue to sharpen the field applications and inform WP5 about new

		approaches and findings.
Overall progress so far: ■ □ □ □ □ = 20%		

Example 7: Multi-vehicle cooperative missions		Objectives: B
Activities Implemented: In WP6, strategies and software have been developed and agreed on for USV and AUV interaction, by partner GEOMAR and IQUA. Partner UiT published a paper about "Mission Planning Framework for Autonomous Marine Vehicles in Seabed Surveys" and prepared its USV for running a multibeam system. GEOMAR reported on smart magnetic AUVs	Outputs delivered: - Agreed on communication protocol - Implementation of smart algorithms for path planning in adaptive missions - Tests of adaptive path planning in the field during WP10 activities - D6.2 produced	Target Groups Reached: Currently project partners only.
Impact achieved so far: No impact outside the project achieved so far.	Changes to expected impact / adaptation: -	Next steps: Sea trials with data communication between surface vessels and AUVs will be conducted throughout the second half of 2026. Testing of autonomy will also be carried out by partner IQUA during the REPMUS trials in late summer.
Overall progress so far: ■ ■ □ □ □ = 40%		

Example 8: Support munitions clearance decisions through 3D-object reconstructions		Objectives: B
Activities Implemented: The derivatives of the photogrammetric process, i.e. the reconstructed 3D geometry and the DEM of photomosaic images has been exploited to enhance the performance of detection and identification (see example 6). The aim is to help clearance operations, e.g. by objectively quantifying the number of overlapping munition objects	Outputs delivered: Approaches on how to analyse images and their 3D DTM have been tested and currently verified.	Target Groups Reached: So far only project partners. Later UXO companies and EOD services who have to make decisions about how to handle munition objects.
Impact achieved so far: The usefulness of photomosaics has been acknowledged during the German Immediate Action Program. Methodological impact has not been achieved outside the project yet.	Changes to expected impact / adaptation: -	Next steps: Continue testing and finalize procedures. Link 3D-object reconstruction with other 2D sensor data. Discuss with EOD and UXO company stakeholder's application and implementation scenarios.
Overall progress so far: ■ □ □ □ □ = 20%		

Example 9: Enable secure data exchange of sensitive data		Objectives: B
Activities Implemented: WP5 has established a dedicated data management plan (DMP) with input from other partners and SEB members. This DMP outlines what and how data is being handled and on which platforms based on the FAIR principles. Furthermore, an initial data platform has been set up based on north.io's Ocean Data Platform TrueOcean in order to	Outputs delivered: - The initial data platform is operational and first data sets have been compiled. - D5.1 and 5.2 produced - M11 achieved	Target Groups Reached: So far partners from the project consortium and SEB members have been reached.

facilitate secure data collection and exchange between partners.		
Impact achieved so far: WP5 has not achieved any impact outside the project so far. The envisioned secure data exchange platform is fully functional.	Changes to expected impact / adaptation: -	Next steps: The platform will be further improved based on feedback collected within WP5 (Task 5.3).
Overall progress so far: ■■■■□ = 80%		

Example 10: Enhance automated munitions detection and classification methods in regional-scale data		Objectives: B
Activities Implemented: Partners involved in WP3 and 5 have started to develop first models individually with a focus on their area of expertise. So far, a supervised detection model for SSS and SAS has been developed as well as a generic unsupervised anomaly detection models based on multibeam derivatives. Analyzing SSS data has been targeted by RMA, GEOMAR, north.io and WTD-71, and the approaches are currently being evaluated against each other. Jointly partners compiled AI approaches. Ethics about the use of AI has been discussed.	Outputs delivered: • Prototypic models developed with WP3/10 data by WP5 • D5.4 produced • D14.1 produced	Target Groups Reached: So far project partners only.
Impact achieved so far: No impact outside the project yet.	Changes to expected impact / adaptation: -	Next steps: Approaches are being handed over to WP6 for integration into AUVs. Testing in 2026 will evaluate the approaches. IQUA and WTD-71 will be present at REPMUS 2026.
Overall progress so far: ■■□□□ = 40%		

Example 11: Make AUVs smarter through magnetic, optic and acoustic sensing		Objectives: B
Activities Implemented: GEOMAR tested smart AUVs in relation with magnetic sensing successfully. Path optimization has been implemented and approaches reach substantial time-saving with respect to regular lawn-mowing patterns. Implementation of AI approaches developed in WP5 are being implemented. All envisioned sensors have been implemented on the AUVs (optical cameras, magnetics, SSS, MBES, and FLS)	Outputs delivered: No output generated to the outside world. D.6.2 produced	Target Groups Reached: So far, project partners have been reached (i.e. IQUA & GEOMAR). Others will come as soon as the technology is running.
Impact achieved so far: WP10, no impact outside the project achieved so far.	Changes to expected impact / adaptation: -	Next steps: Integration of algorithms from WP5 is ongoing in WP6 and will be tested as part of WP10 in 2026 during several cruises.
Overall progress so far: ■■□□□ = 40%		

Example 12: Improvement of BiP with respect to environment and costs		Objectives: A, D
Activities Implemented: FFI compared HOD and LOD, related to facts, impacts and costs. It was found that there are still gaps in	Outputs delivered: • Work on Task 9.2, including surveys on the	Target Groups Reached: project partners, EOD services

standardization, new approaches and potential protective measures were outlined. The findings of the project partner WTD-71 regarding studies of blasting operations and their effects were also considered. Further research into mitigation measures has been made in Task 9.2 by Fraunhofer ICT.	procedures actually used and the associated mitigation measures • D9.1 produced (Onsite LOD and HOD)	of the different EU members
Impact achieved so far: Section D9.1 has provided a clearer overview, even for those project partners not directly involved. No impact yet outside the project.	Changes to expected impact / adaptation: Better risk assessment and decision making regarding ERW disposal methods.	Next steps: Finish Task 9.2 and the connected D9.3 by analysing the EOD service feedback, literature and practical research regarding possible mitigation measures. Cooperate with WTD-71 and the TRANKIEL project running in Kiel, Germany.
Overall progress so far: ■ ■ ■ □ □ = 60%		

1.4 Update of the plan for exploitation and dissemination of results

JPI Oceans and GEOMAR have started, in April 2026, the module "2.1 Dissemination Support" in their cooperation with the Horizon Results Booster. Here experts from the Horizon Results Booster have offered to review the current DEC Plan and give advice on adjustments and potential necessary updates. After this review, the DEC plan will be thoroughly updated before the mid-term meeting in September 2026 and then discussed with the consortium. Some notable updates are:

- The project video has been finished in May 2026 and will be shown for the first time during the European Maritime Day 2026 and promoted on Social Media and beyond.
- To further strengthen the impact of DEC activities and offer space for more strategic discussions on the topic of Munitions in the Sea, next to the Munitions Communication Coordination Group a quarterly exchange between project coordinators of the same projects was initiated in April 2026.
- On the JPI Oceans Munitions Portal new subpages on "Engage" and "Events" were added to raise awareness for outreach activities.
- With regard to impact on policy and governance on the international level, MMinE-SwEEPER has increased their exchange with UN entities and in April 2026 was invited to start contributing to a review process on the International Mine Action Standard 09.60 on Underwater survey and clearance of explosive ordnance (EO).

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2. FOLLOW-UP OF RECOMMENDATIONS AND COMMENTS FROM PREVIOUS REVIEW(S)

n/a

#§FOL-UP-FU§# #@IMP-ACT-IA@#

3. EXPLOITATION PRIMARILY IN NON-ASSOCIATED THIRD COUNTRIES

n/a

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4. OPEN SCIENCE

Knowledge Compilation: All information that is currently compiled in deliverables about technologies, approaches and best practices will be made public (open access). Currently we are discussing the means of publication, e.g. as a GEOMAR report, as publications along with UN standards or as peer-reviewed publication in appropriate journals. Now that we have adequate output generated, we are able to consider the best possible means for distribution. Open access and FAIR principles will drive or considerations.

Field Data: At the time of the 18-month report, no publicly usable data have been generated or have been released. MMinE-SwEEPER deals with sensitive data on munitions in the sea and the large amount of data gathered and compiled are currently used by the project partners to e.g. test the capabilities of the data exchange platform, train AI models or plan upcoming cruises. Once further results have been achieved, we will consider how to anonymise geographic data and publish them as benchmark data sets e.g. for AI training alongside our results.

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5. DEVIATIONS FROM ANNEX 1 AND ANNEX 2

5.1 Tasks/objectives

After 18 months in the project we see all WPs and Tasks on track and do not foresee problems in the future. Due to the collaboration with a number of other EU funded projects to the topic we are constantly adjusting deliverables in cooperation so that synergies and complementarities are used and promoted.

5.1.1 Deviations Formalized through Amendments

The following changes to Annex 1 (Description of Action) were formally approved through amendments to the Grant Agreement. No changes to Annex 2 (Estimated Budget) were made during the reporting period.

Amendment Ref.	Type of Change	Description	Impact on Project Implementation	Impact on Budget
AMD-101167839-5 (launched 18 Feb 2025; accepted 14 May 2025)	Addition of Associated Partner	Rheinmetall was added as an Associated Partner. Annex 1 (Description of Action) was updated accordingly to include R's contribution to WP1, WP2 (particularly Task 2.1 on legal frameworks), WP9, WP10, WP11 and WP12. R brings over 130 years of experience in munitions and explosives, including expertise in the salvage, inspection and environmentally compatible disposal of underwater ordnance.	Strengthened the consortium's technical and operational expertise, particularly regarding underwater ordnance management and legal/regulatory aspects. The addition supports implementation across multiple work packages and enhances collaboration with national and international stakeholders.	No change to Annex 2 (Estimated Budget).
Amendment No. AMD-101167839-13 (launched 17 Feb 2026; accepted 31 Mar 2026)	Correction of Deliverable Title and Lead Beneficiary	Deliverable D11.1 was corrected to align with Task 11.1 "Report on Historical Data Analyses", with KRD-SH designated as the lead beneficiary. The amendment corrected an inconsistency originating during the proposal writing and GAP preparation phases, where the deliverable title and responsible beneficiary had been incorrectly assigned. Annex 1	The amendment ensured full consistency between Deliverable D11.1 and Task 11.1 in WP11 concerning historical data analyses for munition detection, clearance and risk assessment. D11.1 covers methodologies for historical data compilation and analysis, GIS-based identification	No change to Annex 2 (Estimated Budget).

		(Description of Action) was updated accordingly.	of UXO suspect areas, and the use of automated document analysis tools (ErPad). The correction did not affect the project scope, objectives, timing, resources, or implementation.	
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5.1.2 Deviations Implemented without Amendment

The following deviations from Annex 1 (Description of Action) were implemented during the reporting period and did not require a formal amendment under the Grant Agreement provisions. No deviations from Annex 2 (Estimated Budget) occurred during the reporting period.

Deviation	Reason	Corrective Action	Impact
Rescheduling of Milestone 5 “Workshop on ‘Security Risks and Mode of Operation’” to April 2026	Additional time was required to engage with relevant stakeholders and parties across Europe.	The revised schedule was agreed upon in consultation with the EU Project Officer to ensure broader stakeholder participation and higher quality workshop outcomes.	No impact on overall project objectives or implementation capacity.
Rescheduling of Milestone 6 - “Workshop on ‘Assessment and Decision Making’” to June 2026	The consortium decided to align the workshop with the expected publication of the MUNIMAP policy report (January 2026), addressing related issues in the Baltic Sea region.	The revised timing allows incorporation of relevant policy findings into workshop discussions and outputs. The updated timeline was agreed with the EU Project Officer.	No impact on project scope or expected results; improved alignment with external policy developments. The workshop was ultimately held earlier than expected, on 24 February 2026, so the planned rescheduling was not required.
Minor updates to submitted deliverables following feedback from the EU Project Officer (March 2026)	Several deliverables required small revisions and clarifications after review by the EU Project Officer.	The consortium implemented the requested changes and resubmitted the updated deliverables within the requested timeframe.	No impact on project objectives, timeline, or budget.

5.2 Use of resources

See above chapter 5.1.

5.2.1 Unforeseen subcontracting (if applicable)

n/a

5.2.2 Unforeseen use of in-kind contributions

n/a

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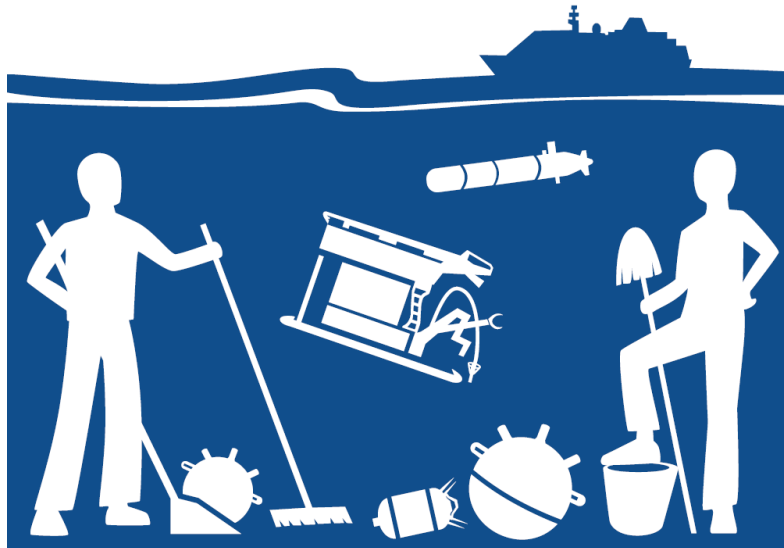


MMinE-SwEEPER

Compilation of Milestone Reports

First Interim Reporting Period

- M1** Stakeholders enrolled
- M2** Stakeholder Workshop 1
- M4** Workshop on “responsibilities and legal frameworks”
- M6** Workshop on assessment and decision-making
- M7** First compilation on best practices of hydroacoustic spatial mapping
- M8** First compilation of best practices of optical studies and photogrammetric reconstructions
- M11** Initial data platform is set up
- M12** First AI-models and code for detection on spatial data
- M13** First AI-models and code classification on optical/acoustic camera data
- M16** Mission Control Report
- M18** Samples for baseline chemical analysis collected from project stakeholders
- M19** Planning of trials in “artificial mine gardens”
- M20** Application for ship time and cruise planning
- M21** First training materials (munition detection/remediation and environmental studies)
- M22** Digital news, newsletter and social media
- M23** Project flyer
- M29** Project Kick-Off Meeting



MMinE-SwEEPER

Milestone Report

Milestone No. 1: Stakeholders enrolled



Funded by
the European Union

Authors | Maria del Rosario Dominguez, Markus Helavuori

Contributing organisations:



DOCUMENT TRACKING DETAILS

Project Information

Project acronym	MMinE-SWEEPER
Project title	Marine Munition in Europe - Solutions with Economic and Ecological Profits for Efficient Remediation
Instrument	Horizon Europe
Grant Agreement	No. 101167839
Starting date	1 October 2024
Duration	31 March 2028
Project Coordinator	GEOMAR Helmholtz Centre for Ocean Research Kiel

Milestone Information

Milestone Name	Stakeholders enrolled
Milestone Number	1
Work Package (WP)	1
Related Task (s)	1.1.
Milestone Beneficiary	HELCOM Secretariat
Author(s)	Maria del Rosario Dominguez, Markus Helavuori
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Submission date	29.01.2025
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Disclaimer

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This document contains information on MMinE-SwEEPER's core activities. Any reference to content in this document should clearly indicate the authors, source, organisation, and publication date.

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 Stakeholders enrolled as of Month 4 (January 2025)	6

Stakeholders enrolled

Summary

In October 2024 MMinE-SwEEPER began outreach collaborators and associated partners from HELCOM, NATO and JPI Oceans, and invited them via email to become stakeholders for the MMinE-SwEEPER project and to disseminate the invitation within their community. During the Kick-off Meeting of the project, held on 13–14 November 2024, we discussed this preliminary list and uploaded it to the project intranet platform allowing other project partners to contribute with their suggestions.

The roster of stakeholders is a living document and will be continuously updated allowing new participants to join, especially during the first half of the project's duration. This milestone is a report of the enrolment status of stakeholders due as of January 2025 (month 4 of MMinE-SwEEPER).

The roster of stakeholders is expected to cover all European marine waters and working or in different social sectors to gather diverse perspectives for the stakeholder dialogue (see Deliverable 1.1. Stakeholder community).

Another noteworthy mention is the collaborative approach taken by MMinE-SwEEPER with other European Commission funded projects, especially MUNIMAP and MUNI-RISK. We have created a joint workgroup to coordinate communications with common stakeholders across these three projects, and ensure synergy, minimize overlapping efforts, and prevent stakeholder fatigue.

This milestone is the first step for establishing a well-connected and diverse community of experts, the objective D1 of MMinE-SwEEPER.

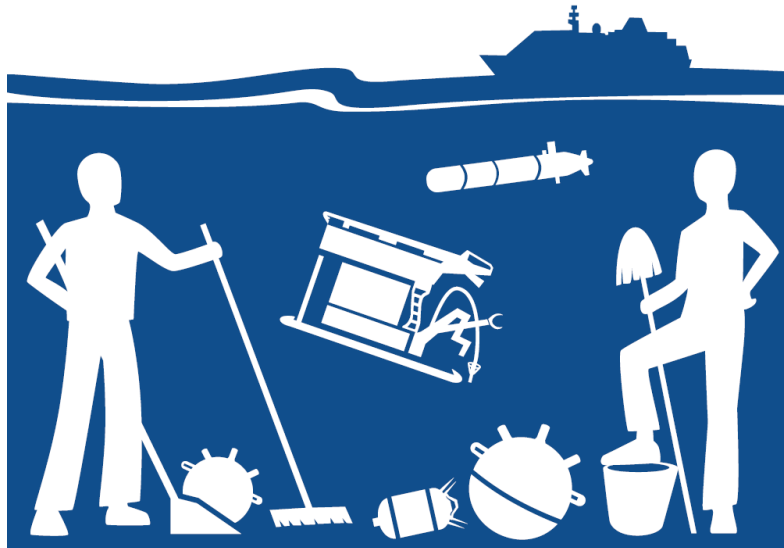
Stakeholders enrolled as of Month 4 (January 2025)

At the end of January, we invited 80 stakeholders from various stakeholder groups. Of these, 17 confirmed their collaboration, 2 declined, and the remaining invitations are still pending a response. We expect to expand the stakeholder roster by collaborating with other projects and by participating in and organizing new workshops and questionnaires.

The current roster of stakeholders includes national governmental (7) and intergovernmental (2) organizations, private-sector entities (3), non-profit organizations (3), and one research institution. Most collaborators are based in the Baltic and North Sea regions (see Table 1).

Table 1. Stakeholders enrolled as of end of January 2025 (Month 4). Columns from left to right indicate the name of the Organization, the Sector and Subsector of the activity, the Operational Territory and Sea region.

Organization	Sector	Subsector	Operational	
			Territory	Sea
Belgium Navy, EOD unit	Government	Security	Belgium	North Sea
Former (Belgisch Militair)	Government	Security	Belgium	North Sea
Institute of Natural Sciences, Operational Directorate Natural Environment	Government	Environment	Belgium	North Sea
Ministry of Defence / Navy Headquarter / Action of State at Sea	Government	Security	France	North Sea
Mecklenburg Vorpommern, Munition department	Government	Security	Germany	Baltic Sea
Swedish Agency for Marine and Water Management	Government	Research	Sweden	Baltic & North Sea
John Nurminen Foundation	Non-profit	Foundation	Finland	Baltic Sea
WWF Baltic	Non-profit	Environmental NGO	International	Baltic Sea
The North Sea Foundation	Non-profit	Foundation	Netherlands	North Sea
KIK Environmental investment centre	Private	Other	Estonia	Baltic Sea
EDF Renewable Energy	Private	Economic activity	France	North Sea
Greenoffshore Stockholm AB	Private	Economic activity	Sweden	Baltic Sea
The Finnish Institute for Verification of the Chemical Weapons Convention	Academia	Research	Finland	Baltic Sea
EU Military Staff	Government	Security	International	EU marine waters
Barcelona Convention, United Nations Environment Programme (UNEP) - MAP	IGO	IGO	International	Mediterranean Sea
Black Sea Commission	IGO	IGO	International	Black Sea
European boating association	Non-profit	Recreational association	International	International



MMinE-SwEEPER

Milestone Report

Milestone No. 2: Stakeholder Workshop 1



Funded by
the European Union

Authors: Hans Sanderson, Frank Akowuge Dugasseh, Delove Abraham Asiedu, Maria del Rosario Domínguez Carrasco

Contributing organisations:



DOCUMENT TRACKING DETAILS

Project Information

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Grant Agreement	No. 101167839
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Duration	31 March 2028
Project Coordinator	GEOMAR Helmholtz Centre for Ocean Research Kiel

Milestone Information

Milestone Name	Stakeholder workshop 1
Milestone Number	2
Work Package (WP)	1
Related Task(s)	Task 1.2. Dialog of requirements
Milestone Beneficiary	Aarhus University
Author(s)	Hans Sanderson, Frank Akowuge Dugasseh, Delove Abraham Asiedu, Maria del Rosario Dominguez Carrasco
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Milestone 2 ‘Stakeholder Workshop 1’

Introduction

MMinE-SwEEPER aims to analyse key concerns and requirements for remediating marine munitions from a multisectoral stakeholder perspective in WP1 and together with the stakeholders revise the legal framework for a better remediation strategy in WP2. For these tasks, MMinE-SwEEPER is organising several activities, including surveys and workshops under these two interconnected WPs. Thus, at the outset of the project, two workshops were jointly held during the Kiel Munition Clearance Week 2025: the “Stakeholder Workshop 1” (Milestone 2), which is the focus of this report, and the “Workshop on Responsibility and Legal Framework” (Milestone 4), reported separately. These workshops contribute to develop MMinE-SwEEPER objective A2. Compilation of stakeholder needs.

Collaboration with EU-(Co)funded projects

Since February 2025, MMinE-SwEEPER has collaborated with the EU-(co)funded sister projects MUNI-RISK and MUNIMAP to align efforts and engage shared stakeholders (see Deliverable 1.1. Stakeholder Community). These collaborations include participation in joint events to support ongoing dialogue with stakeholders.

It was expected that participation during the Kiel Munitions Clearance Week (18-20 June 2025) will include a large community of stakeholders from different activity sectors—private sector, public institutions, administrative bodies, and governmental organisations. To take advantage of this broad and relevant audience, we decided to organise both workshops (M2 and M4) during the conference on a two-day session on 18 and 19 June as described in the following chapter.

2-days of Stakeholder Workshops

Day 1 Stakeholder Workshop. World Café (18 June 2025)

The stakeholder workshop was conducted using the World Café format. Participants were divided into three rotating groups, each discussing two key questions per table for 20 minutes, and their ideas were posted and gathered on a flipchart. After each round, groups rotated to a new table, ensuring diverse input across all topics. The session concluded with a plenary presentation of the gathered responses.

The topics and two main questions discussed in each table were the following:

- Table 1: Risk Assessment (Prioritisation criteria)

Context: We are planning the remediation of submerged marine munitions, e.g., in the Baltic Sea - how and where should we prioritize, recognizing we cannot remediate all - which criteria should be involved in the risk-based decision making - for *prioritization*:

- **Q1:** Prioritization of sites to remediate - but by which risk criteria?
- **Q2:** For *Environmental Impact Assessment* of offshore infrastructure what type of information is most required?

- Table 2: Remediation (Needs and Responsibilities)

Context: When performing munitions clearance and remediation, what are the most important aspects to consider in terms of environmental, economic, security and safety potential risks of the remediation activities? Responsibilities and requirements

- **Q1:** When implementing or considering the implementation of remediation of dumped munition (both conventional and chemical) what are the most important needs; protection aims; requirements and limitations that you can identify?
 - **Q2:** What are the most important risks to understand and protect against during and after remediation? Who has (or should have) the responsibility to do remediation and therefore protect against the risks?
- Table 3: Regulation (Challenges)

Context: Is the current legal framework enough to initiate remediation, considering also the environmental impacts or clearance of single objects? what is the current situation in other countries? Is the legal framework in Europe fulfilling Palanga's commitments?

Hypothetical case: Chemical or conventional munitions are found in the way of an offshore installation in your country:

- **Q1:** Have you experienced any legal challenge regarding who/how to deal with removing the ammunitions? What are (or could be) these legal challenges?
- **Q2:** Do you see a need for an international/European legal framework and/or national legal framework to do remediation?

The insights collected will be shared among the three projects and further analysed within MMinE-SwEEPER deliverables: Deliverable D1.3 Synthesis of findings and, especially outcomes from Table 3, in Deliverable D2.1. Responsibilities. In brief, the workshop engaged lively discussion with more than 20 participants (although only 16 were officially registered due to the non-mandatory registration system). Feedback was overwhelmingly positive, especially for the inclusive environment that allowed diverse stakeholders to share their perspectives, encouraged open dialogue among them and sparked new ideas for addressing marine munitions in an environmentally responsible, safe and secure way.

Stakeholder Dialogue Workshop
Kiel Munitions Clearance Week, 18 June 2025

➡ Room Denmark 16:35-17:35

Everybody is welcome! 😊

MMinE-SwEEPER

MUNIRISK

Interreg
Baltic Sea Region

Co-funded by
the European Union

Sustainable Waters
MUNIMAP

Co-funded by
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Figure 1. Advertisement of the World Café workshop.



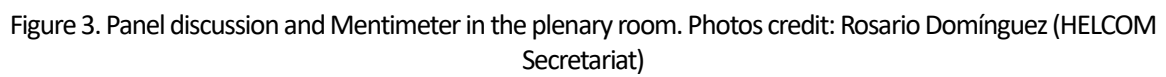
Figure 2. Participants at the three tables and the flip-chart sheets displaying their notes. Photos credit: Agnieszka Jędruch (IOPAN)

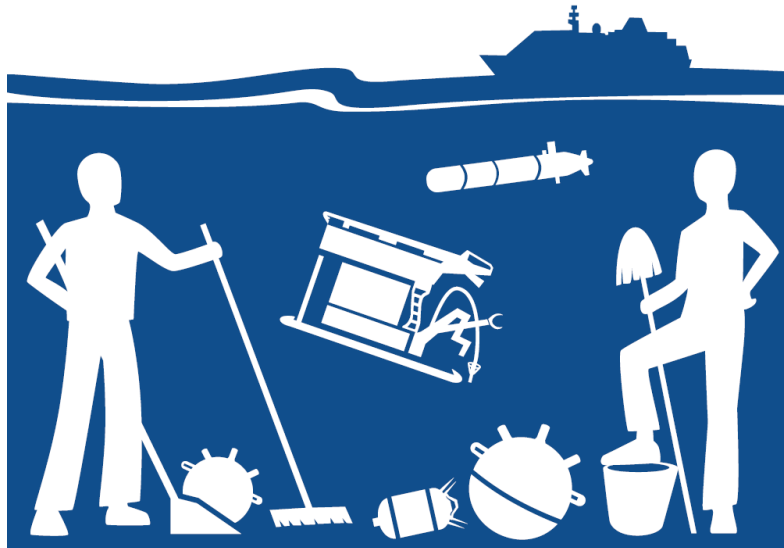
Day 2 Plenary Session and Interactive Engagement. Mentimeter (19 June 2025)

A plenary session featured presentations from all three projects, followed by an interactive segment using the Mentimeter online questionnaire tool. Participants provided input on:

- Concerns regarding marine munitions and remediation actions
- Responsibilities and legal challenges
- Prioritization criteria for initiating remediation efforts

The session was marked by active and constructive stakeholder engagement, with more than 90 respondents to the Mentimeter.





MMinE-SwEEPER

Milestone Report

Milestone No. 4: Workshop on 'responsibilities and legal framework'



Funded by
the European Union

Authors: Maria del Rosario Dominguez (HELCOM Secretariat), Hans Sanderson (AU)

Contributing organisations:



DOCUMENT TRACKING DETAILS

Project Information

Project acronym	MMinE-SWEEPER
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Project Coordinator	GEOMAR Helmholtz Centre for Ocean Research Kiel

Milestone Information

Milestone Name	Workshop on ‘responsibilities and legal framework’
Milestone Number	4
Work Package (WP)	2
Related Task(s)	Task 2.1. Analysis of responsibilities and legal frameworks regarding munition remediation
Milestone Beneficiary	HELCOM Secretariat
Author(s)	Maria del Rosario Dominguez, Hans Sanderson
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Workshop on ‘responsibilities and legal framework’

Introduction

In Work Package 2 (WP2), MMinE-SwEEPER aims to analyse the existing European regulatory and responsibility frameworks relevant to the remediation of marine munitions, focusing on key concerns and requirements identified by stakeholders during the activities conducted in Work Package 1 (WP1). Thus, we decided at the outset of the project to jointly organise two workshops at the same event: the “Workshop on Responsibility and Legal Framework” (Milestone 4 (M4)), which is the subject of this report, and the “Stakeholder Workshop 1” (Milestone 2 (M2)), which is documented separately but referenced here and with common pictures.

Collaboration with EU-(Co)founded projects

Since February 2025, MMinE-SwEEPER has collaborated with the EU-(co)funded sister projects MUNI-RISK and MUNIMAP to align efforts and engage shared stakeholders (see Milestone Report 1: *Stakeholders Enrolled*). This collaboration includes participation in joint events to support ongoing dialogue with stakeholders.

The analysis of the legal and responsibility framework for addressing submerged marine munitions in the Baltic Sea and Skagerrak is a task that MUNIMAP shares particularly with MMinE-SwEEPER. In this context, activities aimed at gathering information and engaging stakeholders and experts on this topic are being coordinated between the two projects.

In this sense the three projects have been present in several events, as at UNOC 2025 side event (briefly described at the end of this report) and at Kiel Munitions Clearance Week (KMCW, 17-20 June, Germany), reported extensively in this milestone since it was the place where the stakeholder workshop took place.

It was expected that KMCW would welcome a large community of stakeholders from different activity sectors—private sector, public institutions, administrative bodies, and governance organisations. To take advantage of this broad and relevant audience, we decided to organise both workshops (M2 and M4) during the conference on a two-day session on 18 and 19 June as described in the following chapter.

2-days of Stakeholder Workshops

Day 1 Stakeholder Workshop. World Café (18 June 2025)

A stakeholder workshop was conducted using the World Café format. Participants were divided into three rotating groups, each discussing two key questions per table for 20 minutes, and their ideas were posted and gathered in a common flipchart. After each round, groups rotated to a new table, ensuring diverse input across all topics. The session concluded with a plenary presentation of the gathered responses.

The discussion topics and the two main questions to discuss were the following:

Table 1: Risk Assessment (Prioritisation criteria)

Context: We are planning the remediation e.g. the Baltic Sea - how should we prioritize where to do this, recognizing we cannot remediate all - which criteria should be involved in the risk based decision making - for prioritization:

Q1: Prioritization of sites to remediate - but by which risk criteria?

Q2: For *Environmental Impact Assessment* of offshore infrastructure what type of information is most required?

Table 2: Remediation (Needs and Responsibilities)

Context: When performing munitions clearance and remediation, what are the most important aspects to consider in terms of environmental, economic, security and safety potential risks of the remediation activities? Responsibilities and requirements

Q1: When implementing or considering the implementation of remediation of dumped munition (both conventional and chemical) what are the most important needs; protection aims; requirements and limitations that you can identify?

Q2: What are the most important risks to understand and protect against during and after remediation? Who has (or should have) the responsibility to do remediation and therefore protect against the risks?

Table 3: Regulation (Challenges)

Context: Are the current legal framework enough to initiate remediation, considering also the environmental impacts or clearance of single objects? what is the current situation in other countries? Is the legal framework in Europe fulfilling Palanga's commitments?. Hypothetical case: Chemical or conventional munitions are found in the way of an offshore installation in your country:

Q1: Have you experienced any legal challenge regarding who/how to deal with removing the ammunitions? What are (or could be) these legal challenges?

Q2: Do you see a need for an international/European legal framework and/or national legal framework to do remediation?

The insights collected will be shared among the three projects and further analysed within MMinE-SwEEPER deliverables: **Deliverable D1.2** and **Deliverable D2.1**. In brief, the workshop engaged lively discussion with more than 20 participants (although only 16 were officially registered due to the non-mandatory registration system). Feedback was overwhelmingly positive, especially for the inclusive environment that allowed diverse stakeholders to share their perspectives, encouraged open dialogue among them and sparked new ideas for addressing marine munitions in a safe and secure way.



Figure 1. Stakeholder Dialogue Workshop, three thematic tables.

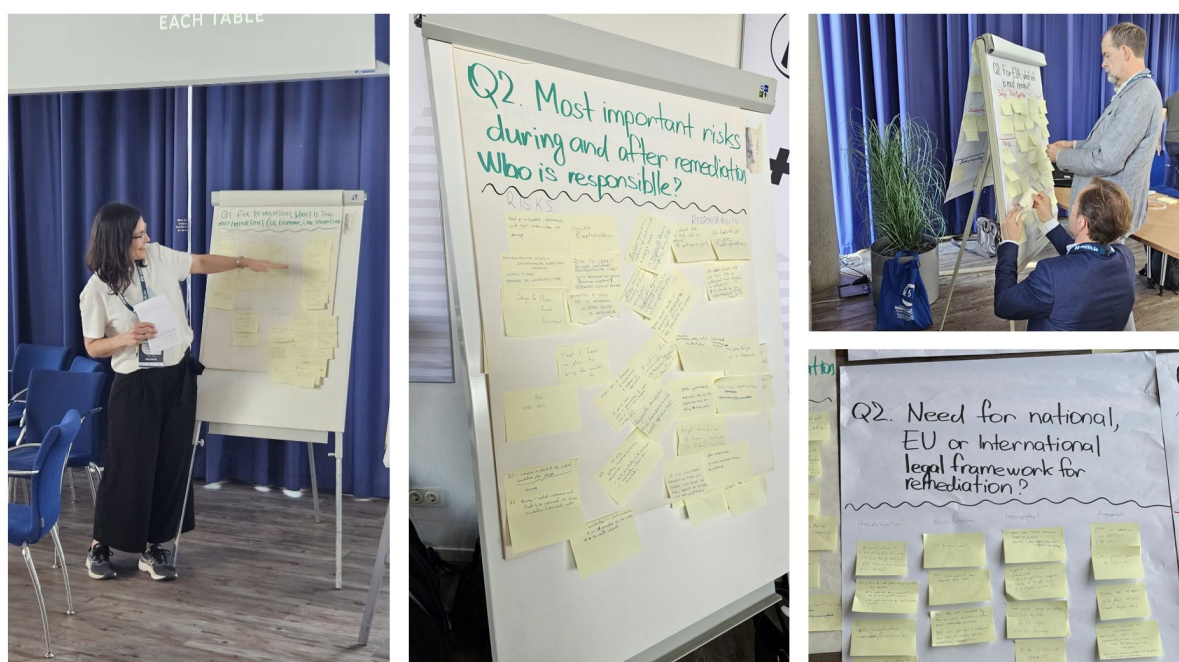


Figure 2. Aggregating participants' responses.

Day 2 Plenary Session and Interactive Engagement. Mentimeter (19 June 2025)

A plenary session featured presentations from all three projects, followed by an interactive segment using the Mentimeter online questionnaire tool. Participants provided input on:

Concerns regarding marine munitions and remediation actions

Responsibilities and legal challenges

Prioritization criteria for initiating remediation efforts

The session was marked by active and constructive stakeholder engagement, with more than 90 respondents to the Mentimeter.



Figure 3. Mentimeter interaction and discussion between the three project leaders and the audience.

Joint participation in the UNOC 2025 side event

11 June 2025 – MMinE-SwEEPER and MUNIMAP jointly participated in the UNOC 2025 side event “No Time to Waste: Tackling Submerged Munitions in European Seas”, held aboard the RV METEOR.

The event welcomed around 80 participants across the world and engaged in a high-level panel discussion involving scientists, policymakers, regional coordinators, and EU leaders with thematic sessions highlighting the latest research on remediating marine munitions in the Baltic Sea and across Europe.

MMinE-SwEEPER and MUNIMAP contributed to the thematic island “Legal Issues”, where they presented their work and took part in dynamic discussions on the legal frameworks, requirements, and challenges involved in addressing submerged munitions in European waters.

The side event was organised by GEOMAR Helmholtz Centre for Ocean Research Kiel, the Baltic Marine Environment Protection Commission (HELCOM), the German Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN) and the German Federal Ministry of Research, Technology and Space (BMFTR).



Figure 4. Panel discussion and questions from the audience (photo credits: Sarah Uphoff, GEOMAR).



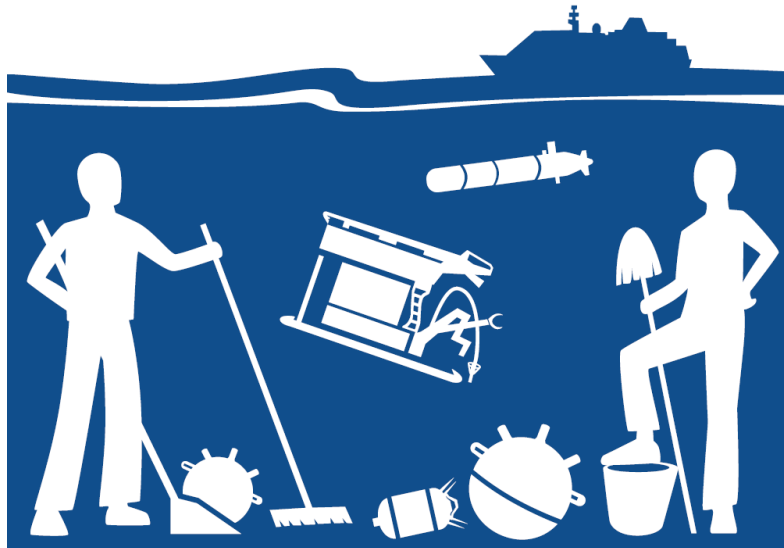
Figure 5. Discussion around thematic island “Legal issues” (photo credits: Sarah Uphoff, GEOMAR).



Figure 6. Family photo of the side event organisers (photo credits: Sarah Uphoff, GEOMAR)

Conclusions

The organization of and participation in these two workshops —UNOC side event and two-day sessions at KMCW—enhanced our collaboration with new stakeholders, especially within policy sector. These collaborations are invaluable for developing objectives A1 Compilation of country-specific management of marine munitions, and A2 Compilation of stakeholder needs, with a particular focus on policy and country-based responsibility frameworks in Europe.



MMinE-SwEEPER

Milestone Report

Milestone No. 6: Workshop on assessment and decision-making



Funded by
the European Union

Authors | Frank Akowuge Dugasseh, Delove Abraham Asiedu, Maria del Rosario Domínguez Carrasco, Hans Sanderson, Adeline Souf, Paul Trautendorfer, Syed Hamza Ahmed, Agnieszka Jędruch, Conrad Wassmer, Regina Wiedenbauer, John Aa Tørnes, Michał Czub, Andriy Grafov, Aino Aho

Contributing organisations:



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Project Coordinator	GEOMAR Helmholtz Centre for Ocean Research Kiel

Milestone Information

Milestone Name	Workshop on ‘assessment and decision-making’
Milestone Number	6
Work Package (WP)	2
Related Task (s)	Task 2.3 Analysis of assessment and decision-making processes for munition remediation
Milestone Beneficiary	Aarhus University
Author(s)	Frank Akowuge Dugasseh, Delove Abraham Asiedu, Maria del Rosario Domínguez Carrasco, Hans Sanderson, Adeline Souf, Paul Trautendorfer, Syed Hamza Ahmed, Agnieszka Jędruch, Conrad Wassmer, Regina Wiedenbauer, John Aa Tørnes, Michał Czub, Andriy Grafov, Aino Aho
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Workshop on assessment and decision-making

Summary

On 24 February 2026, MMinE-SwEEPER organized an online workshop titled *“Why and how should we remediate sea-dumped munitions - and how does/should the EU Ocean Pact impact this?”*.

This workshop marked the midpoint of the ongoing stakeholder dialogue on key concerns and needs regarding the remediation of submerged marine munitions. The dialogues were initiated by MMinE-SwEEPER in 2025 with the stakeholder community (See D1.1. *Stakeholder community*, D1.2. *Identified needs* and [Dugasseh et al. \(2026\)](#)).

During the workshop, the stakeholders evaluated and discussed key lines of evidence from previous stakeholder dialogues while also identifying additional lines of evidence that had not yet been explored. To inform the next phase of dialogues, participants also discussed their perceptions of the implications of the EU Ocean Pact for their current activities, decision-making needs and concerns, and funding allocations for remediation activities. This workshop, together with the M2 stakeholder workshops, contributes to achieving the aim of MMinE-SwEEPER objective A2. Compilation of stakeholder needs, although the topic is focused on the decision-making process.

Content and agenda of the workshop

The workshop lasted for 1.5 hours (see agenda in Figure 1). It began with welcoming and practical remarks, followed by a presentation of the key findings from the 2025 stakeholder engagements. Participants were then invited to indicate whether they agreed or disagreed with the presented conclusions via a Mentimeter questionnaire.

Afterwards, participants were divided into breakout groups to discuss in greater detail selected statements relevant to their expertise. Each breakout group had a moderator and a note-taker, both of whom were partners in the MMinE-SwEEPER project. The breakout discussions lasted 30 minutes, after which all participants reconvened in plenary, where moderators or note-takers presented summaries of their discussions.

The participants were then invited to respond to a second set of Mentimeter questions on the implications of the EU Ocean Pact for their activities, decision-making needs and concerns, and funding allocations for remediation activities. The workshop concluded with an invitation to participants to upcoming stakeholder dialogue events on decision-making topics scheduled for autumn 2026.

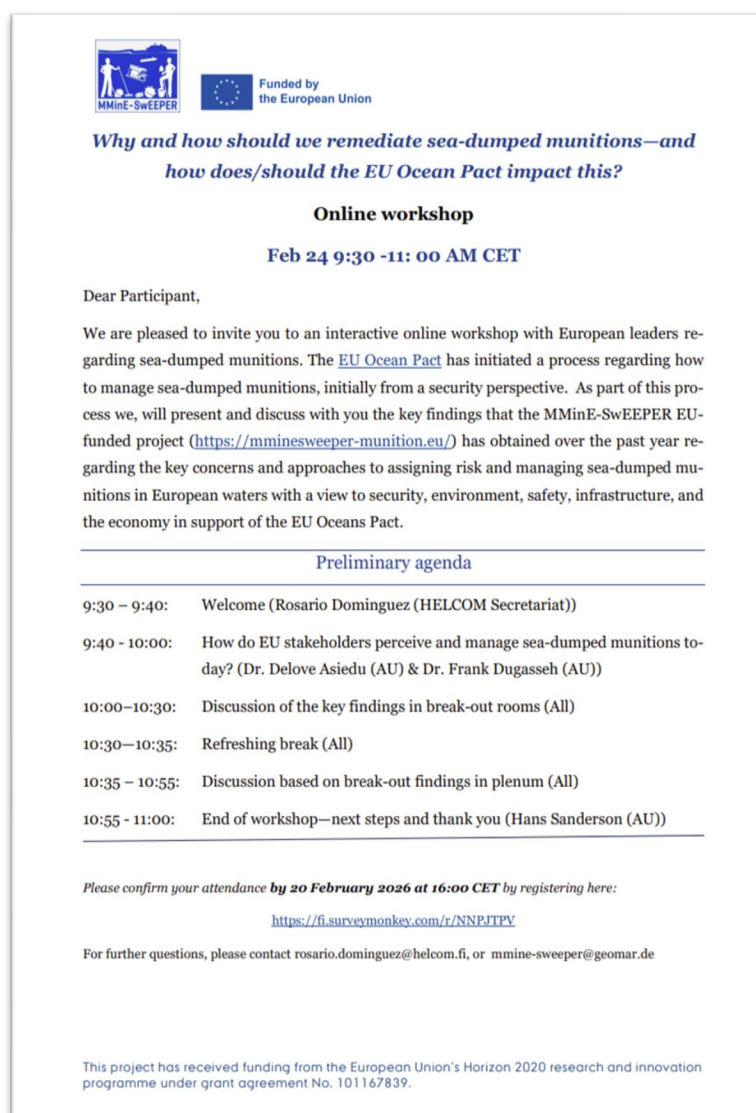


Figure 1. Content and agenda of the online workshop

Preliminary results

A total of 25 participants (external to the consortium) took part in the workshop, although more than 50 have expressed their interest in staying informed but were unable to attend this time. Engagement in both Mentimeter questionnaires and in the smaller group discussions was very active and constructive.

The results will be analysed and discussed further in deliverables D1.3. *Synthesis of findings* and D2.3. *Risk assessment & decision*. A summary of the results of the first and second Mentimeter polls is presented below.

First Mentimeter Poll - Evaluating findings and conclusions from previous stakeholder engagements:

More than half of the participants agreed with most statements, although a few remained neutral and disagreed with some conclusions. Notably, there was unanimous agreement on the criteria for prioritizing remediation sites, as well as the factors to be considered when assessing remediation strategies.

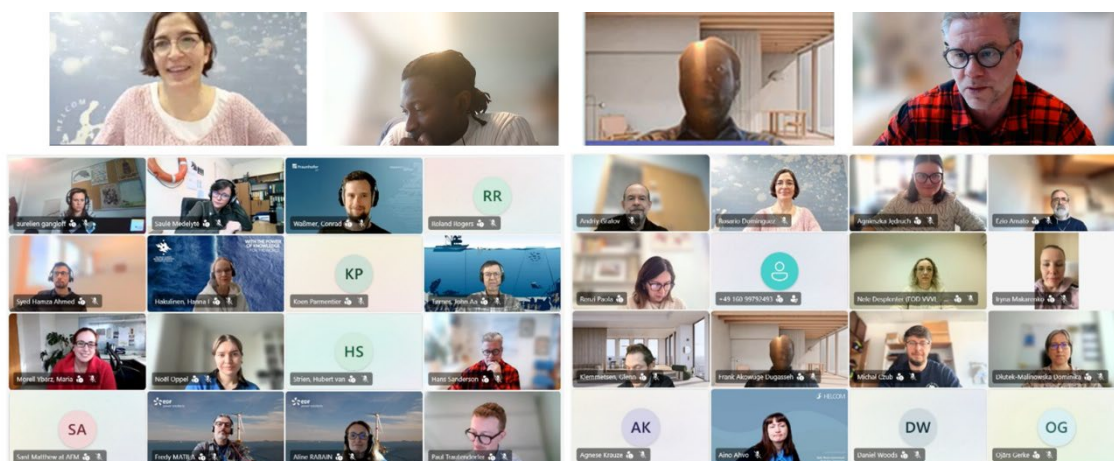
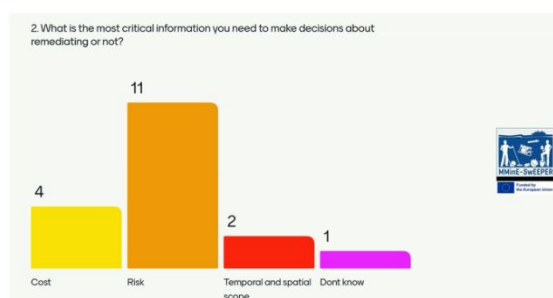
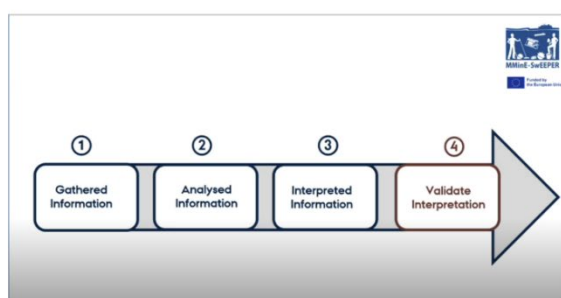
Second Mentimeter Poll - Implications of the EU Ocean Pact on stakeholder activities, decision-making needs and concerns, and funding allocations for remediation activities.

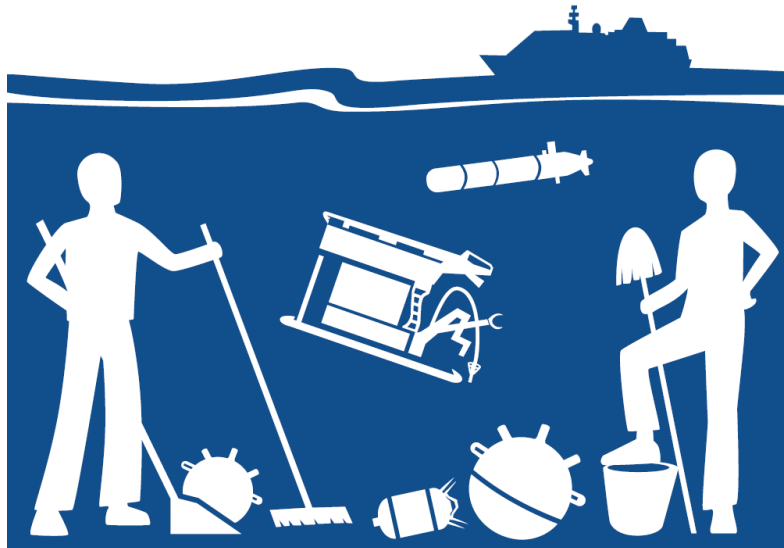
Most participants were unaware of the potential implications of the EU Ocean Pact for their activities, nor of the costs of remediation efforts. They also expressed a need for further information on the risks posed by sea-dumped munitions before deciding whether to proceed with remediation. In addition, while occupational risks were of greatest concern for remediation activities, the marine environment was highlighted as one of the most important co-benefits of a security-based remediation plan.

Conclusions

The workshop validated our key findings from the previous stakeholder workshops (see deliverable M2). It was also clear that remediation should be considered on a case-by-case basis and that blast-in-place remains an important option for safety, cost, and time reasons. It is also clear that the impact of the EU Ocean Pact remains to be seen. We will explore these aspects further in the coming stakeholder activities we are planning based on the findings in this milestone.

Photos of the workshop





MMinE-SwEEPER

Milestone Report

Milestone No. 7: First Compilation on Best Practices of Hydroacoustic Spatial Mapping



Funded by
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Authors Roy Edgar Hansen, Mareike Keller

Contributing organisations:



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Project Coordinator	GEOMAR Helmholtz Centre for Ocean Research Kiel

Milestone Information

Milestone Name	First compilation on best practices of hydroacoustic spatial mapping
Milestone Number	7
Work Package (WP)	3
Related Task (s)	3.1 Compilation of methods and best practices for MBES, SSS and SAS approaches
Milestone Beneficiary	FFI, GEOMAR
Author(s)	Roy Edgar Hansen, Mareike Keller
Due date	30.09.2025
Submission date	30.09.2025
Type of milestone	Draft-report available through webpage
Dissemination level	Public

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Introduction

This report is a draft report of the Compilation of methods and best practices for Multibeam Echosounder (MBES), Side-scan sonar (SSS) and Synthetic Aperture Sonar (SAS) approaches, representing Milestone 7 in the EU Horizon project “Marine Munition in Europe - Solutions with Economic and Ecological Profits for Efficient Remediation” (MMinE-SWEEPER). The final version of this report is Delivery 3.1 with deadline Month 40 in the project.

The aim of this report is to provide stakeholders comprehensive and complete background information about underwater munition mapping techniques using sonar. That information should enable them to weigh up the options and make the right decisions. In particular, the advantages and limitations of each method will be discussed. In addition, a brief explanation of the physical background and the practical implementation should enable a realistic assessment of the usability. Other documents (and deliveries) in the project describe the platforms, underwater navigation, and optical systems.

Sonar imaging principles

Underwater acoustics

Sonar (Sound Navigation and Ranging) is based on transmitting and receiving acoustic pulses in the water, thereby being able to perform echolocation. Acoustic waves are the only waves that can propagate over large distances in the sea. The main applications of sonar are nautical charting, fish finding, and military applications. Today, acoustic waves (and sonar) is the only practical tool for underwater remote sensing over large areas. For more detailed information about the essence of sonar, see any book in underwater acoustics, e.g. [Lurton 2010]. For sonar examples, see [Wille 2005].

The speed of sound in seawater, c , typically varies between 1450 m/s and 1550 m/s, depending on salinity, temperature and depth. Acoustic wavelength is given as $\lambda = c/f$, where f is the acoustic frequency.

Seawater is acoustically a dissipative medium through viscosity and chemical processes. The acoustic absorption in seawater is frequency dependent, such that lower frequencies will reach longer than higher frequencies. Figure 1 shows the absorption in dB per km as a function of acoustic frequency. The absorption limitation gives a direct relation between acoustic frequency and achievable range. The achievable range for any sonar can be approximated and summarized as shown in Table 1.

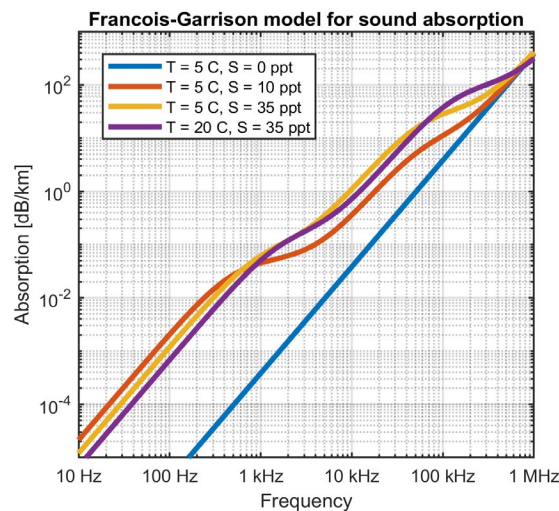


Figure 1 Absorption in seawater as function of acoustic frequency. T is temperature in Celcius, and S is salinity in Parts Per Thousand (PPT).

Table 1 Approximate relation between acoustic frequency and achievable range.

Frequency	Wavelength	Maximum range
100 Hz	15 m	1000 km
1 kHz	1.5 m	100 km
10 kHz	15 cm	10 km
100 kHz	1.5 cm	1 km
1 MHz	1.5 mm	100 m

Figure 2 Maximum range (left) and angular resolution (right) as function of frequency. Data from four different sidescan sonar vendors, and four different sector-scan sonar vendors. (left panel) shows the vendor specified achievable range and angular resolution for different products operating at different frequencies. Data was gathered from four different side-scan sonar vendors, and four different sector-scan sonar vendors in September 2025. Note the almost linear trend in achievable range as function of frequency (with logarithmic axis). Doubling the frequency causes approximately a halving of the achievable range. The right panel of Figure 2 shows the vendor specified angular resolution as function of acoustic frequency. Here, we see no trend although higher frequency allows for higher angular resolution on a fixed array. This is merely since it is common to design sonar to obtain a given angular resolution.

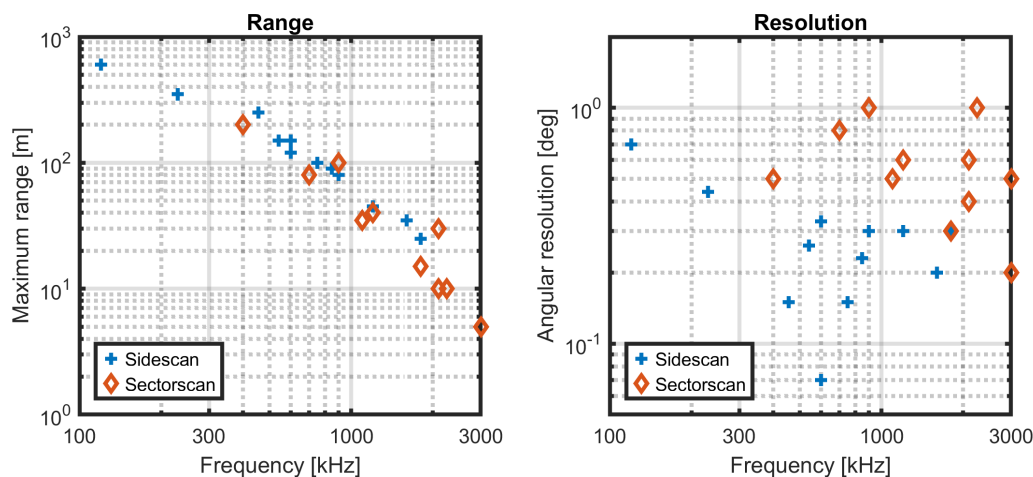


Figure 2 Maximum range (left) and angular resolution (right) as function of frequency. Data from four different sidescan sonar vendors, and four different sector-scan sonar vendors.

Imaging

Sonar imaging is commonly done by transmitting pulses, receiving the echoes at multiple receivers, and combining the data to transform the recorded timeseries into images, so called *beamforming*. Images can also be formed by stacking data from multiple transmits. The properties of a sonar image can be characterized through a set of performance parameters, as listed in Table 2. Note that these parameters are generic for all pulse-echo modalities, such as sonar, radar, and ultrasound. See [Wright 1997] for details.

Table 2 Performance parameters for pulse-echo imaging systems.

Parameter	Description
Geometrical resolution	Minimum separable distance between point scatterers, or independent pixel size. Typically specified in range, azimuth and elevation (if available). Note that this parameter might change in an image.
Radiometric accuracy	Pixel value accuracy. Required for transforming measured pixel values into physical quantities such as acoustic reflectivity. Called <i>contrast resolution</i> in ultrasound. Requires a calibrated system in which not all sonars are.
Temporal resolution	Number of independent images that can be acquired per unit time. Also called <i>framerate</i> . Only available on certain sonar systems.
Dynamic range	The ability to resolve weak targets in the presence of strong targets. This parameter is related to the properties of the point-spread function (PSF).
Sensitivity	The ability to detect low level echoes. This parameter is related to Signal-to-Noise Ratio (SNR).

The imaging resolution (geometrical resolution) in sonar in azimuth is given by the length of the sonar array L measured in wavelengths λ , and the signal bandwidth B in range:

$$\text{Azimuth resolution: } \delta\beta \approx \frac{\lambda}{L} [\text{rad}]$$

$$\text{Range resolution: } \delta R \approx \frac{c}{2B} [m]$$

These formulas are approximately correct and general, and applies to sonar, ultrasound, and radar. For a sector-scan sonar or side-scan sonar, the geometrical azimuth resolution becomes linearly a function of range, such that larger range gives poorer cross-range (azimuth) resolution (see Figure 3). On the other hand, the range resolution is invariant of range.

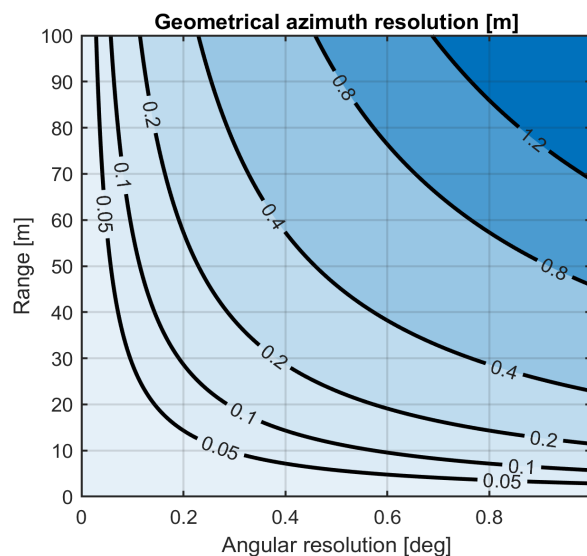


Figure 3 Geometrical azimuth resolution as function of range and angular resolution.

Many sonar systems are designed following a set of simple rules, as illustrated in Figure 4:

- Select the desired range. This gives a direct limitation to the highest possible frequency.
- Then select desired angular resolution. This gives the sonar array length.
- Select field of view (FOV). This determines the number of elements required in the array.
- Then select suitable pulse bandwidth, and waveform properties suitable for the type of operation.

All this should be done within obvious limitations such as space, and power consumption.

High range resolution (from bandwidth) is in general much easier to obtain than high angular resolution. Number of independent elements is a cost driver. Larger number of elements gives more hardware complexity, and larger data rate, thereby more demand for processing power. But larger number of elements gives larger number of independent pixels in the sonar image.

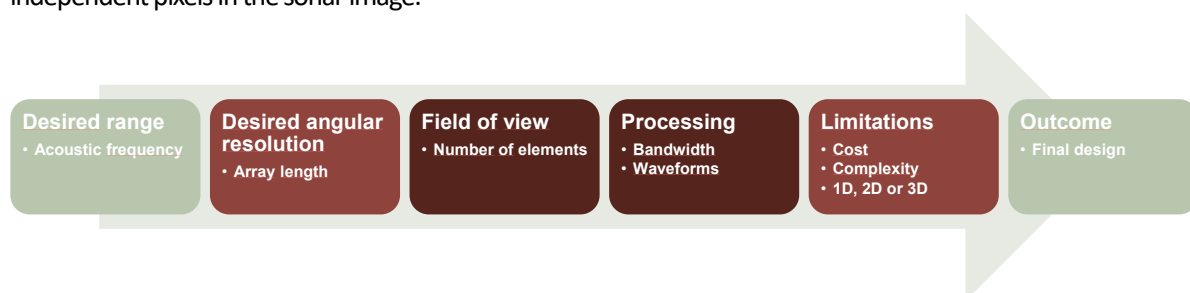


Figure 4 Imaging sonar design rules.

Sector-scanning sonar

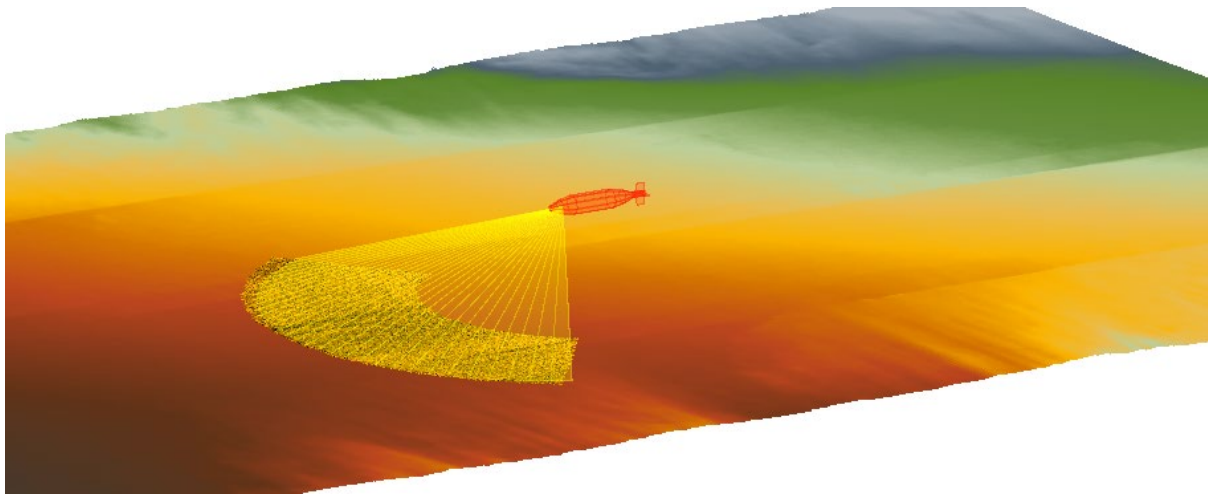


Figure 5 Sector-scanning sonar imaging geometry.

A sector-scanning sonar is a sonar that produces a full two-dimensional (or three-dimensional) image per ping, as illustrated in Figure 5. Typical use-cases are forward looking sonar (FLS) for anticollision or inspection. Technically, a sector-scanning sonar is a multibeam sonar. Another term used on short-range high frequency sector-scanning sonar is *acoustic camera*.

The field of view (FOV) is determined by the transmit beamwidth, and each receive element beamwidth. The azimuth resolution is typically determined by the receiver array length (see Figure 6). The maximum range is either limited by the Signal-to-Noise Ratio (SNR) or the requirement for a desired framerate which again limits the Pulse Repetition Frequency (PRF). The angular resolution is typically a function of look angle. At a look angle of 60 degrees off broadside, the effective array length becomes halved on a linear array, and the angular resolution (or beamwidth) becomes doubled. As a rule-of-thumb it is not possible to have more independent pixels in azimuth, than receiver elements. Therefore, wide FOV sector-scan sonars with high angular resolution have a large number of elements, which, again, requires a larger number of computations per image (or frame). Some light-weight affordable sector-scanning sonars use simplified hardware and software at the cost of image quality.

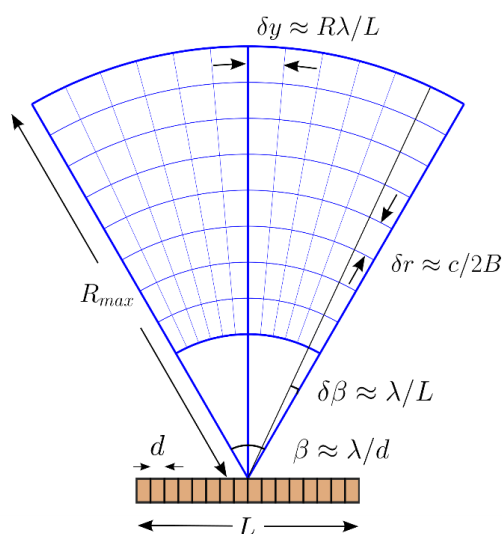


Figure 6 Sector-scanning field of view and resolution.

Multibeam echosounder

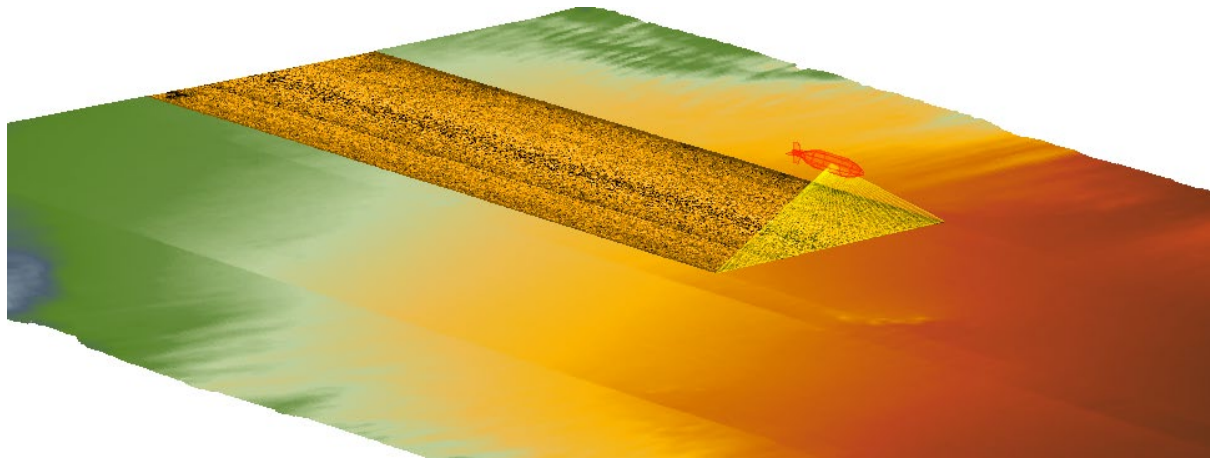


Figure 7 Multibeam echosounder (MBES) mapping geometry.

A Multibeam Echosounder (MBES) is a vertically oriented sector-scanning sonar, where the distance to the seabed is estimated per beam. By orienting it such that the wide sector is cross-track, an area of the seabed can be mapped under the platform track (see Figure 7). This is commonly done by organizing the sonar transducers in a Mills-cross (or magic-T) configuration, where the transmit array has its long axis along-track, and the receive array has its long axis across-track. The main application of MBES is seabed mapping for nautical charting. The main output is the depth map of the seabed, and the corresponding backscatter estimates. Being a vertically oriented sector-scanning sonar, it can also be used as an imaging sonar, where the output images (per ping) often are referred to as *water-column images*. For these images, the same rules and relations applies as for sector-scanning sonar. Modern MBES may be very sophisticated, using multiple frequency bands, multiple sectors and swaths to improve performance. High-end MBES may also be backscatter-calibrated such that the measured backscatter values can be turned into acoustic reflectivity. See [Lurton 2010, chapter 8] and [Hughes Clarke 2018] for details.

The geometrical resolution of the MBES image of the seabed is a function of the cross-track beam direction, the cross-track and along-track beamwidth, and the range resolution (see Figure 8). This means that the pixel size on the seabed becomes directly a function of the sensor altitude above the seabed. For a hull-mounted MBES with 0.5×0.5 degrees beamwidth (close to state-of-the-art), the pixel size on the seabed at nadir becomes 0.8×0.8 m at 100 m water depth, 8×8 m at 1000 m water depth, and 40×40 m at 5000 m water depth. Most modern MBES uses time-of-arrival (TOA) estimation of the seabed depth at beams near nadir, and direction-of-arrival (DOA) for the beams near grazing incidence.

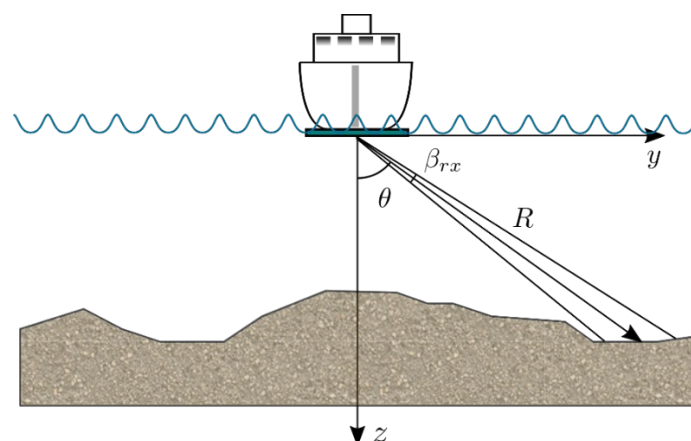


Figure 8 Mapping principle in MBES.

Side-scan sonar

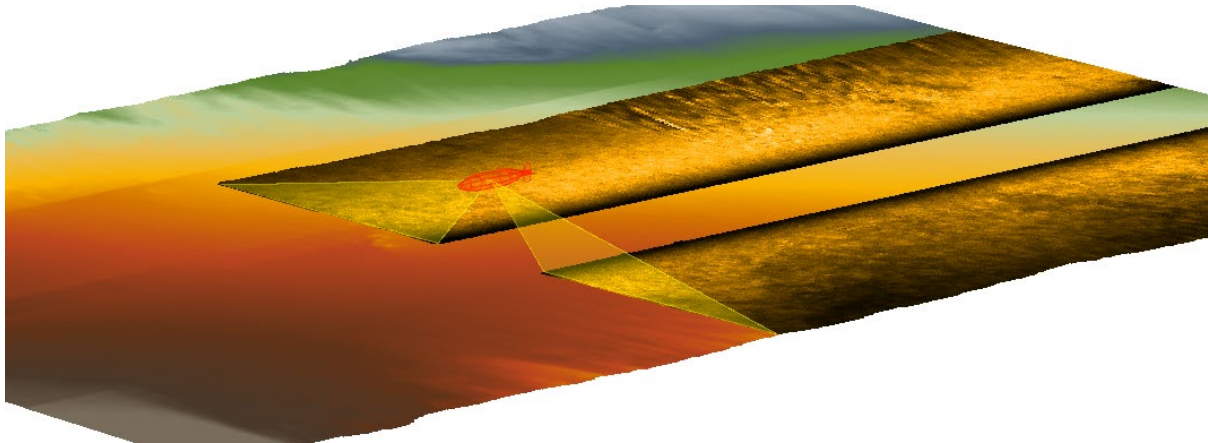


Figure 9 Side-scan sonar imaging geometry.

Side-scan sonar (SSS) is a side looking imaging sonar typically mounted on a towfish, where an image of the seabed is made by combining scan-lines cross-track from consecutive pings on a moving platform. In its simplest form, the SSS is a single beam sonar with a narrow horizontal along-track beam. A typical SSS is two-sided, that is, one sonar on port side, and one sonar on starboard side, where there is a nadir gap (see Figure 9). After its invention in the 1950s, it has revolutionized seabed imaging, bringing very high resolution into affordable light-weight systems. Modern SSS can be very advanced systems with multiple transmit-receive elements, multiple frequencies, and being able to form multiple beams using dynamic focusing. High-end SSS can also be interferometric, being able to produce seabed maps in the full imaging swath. See [Blondel 2009], [Klaucke 2018] and [Fish and Carr 2001] for details.

The along-track (or azimuth) resolution in SSS is determined by the horizontal beamwidth and the range (left panel in Figure 10). A required geometrical resolution may therefore limit the range of the system, as illustrated in Figure 3. The horizontal cross-track ground range resolution is given by the bandwidth of the sonar, and the vertical geometry or the grazing angle (right panel in Figure 10). This is typically very high (on the order of centimetres). It is common to specify a desired vertical geometry by choosing the platform altitude when the water depth allows for it. A common rule-of-thumb is that the maximum range should not exceed e.g. 10 times the altitude to avoid too low grazing angles.

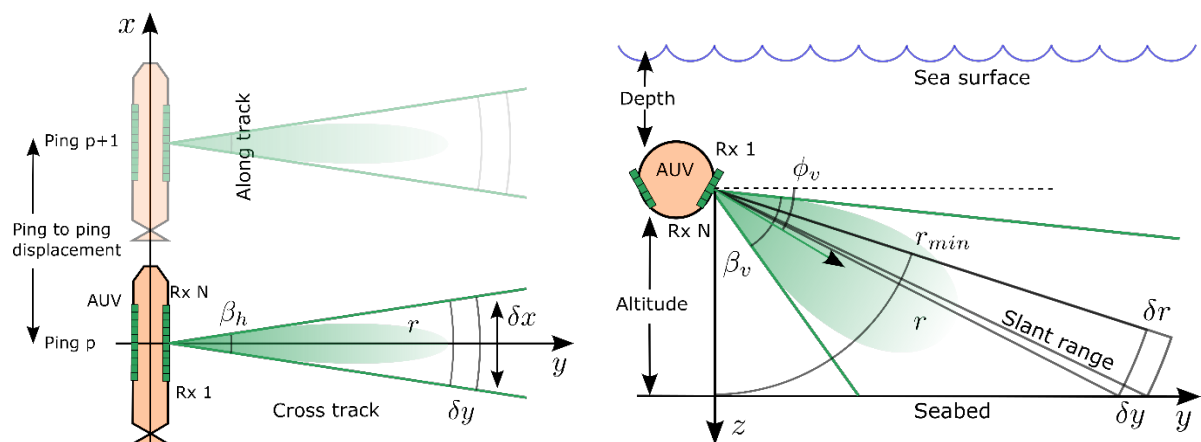


Figure 10 Horizontal (left) and vertical (right) geometry for SSS.

Synthetic aperture sonar

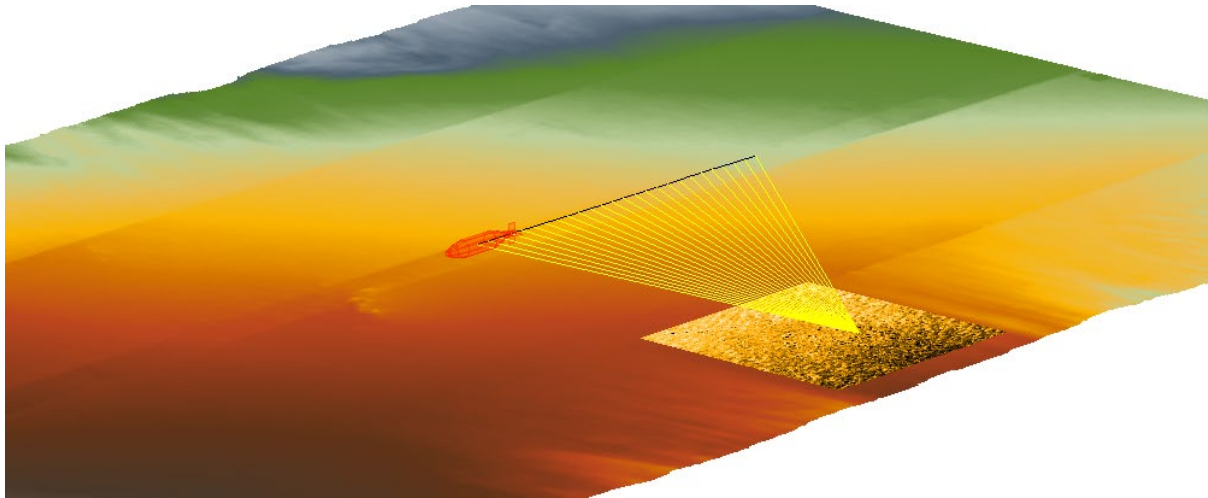


Figure 11 Synthetic Aperture Sonar (SAS) imaging geometry (one-sided).

Synthetic Aperture Sonar (SAS) is, like SSS, a side looking imaging sonar typically mounted on an AUV or a towfish. The images are created by coherently combining data from multiple pings into each pixel in the image thereby forming a synthetic array (or aperture) larger than the physical sonar itself, as illustrated in Figure 11. SAS-systems are typically also two-sided with a nadir gap. Most current SAS systems available are interferometric, being able to estimate the seabed depth and produce a map in the full swath. Although invented more than 50 years ago [Sternlicht et al 2018], SAS is still considered new and not fully matured. This is in stark contrast to its equivalent in radar: synthetic aperture radar (SAR), which has reached a very high level of sophistication and maturity. Currently, well-functioning SAS imaging is dependent on good data quality and a stable platform during data collection. See [Hansen 2011], [Hansen 2013] for details.

By increasing the synthetic array length as function of sonar range, the along-track resolution becomes independent of range (left panel of Figure 12). By increasing the synthetic aperture length when lowering the frequency (right panel of Figure 12), SAS also obtains frequency independent along-track resolution. This opens for very high along-track resolution at lower frequencies and longer ranges. SAS thereby obtains range and frequency independent along-track resolution. This is a significant difference from SSS. It should be noted that the spatial along-track sampling criterion in SAS, a unique SAS limitation, directly determines the achievable range for a given platform speed. The unit area covered per unit time with SAS, the *area coverage-rate*, is directly determined by the SAS array configuration. A larger physical SAS array gives larger area coverage-rate, or larger speed for a given range. A somewhat similar limitation exists in SSS where a larger SSS array allows for longer range and better angular resolution. SSS does not, however, have any explicit speed limitation.

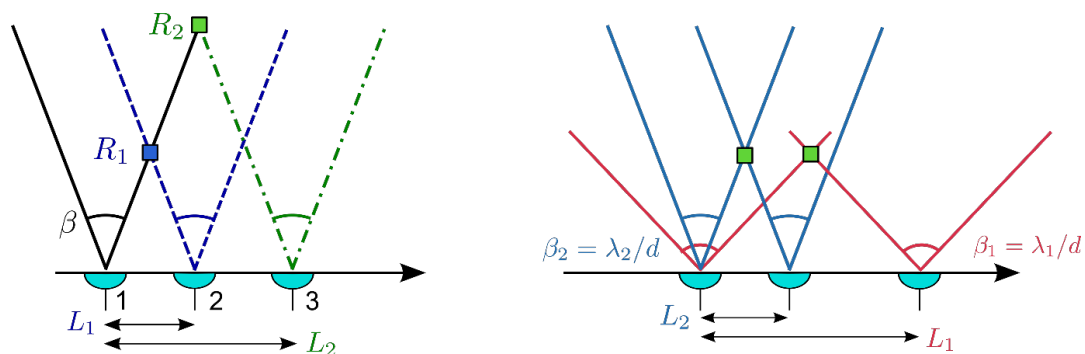


Figure 12 Left: Synthetic aperture length as function of range. Right: Synthetic aperture length as function of frequency.

Sonar types and key properties

The four different types of sonar previous presented has their benefits and shortcomings for the different types of applications and for which platform they intend to be used from. In Table 3 we summarize key properties.

Table 3 Sonar types and their key properties.

Sonar type	Geometry	Platform s	Frequency	Maximum range	Requirements and features	Suitable for
Sector-scan sonar	Forward-looking horizontal	ROV	400 kHz – 3 MHz	5 – 100 m	Full image per ping. Agile.	Detailed inspection
Multibeam echosounder	Vertical cross-track	Ship, AUV	200 kHz – 700 kHz	10 – 500 m	Requires platform motion to build an image. Downward looking.	Surveying, mapping
Side-scan sonar	Side looking horizontal	Towfish, AUV	100 kHz – 1.6 MHz	20 – 500 m	Requires platform motion to build an image. Two-sided with nadir gap.	Surveying, imaging
Synthetic aperture sonar	Side looking horizontal	AUV, towfish	100 kHz – 400 kHz	100 – 400 m	Requires platform motion to build an image. Two-sided with nadir gap.	Surveying, imaging

We have used typical numbers relevant for smaller systems regarding the frequency range and maximum range. For a specified geometrical resolution, the maximum range may be reduced for all types except SAS.

Search and Localization

In the previous chapter, we considered sonar imaging principles, common sonar types, and their main operating geometries. In this chapter, we consider the suitability of using sonar to detect and classify UXOs, and which parameters affect this.

Detection and classification principles

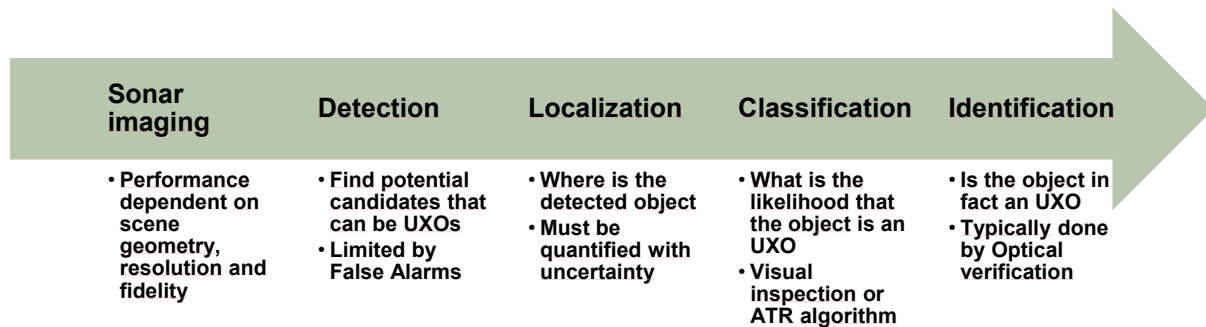


Figure 13 Overview of the object detection stages.

Traditional search for objects of interest on the seabed, such as in naval Mine Countermeasures (MCM), consists of several stages as illustrated in Figure 13. It is common to divide the search into two stages related to the sonar data especially when considering automated processing, see [Dura 2011] and [Steiniger et al 2022]:

1. A detection stage where all candidate objects of approximately correct size are listed. This is often done using a matched filter that looks for a certain object size, and a highlight – shadow pattern. If detected, a snippet (small image selection) around the target is selected and catalogued. The main challenge in the detection stage is that any natural object (e.g. a rock) of equal size of the desired object is likely to be detected, causing a so-called *False Alarm*.
2. A classification stage where the likelihood of each detected object is an UXO (desired object), is calculated. This is typically done by pattern recognition on each snippet. A high probability of correct classification requires higher resolution, and good SNR [Johnson 1958]. A simplified rule-of-thumb using information theory is that 7 independent pixels per dimension on the target gives near full classification score if the SNR is high [Myers et al 2007], [Pailhas et al 2010]. Today, most target recognition algorithms are based on deep learning. The main challenge in classification is to separate desired objects (UXOs) from natural objects (rocks) of equal size with good probability. In effect, this lowers the false alarm rate.

The *identification*, that is, establishing whether an object is actually an UXO, is sometimes required to be done with optical sensors or other means. In order for this to be feasible, the objects of interest must be *localized* with a certain accuracy in the detection/classification stage.

Information content

The information content in a sonar image is a function of several important parameters (see Figure 14):

- The geometrical resolution: How many independent pixels do we have on the target
- SNR: How much of the signal in each pixel is desired backscattered signal from the target
- Geometry: Do we have a slant geometry enabling target shadow
- Seafloor statistics: Is the background seafloor textured or homogeneous
- Speckle: Random variability in the signal, per pixel, is typically always there for all sonar imaging types

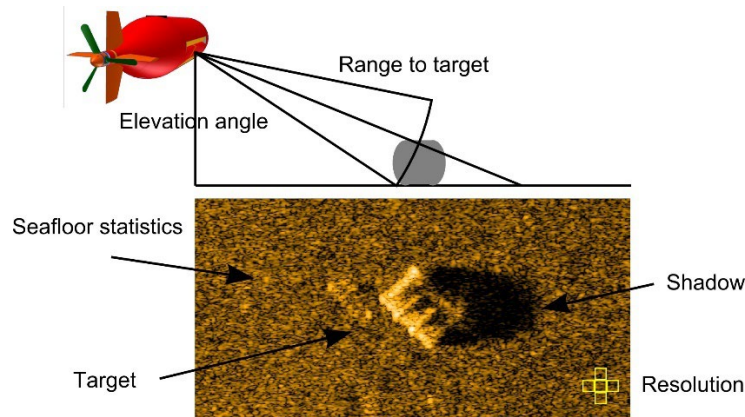


Figure 14 Image properties.

In [Wehner and Frey 2022], [Wehner et al 2021], the authors gathered information from expert users and other documentation on the desired parameters and their requirements from MBES and SSS. Table 4 summarizes the results for SSS.

Table 4 Suggested SSS parameter requirements (from [Wehner and Frey 2022]). d_1 is the smallest length on the desired objects.

Parameter	Description	Requirement
Along-track sampling	Distance between pings	$D \leq d_1/3$
Along-track footprint	Geometrical azimuth resolution	$F_{al} \leq d_1/2$
Across-track footprint	Geometrical range resolution	$F_{ac} \leq d_1/2$
Coverage	Area coverage	$\geq 200\%$
Altitude-range ratio	Smallest grazing angle	$R_{max} \leq 10A$
Horizontal position accuracy	Global horizontal position accuracy	$\leq 1\text{ m}$
Vertical position accuracy	Global vertical (depth) accuracy	$\leq 0.25\text{ m}$
SNR	SNR per pixel	$\geq 2\text{ (3 dB)}$
Acoustic center frequency		$\geq 500\text{ kHz}$

The results from the user survey align fairly well with common knowledge in the naval MCM community. Note that from first principles, acoustic center frequency, as specified by the SSS vendors, does not directly determine either range or angular resolution alone, and is therefore only weakly coupled with the recognition ability, especially for metal objects. The reason this may play a role in the user survey, is due to the actual experience with specific SSS systems at different frequencies from different vendors. It should be noted that all available SAS systems today (to the authors knowledge) use acoustic center frequencies lower than 500 kHz.

The effect of resolution

The geometrical resolution in the sonar image is directly related to the ability to recognize an object of interest. To visualize this, we consider a small historical shipwreck found in the Skagerrak strait when using AUV with SAS to survey for dumped WWII chemical munitions. Figure 15, upper left, shows the SAS image in full resolution, 3.5 x 3.5 cm. The upper right, and the lower left and right panels show the corresponding progressively poorer resolution at 7 x 7 cm, 14 x 14 cm, and 28 x 28 cm. The reduction of resolution has been done by filtering in wavenumber domain [Jakowatz et al 1996] in combination with resampling. This to ensure that the images maintain their essential properties as if the imaging system had lower resolution.

We see in the upper left panel (in full resolution, 3.5 x 3.5 cm) that there are three anchors clearly visible. When reducing the resolution by a factor four per dimension to 14 x 14 cm (lower left panel), we no longer can recognize the anchors. At 28 x 28 cm resolution (lower right panel), it is no longer clear what the outer shape of the wreck is. Note that random variability from speckle reduces the interpretability of the images, effectively causing a demand for higher resolution.

In Figure 16 we reduce the resolution correspondingly, but now only in the along-track dimension. This is similar to how SSS works. The azimuth angular resolution is 0.03 degrees, 0.11 degrees, 0.22 degrees and 0.45 degrees in the different panels. Comparing the lower left panel of Figure 15 with the lower left panel of Figure 16 we see that lowering the resolution in one dimension to 28 cm gives better recognition ability than lowering the resolution to 14 cm in two dimensions. Hence, high range resolution compensates partly for low azimuth geometrical resolution.

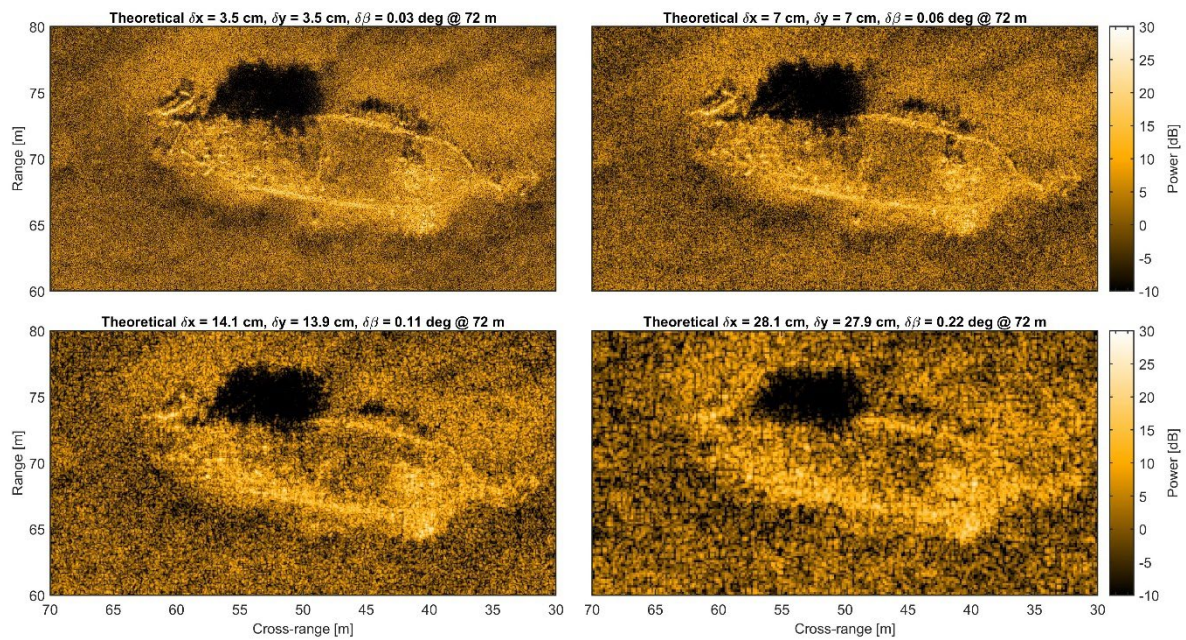


Figure 15 Geometric resolution test in two dimensions.

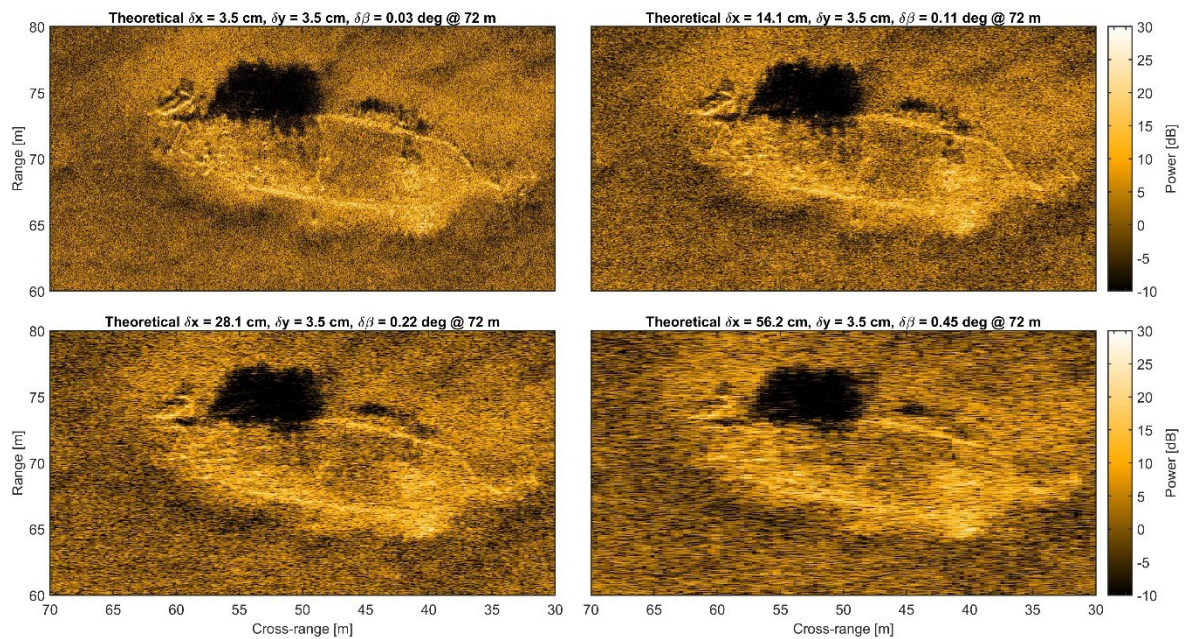


Figure 16 Geometric resolution test in one dimension.

Observability

There is a fundamental question related to sonar imaging in general. What can be observed in an acoustic image? In this section, we compare optical images (as ground truth) with SAS snippets collected at different view-angles and different ranges. Our test-data set is a scene around wreck 13 in the WWII chemical munitions dumpsite in Skagerrak, where there is a large UXO/debris field (see Figure 17). The SAS image is made from approximately 210 seconds of data collection from one of the sides of the SAS-system. The theoretical image resolution is approximately 3 x 3 cm. Each small object in the right of the image is a potential UXO. See [Hansen et al, 2019] for details.

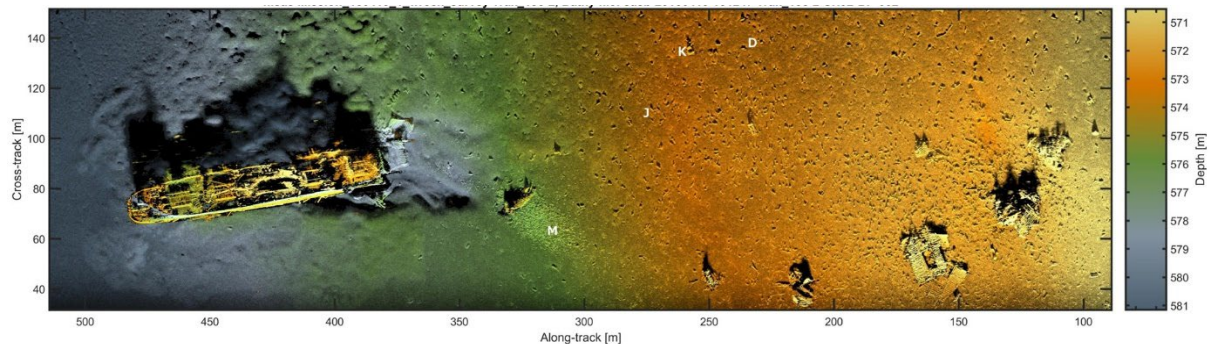


Figure 17 SAS image combined with SAS bathymetry of Wreck 13 in the WWII chemical munitions dumpsite in Skagerrak.

Figure 18 shows an optical image of an UXO (left) compared with two different SAS tiles (middle and right). The optical image is taken using a downward looking camera with artificial light, at approximately 5.5 m altitude. The target size is approximately 1.6 x 0.4 m. The two SAS snippets are from different passes at 50 m and 128 m range (shortest distance from the vehicle track). The yellow arrows indicate the sonar horizontal look direction in each pass. The middle image is of good quality. The right image is affected by slight defocusing (smearing along-track). Both SAS snippets are dominated by speckle variation in the image. This is random variability in the signal itself, which cannot be avoided in coherent pulse-echo imaging systems. There are techniques to reduce speckle, common in medical ultrasound and radar, but they all trade image resolution for less variability [Oliver and Quegan 1998]. We see that the SAS image is suitable for detecting and recognizing the general shape of the object, its size and orientation. It is, however, difficult to determine directly from the sonar images the actual object, and its structural integrity. Note that there is a significant difference between the survey efficiency of searching the seabed using SAS vs using optical cameras [Hansen et al 2019].

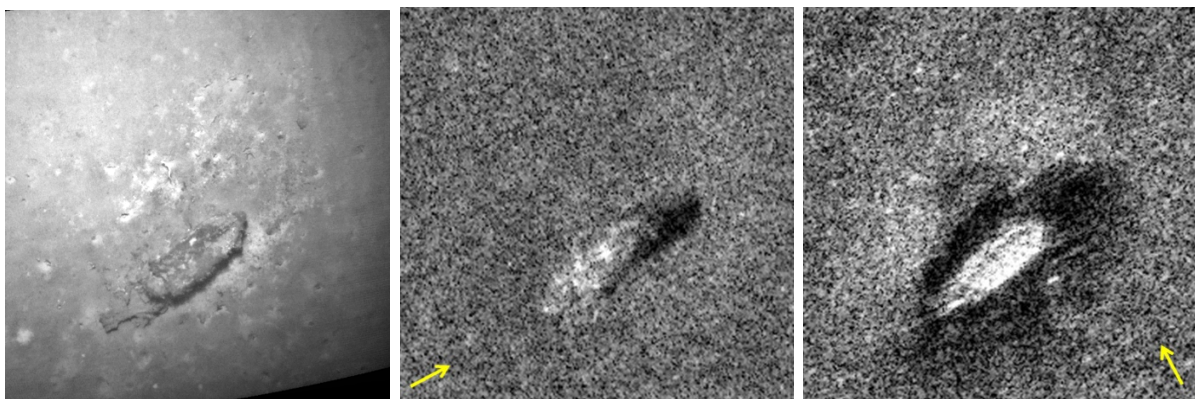


Figure 18 Comparison of optical image (left) with SAS images. The yellow arrow indicates the sonar aspect (or look) angle for the SAS images. Middle: Range 50 m, port side. Right: Range 128 m, starboard side.

Figure 19 shows the camera mosaic of 6 optical images (upper) compared with three different SAS snippets. The scene size is approximately 6 x 12 m. Again, we see that the SAS images are suitable for detection, recognition of general shape, orientation and size, especially for the three UXOs.

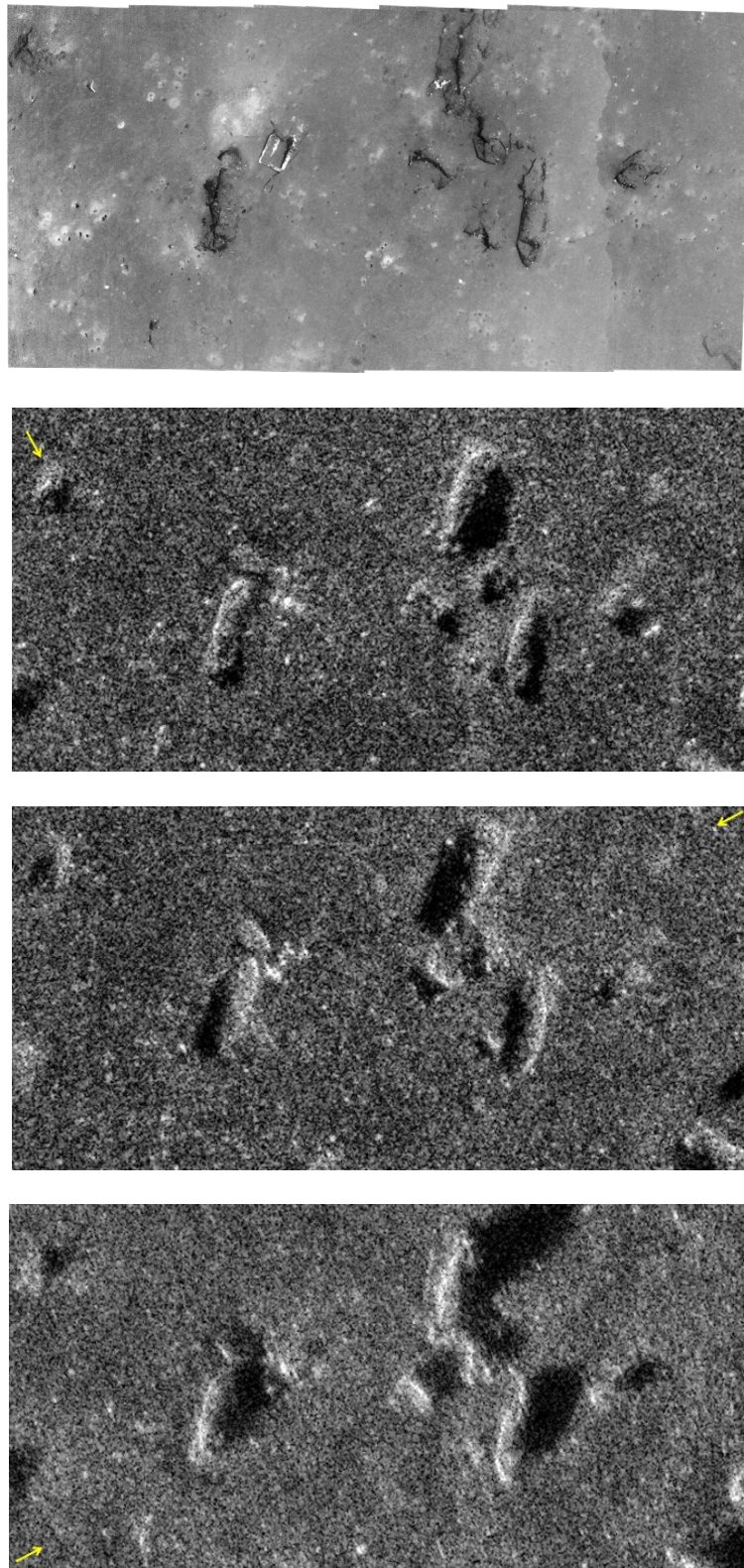


Figure 19 Comparison of camera mosaic of six optical images covering approximately 6 x 12 m (upper) and SAS images from different views. Scene J. Upper middle: 70 m range, starboard side. Lower middle: 63 m, port side. Lower: 111 m range, port side.

Figure 20 shows the camera mosaic of 4 optical images (upper left) compared to SAS snippets from three different passes. The scene content is arbitrary debris, likely a frame made of metal (not UXOs). The three different SAS images show a remarkable difference in the different edges of the frame, depending on the horizontal look angle. This is a direct effect of the scattering physics which states that specular reflection from smooth objects is much stronger than non-specular scattering [Jackson and Richardson 2007]. In effect, the leading edges approximately normal to the sonar look direction (yellow arrow) will be stronger than the other parts of the object.

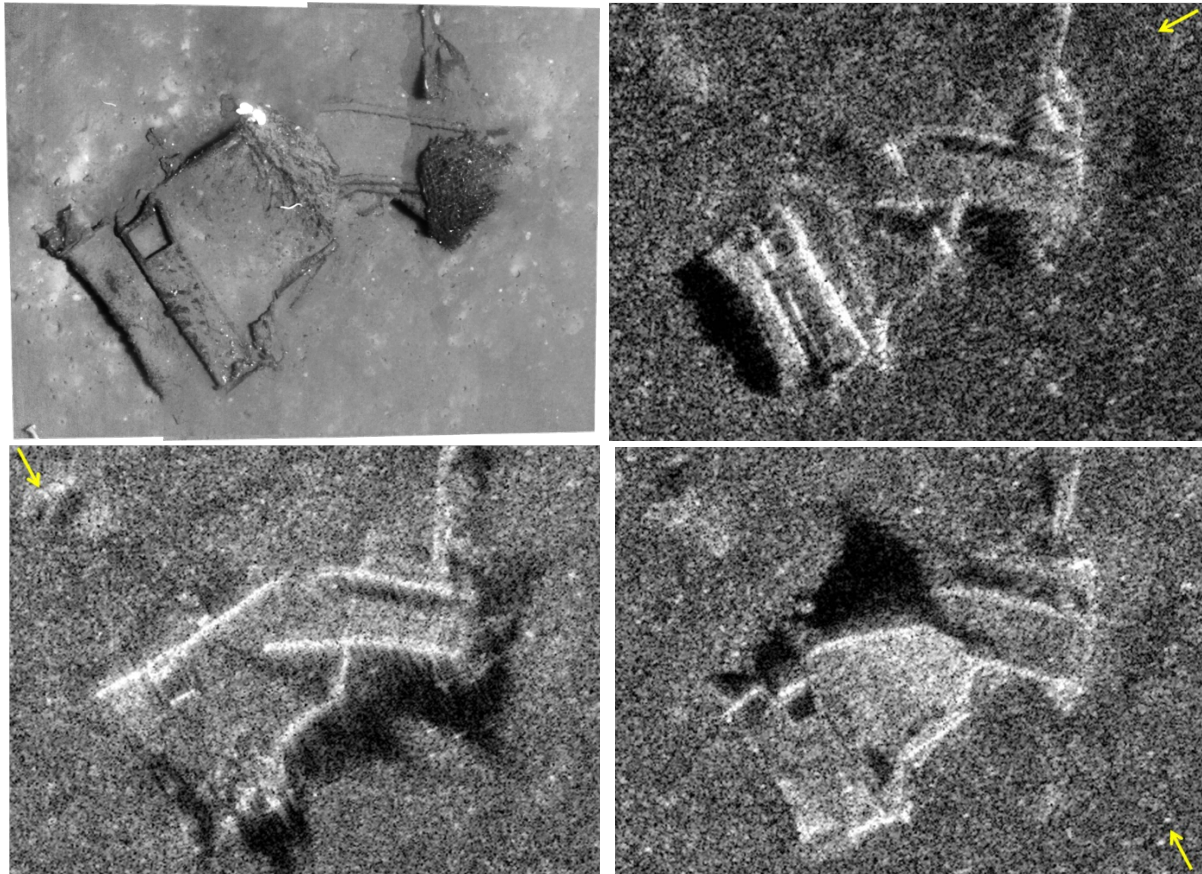


Figure 20 Comparison of optical camera mosaic covering 6 x 8 m (upper left) with SAS images of different views. Scene K. The range to the target is 44 m (top right), 79 m (bottom left), and 41 m (bottom right). The yellow arrows indicate the sonar horizontal look direction.

Shallow water limitations

The MBES swath width is given by the sensor altitude over the seabed, and the angular width (or vertical FOV), as illustrated in Figure 21. In shallow waters, the maximum distance to the seabed is limited by the water depth, thereby potentially also limiting the swath width. Note that the horizontal geometrical resolution is also limited by the range. For a 0.5 x 0.5 degrees MBES (representative for state-of-the-art), the horizontal geometrical resolution at 60 degrees look angle and 10 m altitude becomes 17 x 17 cm, and 8.5 x 8.5 cm at nadir.

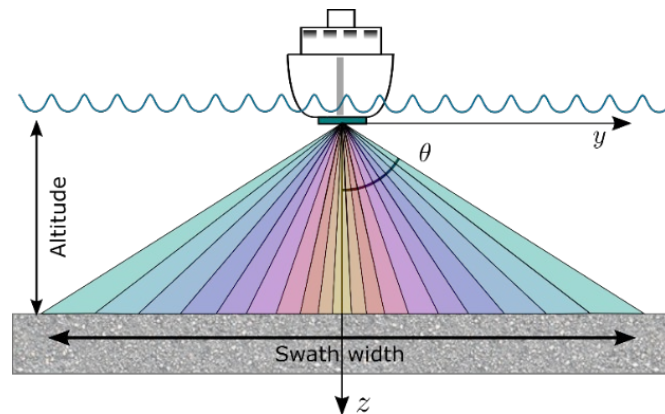


Figure 21 MBES swath width is directly determined by the altitude

Side looking systems, SSS and SAS, typically have wide vertical beams. This may allow for the acoustic waves to take undesired paths via the sea surface and the seabed multiple times (so-called multipath) in addition to the desired direct signal, as illustrated in Figure 22. In this case, the signal becomes contaminated by multipath in addition to additive noise. See [Pearce 2014] for a detailed description of the multipath problem for SSS. Figure 23 shows SAS images taken at a scene in 9 m of water depth, where the vehicle ran at 6 m altitude. The range in the scene is 140 m, making this shallow waters. In the left image there is little multipath contamination, and the SAS image is of good quality. In the right panel, data was collected one week later, more multipath contamination is present, and the contrast in the image is reduced. Especially, the shadow contrast is lowered. The reason for this difference is that the sea surface roughness was different during the two data collections [Synnes et al 2009].

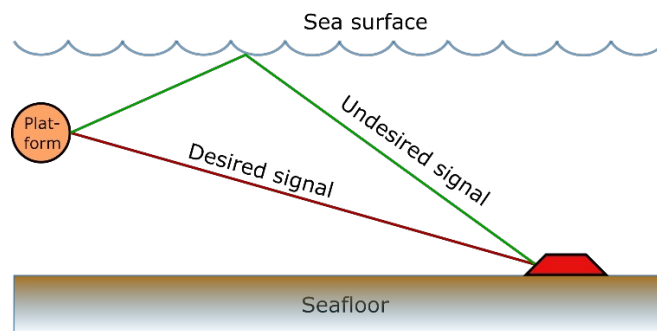


Figure 22 Shallow water limited side looking sonar.

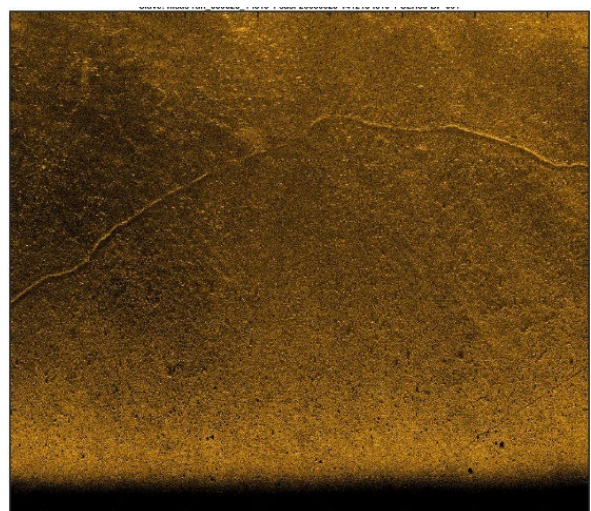


Figure 23 SAS image taken at 9 m water depth, 6 m altitude. The image size is 160 m along-track and 140 m in range. The dynamic range is 40 dB. Left: June 19, 2009. Right: June 28, 2009.

Survey strategies & recommendations

Procedures and guidelines for conducting complete UXO disposal is described in detail in [Frey 2020] and other similar sources. In this report, and this section, we consider the different sonar technologies available.

Given the features and disadvantages of current imaging and mapping sonar suitable for UXO surveys, we recommend the following procedure with corresponding factors involved, for planning and conducting sonar surveys:

1. Which are the available tools, platforms and sonars.
2. What is the water depth within the UXO survey box. Consider platform limitations in this regard.
3. Are there any environmental conditions affecting the performance, e.g. ocean currents, sound speed variability, and shallow waters.
4. Which targets are expected to be there, material, size, shape, conditions.
5. Are there any secondary requirements to the data collection: finding all kinds of man-made structures, mapping the seabed, characterizing the seabed, etc.
6. If SSS or SAS is the primary sensor, are there suitable gap-fillers available.
7. What is the desired image resolution to conduct the mission. This affects directly the likelihood of finding all targets of interest.
8. Are there a required overlap or multiple views to improve detection and classification performance.
9. Are there any vertical geometry limitations.
10. Design tracks given search box and requirements and conduct data collection of sonar imagery.
11. Perform target detection and classification on the sonar images, either manually (computer aided) or automated.

Prioritize hotspots, plan route through areas of interest, and run suitable sensors for identification, e.g. optical, magnetic, and / or chemical analysis.

For the different sonar types, there are different strategies regarding planning a mission such that a rectangular search box on the seabed is fully covered. There are two different cases:

FLS and MBES are single sensor full swath per ping sensors. The track spacing can then directly be determined from the platform altitude and the requirement for azimuth resolution, and overlap. The track spacing simply becomes the sonar swath width or FOV mapped in ground range with the overlap withdrawn. Note that the desired geometrical azimuth (or cross-track) resolution must be taken into account when calculating the maximum range of the sonar. See [Cotter and Polagye 2020] for details on FLS surveys.

SSS and SAS are two-sided systems with a nadir gap. To fill the gap caused by one line, the next line must be carefully chosen, where the line spacing is given by the altitude, and the minimum and maximum ground range $[R_{min}, R_{max}]$ of the system. There are different alternatives for choosing line spacing and overlap, as illustrated in Figure 24. It should be noted that the minimum ground range is determined by the vertical beamwidth of the system, which may vary between vendors. The maximum ground range is limited by the chosen acoustic frequency and the spatial sampling requirement (especially for SAS). Table 5 summarizes the area coverage rate for the different strategies. See [Hagen and Hansen 2007] for details.

Table 5 Area coverage rate for SSS and SAS without gap filler.

Strategy	Area Coverage Rate	$R_{min}=R_{max}/10$	Coverage	Comments
Instantaneous	$(R_{max}-R_{min}) 2 v$	$1.8 v R_{max}$	100%	
One view	$(R_{max}-R_{min}) 2 v$	$1.8 v R_{max}$	100%	$3R_{min}=R_{max}$
Two views	$(R_{max}-R_{min}) v$	$0.9 v R_{max}$	200%	Equispaced lines
Maximum coverage	$(3/2 R_{max} - 1/2 R_{min}) v$	$1.45 v R_{max}$	124%	$3R_{min} < R_{max}$
Overlapped (sym)	$(R_{max}+R_{min}) v$	$1.1 v R_{max}$	163%	$3R_{min} < R_{max}$

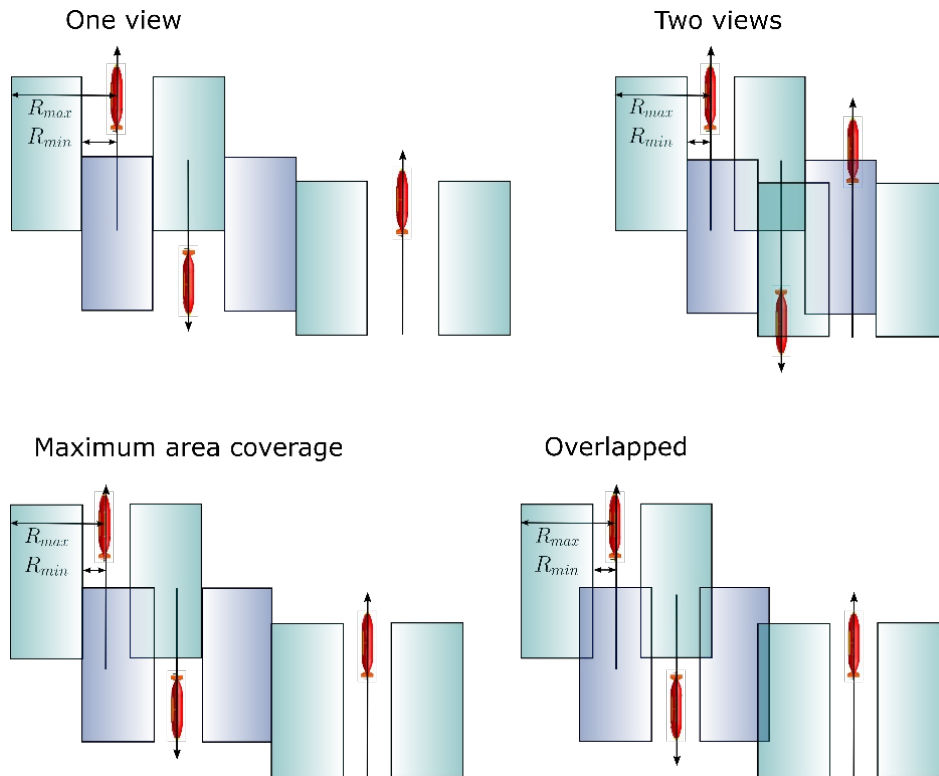


Figure 24 Line spacing alternatives for two-sided imaging sonar without gap-filler

Conclusions

In this draft report, we have presented a compilation of methods and best practices for Sector scanning sonar, Multibeam Echosounder (MBES), Side-scan sonar (SSS) and Synthetic Aperture Sonar (SAS) approaches for use in detection, localization and classification of marine munitions at the seabed.

This represents Milestone 7 in the EU Horizon project “Marine Munition in Europe - Solutions with Economic and Ecological Profits for Efficient Remediation” (MMinE-SwEEPER). The final version of this report is Delivery 3.1 with deadline Month 40 in the project.

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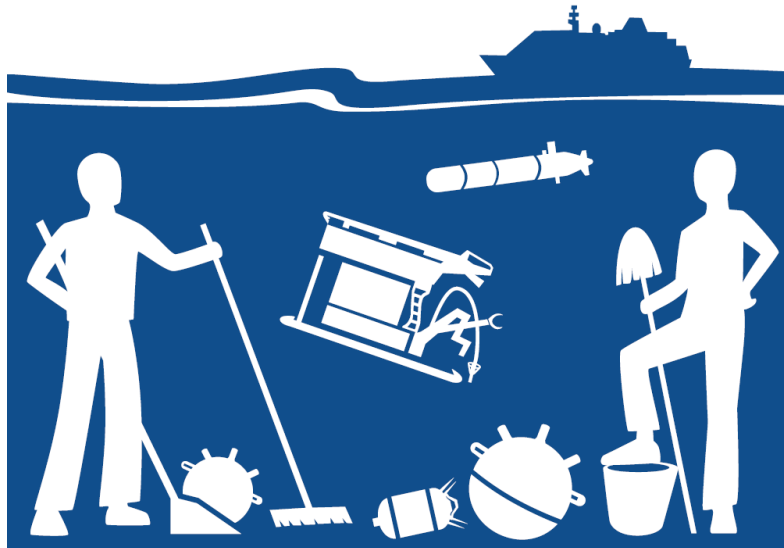
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Appendix A: Acronyms

ATR	Automated Target Recognition
AUV	Autonomous Underwater Vehicle
CTD	Conductivity, Temperature, Depth
DOA	Direction of Arrival
DVL	Doppler Velocity Logger
FLS	Forward Looking Sonar
FOV	Field of View
GNSS	Global Navigation Satellite System
INS	Inertial Navigation System
MBES	Multibeam Echosounder
MCM	Mine Counter Measures
PPT	Parts Per Thousand
PRF	Pulse Repetition Frequency
PSF	Point Spread Function
ROV	Remotely Operated Vehicle
SAR	Synthetic Aperture Radar
SAS	Synthetic Aperture Sonar
SNR	Signal-to-Noise Ratio
SSS	Side-scan Sonar
TOA	Time of Arrival
USV	Unmanned Surface Vehicle
UXO	Unexploded Ordnance



MMinE-SwEEPER

Milestone Report

Milestone No. 8: First compilation of best practices of optical studies
and photogrammetric reconstructions



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Authors | Jens Greinert

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Refraction, illumination and color correction	6
Data management	7
Photogrammetric reconstruction guidelines	7
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Introduction

This milestone delivers a first, structured compilation of peer-reviewed literature relevant to best practices in optical studies and photogrammetric reconstructions. It directly addresses Objective A3: Compilation of state-of-the-art and newly generated knowledge by consolidating key references into a shared knowledge base.

A number of openly accessible publications address underwater optical imaging and photogrammetric reconstructions. The covered topics range from discussions of suitable platforms (e.g., towed video sleds, ROVs, AUVs, submersibles, and diver-operated systems) to lightning systems, camera calibration, photogrammetric reconstructions and data management. The list below cites selected papers and reports that provide both an entry point and more in-depth discussion of these aspects.

This milestone is not meant to be a full literature review but to generate thematic groups in which publicly available first papers to the topic have been listed. The thematic groups are: (1) general overview papers, (2) papers on refraction, illumination, and colour correction, (3) data management, (4) photogrammetric reconstruction methods, and (5) application papers that present photogrammetric reconstructions.

General overview on underwater imaging

Gomes-Pereira, J.N., Vincent Auger, Kolja Beisiegel, Robert Benjamin, Melanie Bergmann, David Bowden, Pal Buhl-Mortensen, Fabio C. De Leo, Gisela Dionísio, Jennifer M. Durden, Luke Edwards, Ariell Friedman, Greinert, J., Nancy Jacobsen-Stout, Steve Lerner, Murray Leslie, Tim W. Nattkemper, Jessica A. Sameoto, Timm Schoening, Ronald Schouten, James Seager, Hanumant Singh, Olivier Soubigou, Inês Tojeira, Inge van den Beld, Frederico Dias, Fernando Tempera, Ricardo S. Santos (2016): Current and future trends in marine image annotation software, *Progress in Oceanography* 149 (2016) 106–120, doi: <http://dx.doi.org/10.1016/j.pocean.2016.07.005>

Durden, J.M., Schoening, T., Althaus, F., Friedman, A., Garcia, R., Glover, A.G., Greinert, J., Jacobsen Stout, N., Jones, D.O.B., Jordt, A., Kaeli, J.W., Köser, K., Kuhn, L.A., Lindsay, D., Nattkemper, T.W., Osterloff, J., Ruhl, H.A., Singh, H., Tran, M., Morris, K.J., and Bett, B.J. (2016): Perspectives in visual imaging for marine biology and ecology: from acquisition to understanding. *Oceanography and Marine Biology: An Annual Review*, 2016, 54, 1-72. https://nora.nerc.ac.uk/id/eprint/530878/24/10.1201_9781315368597-6_chapterpdf.pdf

Köser, K., She, M., Diller, N., Reissmann, S., Weiß, T., Heger, K., Song, Y., Schöntag, P., Nakath, D., Schoening, T., Mohrmann, J., Gazis, I.-Z., Kampmeier, M., Rothenbeck, M., Wenzlaff, E., & Greinert, J. (2024). Autonomous Visual 3D Mapping of the Ocean Floor by Underwater Robots Equipped with a Single Photo Camera. In J. C. Rodríguez-Quinonez, W. Flores-Fuentes, M. J. Castro-Toscano, & O. Sergiyenko (Hrsg.), *Scanning Technologies for Autonomous Systems* (S. 67-100). Springer Nature Switzerland Cham. https://doi.org/10.1007/978-3-031-59531-8_3

Refraction, illumination and color correction

She, M., Nakath, D., Song, Y., & Köser, K. (2022). Refractive geometry for underwater domes. *ISPRS Journal of Photogrammetry and Remote Sensing*, 183, 525-540. <https://doi.org/10.1016/j.isprsjprs.2021.11.006>

- Song, Y., Nakath, D., She, M., & Köser, K. (2022). Optical Imaging and Image Restoration Techniques for Deep Ocean Mapping: A Comprehensive Survey. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 90(3), 243-267. <https://doi.org/10.1007/s41064-022-00206-y>
- Song, Y., She, M., & Köser, K. (2024). Advanced underwater image restoration in complex illumination conditions. *ISPRS Journal of Photogrammetry and Remote Sensing*, 209, 197-212. <https://doi.org/10.1016/j.isprsjprs.2024.02.004>
- Wang, H., Köser, K., & Ren, P. (2025). Large Foundation Model Empowered Discriminative Underwater Image Enhancement. *IEEE Transactions on Geoscience and Remote Sensing*, 63, 1-17. Artikel 5609317. <https://doi.org/10.1109/TGRS.2025.3525962>

Data management

- Schoening, T., Köser K., and Greinert, J. (2018): An acquisition, curation and management workflow for sustainable, terabyte-scale marine image analysis. *Scientific Data*, 5:180181, DOI:10.1038/sdata.2018.181

Photogrammetric reconstruction guidelines

- Mohrmann, Jochen, Frey, Torsten, Diller, Nikolaj, von See, Tim-Benedikt, Heger, Karl und Greinert, Jens (2025) Practical Guide for Underwater Photogrammetric Reconstruction Version 1.0. Deep Sea Monitoring Reports, 0001. GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany, 35 pp. DOI 10.3289/DSMR-0001.

Photogrammetric reconstruction examples

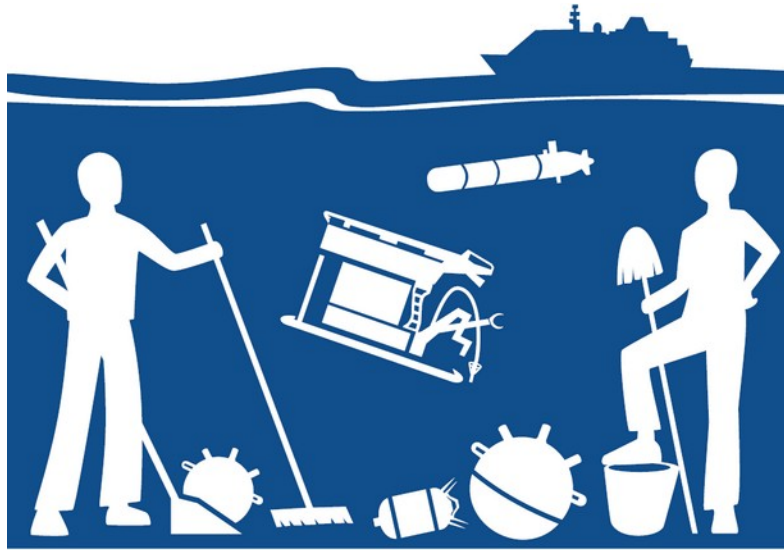
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Conclusion

Underwater optical imaging techniques are widely used and became standard methodologies for marine exploration, including classification and identification of marine munitions. Methodologies for deploying cameras, lightening set up, color correction and refraction issues have been investigated and solutions have been presented. Important for a meaningful use of the large amount of data

created with optical systems is a good data management strategy, one specific literature example is presented.

With respect to photogrammetric reconstruction, substantial literature from the machine vision domain does exist but often links to in air reconstructions. However generally the same techniques, workflows and software packages can be used also for underwater reconstructions. Listed is one recent 'best practice guide line' that has been put together by GEOMAR colleagues as a multi-project compilation. The final three publications show the applicability in different environmental settings, highlighting that underwater photogrammetric reconstructions are possible and give the best resolution and munition identification possibility. Despite these possibilities, photogrammetry is not often used for munition investigations. This is because of the additional complexity to handle and process the data and the need for additional time or equipment (AUVs) to generate useful imagery in the first place.



MMinE-SwEEPER

Milestone Report

Milestone No. 16: Mission Control Report



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List of Abbreviations

AI	Artificial Intelligence
ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicle
COTS	Commercial Of The Shelf
DVL	Doppler Velocity Log
GIS	Geo Information System
GPS	Global Positioning System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LBL	Long BaseLine
ROS	Robot Operating System
ROV	Remote Operated Vehicle
RTK	Real Time Kinematic
SCS	Self-Contained Systems
TMS	Tether Management System
UI	User Interface
USBL	Ultra Short BaseLine
UXO	UnExploded Ordinance

Introduction

Millions of conventional and chemical munitions were purposely and accidentally discarded or lost throughout European waterways both during and after the World Wars (WWI & WWII). Only adding to the problem, the dumping of munitions at sea was a standard demilitarization practice following WWII. Consequently the ocean floor has become humanities largest landfill for explosive remnants of war. Research from the MarTERA EROVMUS and CONMAR projects indicates that corrosion is accelerating, releasing carcinogenic compounds like TNT, 1,3-Dinitrobenzene, and arsenic into the water column, where they enter the food web and endanger human health (Greinert et al., 2024; Böttcher et al., 2011).

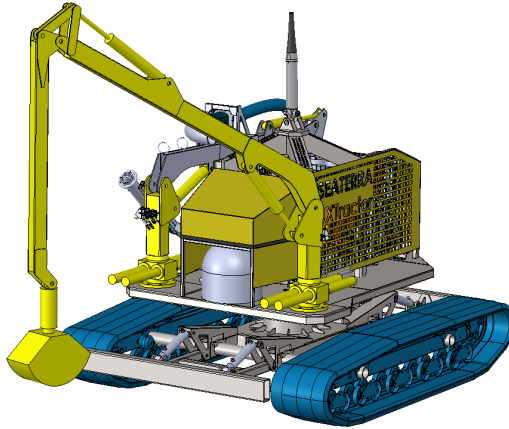
Simultaneously, the economic utilization of the seabed is intensifying. The European Union's renewable energy targets demand a massive expansion of offshore wind capacity, requiring unobstructed seabeds for turbine foundations and cable routes. UXO clearance has thus become an indispensable activity. This creates a technological paradox: industry needs robotic swarms to cover vast areas efficiently, yet requires high-bandwidth human supervision to satisfy legal frameworks that mandate an "Expert-in-the-Loop" for target identification and neutralization. The industry is therefore pivoting to "Supervised Platoons" (Figure 1), that is groups of robots tethered to a parent vessel or using short-range optical modems to provide the necessary video feeds to human supervisors (Khalid et al., 2023).

Key Definitions and Technological Landscape

To engineer a control system for this paradigm, several foundational technologies and concepts must be defined:

- ❑ **Geographic Information Systems (GIS):** In the marine domain, GIS is a dynamic, volumetric 4D database integrating bathymetric data, sidescan sonar mosaics, magnetic anomalies, and environmental variables. It manages the "Target List" of potential UXO contacts and serves as the foundational world model for path-planning algorithms (NOAA, n.d.).
- ❑ **Underwater Acoustic Positioning (USBL, LBL, INS):** Because GPS (RF signals) attenuates within centimeters underwater, acoustics are used for positioning.
 1. **USBL (Ultra-Short Baseline):** A transceiver on the ASV measures the range and phase difference (bearing) of acoustic replies from a crawler's transponder. It provides high mobility but its accuracy degrades with depth (Advanced Navigation, n.d.).
 2. **LBL (Long Baseline):** Uses a network of seabed transponders to triangulate a vehicle's position, offering centimeter-level accuracy but requiring expensive, time-consuming setup (Advanced Navigation, n.d.).
 3. **INS (Inertial Navigation System) & DVL (Doppler Velocity Log):** INS calculates position via dead reckoning using gyroscopes and accelerometers. To correct inherent drift, a DVL measures velocity relative to the seabed via acoustic Doppler shifts. A DVL-aided INS allows a crawler to navigate precisely between sparse acoustic updates from the surface (Nortek, n.d.).
- ❑ **Swarm Telemetry:** The exchange of state data (position, health, intent) between multiple agents. Underwater, this is heavily constrained by acoustic physics (low bandwidth, high latency, multipath interference), requiring highly compressed, semantic data payloads and delay-tolerant networking (Han, G., et al., 2015).
- ❑ **Leader-Follower Behavior:** A hierarchical control topology where one agent (the Leader, often the ASV) dictates the global path, while Follower agents (crawlers) maintain a relative spatial formation based on the leader's broadcasted state (Kabanov, A., et al., 2024).
- ❑ **Decentralized Routing:** A robust networking and control approach where agents independently calculate paths and relay messages without relying on a central node, utilizing local sensor data and peer-to-peer sharing to avoid obstacles and maintain formation (Han, G., et al., 2015; Qiao, Z., et al., 2020).
- ❑ **Enhanced Centralized Routing:** A more realistic approach for clearance areas (a focus of MMinE-SwEEPER), although crawlers independently calculating their own paths might be too ambitious. It will be

based on a central planner aware of the whole fleet being used to define missions and assign paths/tasks, and each individual crawler being able to carry out assigned tasks independently. Examples of crawlers at SeaTerra are presented in Figure 2 and Figure 3. On-board path planning would then be limited to obstacle avoidance and maybe end stage navigation to locally identified targets.



SwEEPER

Figure 2: UXTractor. A 5T crawler co-developed within MMinE-

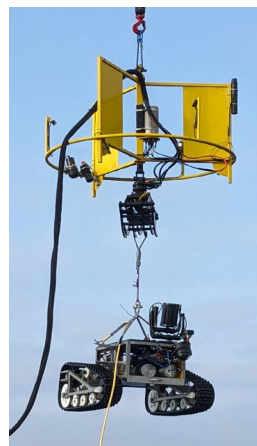


Figure 3: NORPPA crawler on the immediate action program

The ROS 2 Framework Backbone

Many modern marine robots fundamentally rely on Robot Operating System 2 (ROS 2). Unlike its predecessor, ROS 2 is built upon the Data Distribution Service (DDS) standard, an industrial-grade, decentralized publish-subscription middleware (Figure 4). This is highly relevant to underwater crawlers for several reasons:

1. **Quality of Service (QoS):** ROS 2 allows developers to tune QoS profiles (e.g., "Best Effort" vs. "Reliable", "Volatile" vs. "Keep Last"). In a lossy underwater acoustic environment, tuning QoS ensures that critical commands (like an emergency stop) are guaranteed delivery, while high-frequency but non-critical telemetry can be dropped if packets are lost (Macenski, S., et al., 2020).
2. **Lifecycle Nodes:** ROS 2 introduces managed nodes with deterministic states (Unconfigured, Inactive, Active, Finalized). This allows the mission control software to systematically boot up, verify, and monitor the health of every sensor on the crawler before it leaves the ASV deck (Macenski, S., et al., 2020).
3. **Decentralization:** ROS 2 lacks the central "roscore" master node of ROS 1. This means if the ASV loses connection to the crawler, the crawler's internal ROS 2 network continues to function autonomously, allowing its Nav2 stack to execute obstacle avoidance and safe-surfacing routines independently.

Key Analysis: The Mission Control Software Ecosystem

Designing an optimal software architecture requires a rigorous evaluation of the existing landscape. Likewise, it is important to understand why traditional hydrographic tools struggle with multi-robot autonomy, and how modern robotic frameworks can bridge these gaps.

Commercial Off-the-Shelf Solutions (COTS)

Traditional marine software suites are the gold standard for high-precision data acquisition and compliance logging. However, their monolithic architectures present challenges for decentralized swarm control.

Eiva NaviPac

NaviPac, the flagship navigation suite from Eiva, is heavily utilized in offshore construction and survey industries.

- **Strengths:** NaviPac excels in multi-vessel and subsea positioning (Figure 5). It systematically ingests data from USBL, LBL, INS, and DVLs, applying advanced Kalman filtering to produce a highly accurate, smoothed position for tethered ROVs (Eiva, n.d. a). Its "Remote Supervision" feature allows an onshore UXO expert to take control of an offshore ASV and ROV via an IP network, pushing waypoints and altering configurations remotely (Eiva, n.d. b).
- **Weaknesses for Swarms:** NaviPac is designed around a single human operator managing a high-bandwidth link to a small number of assets. It is not an autonomous fleet orchestrator. It lacks native integration with modern robotic fleet protocols (like VDA5050) and does not possess the decentralized "hive mind" logic required to autonomously re-route a swarm of ten crawlers if one encounters a dynamic obstacle or a tether entanglement.

QPS Qinsy

Qinsy is renowned for its stability in complex marine construction and multi-sensor survey acquisition.

- **Strengths:** Qinsy provides exceptional multi-object tracking, vital for managing complex kinematic chains (e.g., an ASV towing a magnetometer array while tracking multiple ROVs). It boasts an "autonomous survey mode" that can dynamically generate new survey lines based on the bathymetric coverage achieved in the previous pass to ensure no gaps remain (QPS, n.d. a). Its tight integration with post-processing tools (Qimera, Fledermaus) makes it ideal for generating the rigorous data deliverables required for UXO clearance certificates (QPS, n.d. b).
- **Weaknesses for Swarms:** Qinsy is a proprietary, closed ecosystem. Integrating custom bio-inspired flocking algorithms or highly specialized tether-management heuristics into its core is exceptionally difficult. It focuses heavily on sensor data quality and hydrographic mapping rather than dynamic, multi-agent robotic behavior control.

Hypack

Hypack (a Xylem brand) is globally one of the most widely used hydrographic packages.

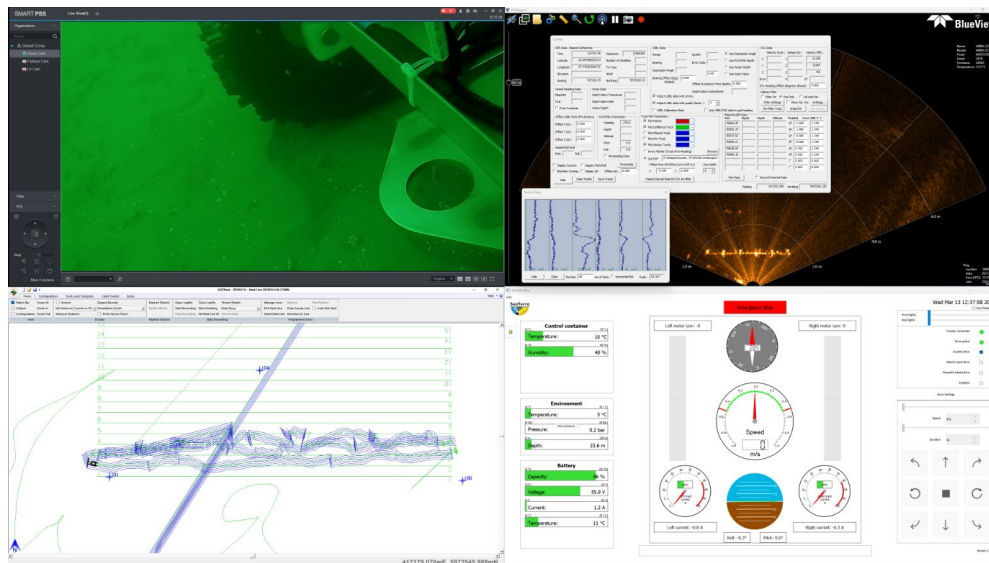
- **Strengths:** Its defining feature is its broad hardware compatibility. Hypack supports over 400 different sensors and features a generic parser for integrating novel devices (Xylem, n.d.). The HYSWEEP module is

highly effective for processing multibeam and LiDAR data, creating the base 3D maps necessary for crawler navigation (Subsea Technologies, n.d.).

- **Weaknesses for Swarms:** Hypack is fundamentally a data logging and display tool designed for human surveyors. It lacks the event-driven, state-machine architecture required for autonomous decision-making in a multi-agent robotic system. It relies entirely on the operator to interpret data and initiate actions.

SeaTerra AGSTrack

AGSTrack is a marine software suite, exclusively developed for SeaTerra. While it is already capable of interacting with crawler systems, such as providing positioning information and on-track control (Figure 6), it has further been developed as a tool for human surveyors and remediation experts, although not with multi-agent robotic system in mind.



Software AGSTrack operating with the NORPPA 300 crawler on a magnetic survey.

Figure 6: SeaTerra

Analysis

COTS solutions are indispensable for the Survey and Compliance Layer (generating the map and logging data for legal sign-off). However, they are fundamentally passive. They visualize where robots *are*, but are not designed as the active, autonomous Control Layer that decides what multiple interacting robots *should do next* based on real-time environmental stimuli.

Historical Precedents: Lessons from ORCA and T-REX

Current architectural choices for autonomous underwater vehicles are heavily informed by decades of academic research. Two notable historical systems highlight the evolution toward today's standards:

- **ORCA (1990s):** Initially developed at the University of New Hampshire for use in the EAVE AUV, ORCA introduced a layered, intelligent control architecture. It insulated high-level planning from real-time execution constraints (Figure 7). It utilized an "Event Handler" to process sensor interrupts, an "Agenda Manager" to prioritize tasks, and a "Schema Applier" using procedural language (if-then-else) to execute actions. This pioneered the concept of adaptive mission control essential for dynamic subsea environments. (Turner, 1995)

- **T-REX (Teleo-Reactive Executive):** Developed by MBARI in the late 2000s, T-REX represented a leap forward in autonomy. It partitioned deliberation functionally and temporally using units called "Teleo-Reactors." This allowed the AUV to synthesize sensing, planning, and execution into a single agent. By utilizing mechanisms like timeline ownership and synchronization at the execution boundary, T-REX ensured consistent state management during complex scientific sampling missions. (McGann et al. 2007)

These historical models laid the direct theoretical groundwork for the modern behavior trees, state machines, and lifecycle nodes found in ROS 2 and Isaac ROS today.

Open-Source & Robotics Frameworks

To achieve scalable, supervised autonomy, the architecture must integrate frameworks born from advanced robotics and space exploration. The idea is to combine several tools to provide a robust pipeline.

NASA OpenMCT (Open Mission Control Technologies)

Developed by NASA Ames for Mars rover operations, OpenMCT is a web-based, open-source visualization framework designed for distributed operations (NASA, n.d. a).

- **Architecture:** It uses a lightweight, plugin-based JavaScript/Vue.js architecture running entirely in the browser.
- **Strengths for Marine Robotics:** OpenMCT excels at visualizing complex, time-series telemetry (battery levels, thruster RPM, INS drift) across multiple coordinated views. Its Object-Oriented Composition allows operators to build custom dashboards by dragging and dropping domain objects (e.g., "Crawler 1," "Magnetometer A") (NASA, n.d. b). Crucially, it manages data staleness—a vital feature for acoustic communications where a crawler's telemetry might be delayed by several seconds due to bandwidth limits or distance.
- **Role:** OpenMCT acts as an ideal Presentation Layer for an UXO expert. Because it is web based, an expert can sit onshore and view low-latency WebRTC video feeds alongside rich telemetry, fulfilling the legal "Expert-in-the-Loop" requirement without needing to be physically present on the ASV.

MOOSDB and MOOSDP Web Link

The MOOSDB Web Link and the MOOSDP (MOOS Data Protocol) represent the modern bridge between the classic, high-performance MOOS (Mission Oriented Operating Suite) middleware and contemporary web-based mission control and simulation ecosystems. By enabling a "Web-aware" MOOSDB, developers can move beyond traditional desktop-bound GUIs (like uMS or pMarineViewer) toward flexible, browser-based command-and-control (C2) interfaces and heterogeneous robotic stacks involving ROS 2 and NVIDIA Isaac Sim.

- **MOOS:** At its core, MOOS utilizes a star-topology where all applications communicate via a central server called the MOOSDB. While the native MOOS protocol is a high-speed, binary TCP/IP implementation optimized for low-latency embedded systems, it is not natively compatible with standard web technologies.
- **MOOSDB Web Link:** MOOSDB Web Link is typically a bridge application that maintains a persistent client connection to the MOOSDB while simultaneously hosting a WebSocket server. It acts as a bidirectional translator, converting native MOOS messages into a format suitable for the web.

NVIDIA Isaac ROS & Mission Control

NVIDIA Isaac ROS brings GPU-accelerated AI and standardized fleet management to the ROS 2 ecosystem.

- **Architecture:** It relies on a collection of containerized microservices (GEMs) optimized for edge computing (e.g., NVIDIA Jetson Orin) (NVIDIA, 2022).
- **Mission Dispatch & Client:** Isaac uses the VDA5050 protocol (an open standard for Automated Guided Vehicles) transmitted over MQTT to handle fleet logistics (NVIDIA, 2022). The Mission Dispatch service (running on the ASV or Shore) translates high-level clearance goals into specific VDA5050 JSON orders. The Mission Client (running on the subsea crawler) receives these orders and translates them into ROS 2 Nav2 action goals (NVIDIA, n.d.).
- **Behavior Trees:** Isaac ROS manages complex task sequences using Mission Behavior Trees (e.g., "Navigate to UXO Target" -> "Deploy Airlift" -> "Confirm Visual"). If a crawler fails a node (e.g., snagged tether), the tree logic automatically triggers alternative recovery branches (e.g., "Retrace Path," "Request Human Override") without requiring constant manual joystick input (NVIDIA, 2022).

ROS 2 (Robot Operating System 2)

ROS 2 (Robot Operating System 2) is the industry-standard, open-source middleware suite designed to build complex robotic systems. Unlike its predecessor, ROS 2 is built on DDS (Data Distribution Service), providing a secure, fault-tolerant communication backbone suitable for production-grade, multi-robot deployments.

It organizes software into modular nodes that exchange data through a "publish-subscribe" model. This allows for a seamless integration of diverse hardware, from microcontrollers to powerful GPUs. With native support for real-time operating systems via modern platforms like Linux, Windows, and macOS, ROS 2 is essential for perception, navigation, and control in modern robotics. The SeaTerra crawlers NORPPA 300 and UXTractor are operated by ROS2 software (Figure 2 and Figure 3).

Self-Contained Systems (SCS) Architecture

Integrating open survey engines, OpenMCT, and Isaac ROS into a cohesive unit requires a robust macro-architecture. Microservices can become overly complex, while monoliths are too brittle. The optimal solution is the Self-Contained Systems (SCS) architecture (InnoQ, n.d.).

- **Definition:** SCS partitions a large software system into independent, autonomous web applications based on Domain-Driven Design (DDD) boundaries (InnoQ, n.d.). Each SCS owns its own data, business logic, and web UI.
- **Resilience and Decoupling:** SCS communicate asynchronously via messaging (e.g., Kafka, MQTT) and integrate at the UI level via hyperlinks or transclusion (Martinelli, S., 2023). If the "Payload Analysis SCS" crashes due to a corrupt sonar file, the "Navigation SCS" continues running completely unaffected, ensuring the crawler does not collide with the seabed. This strict fault isolation is critical for the safety of systems operating near explosives (InnoQ, n.d.; Martinelli, S., 2023).

Proposed Design: The "Hydra" Supervised Control Ecosystem

Based on the analysis, this report proposes "Hydra," a Hybrid SCS Architecture tailored for marine munition remediation. It utilizes OpenMCT as the unified frontend, providing the "eyes" for the human operator. MOOS and Isaac ROS as the robotic brain, and ROS 2 bringing it to life. The system still relies on tethered/optical links for expert supervision.

System Topology and Data Flow

To satisfy both logistical scale and legal compliance, the human interface layer spans three physical tiers and is decentralized into distinct, specialized control stations.

Tier 1: The Distributed Command Tier (Shore or Mothership)

Rather than a single monolithic control room, the operational layer is split into two distinct types of control stations, which can be geographically separated:

- **The Fleet/Project Manager Station:** This is the macro-level command center.
 - **Function:** Provides a comprehensive overview of the entire multi-robot operation. The project manager uses this station to give high-level operational orders, assign search zones, monitor fleet health, and manage logistics.
 - **Software (SCS 1 - Fleet Management):** Integrates Isaac Mission Dispatch within an OpenMCT dashboard. It displays the global GIS map, the status of all ASVs and crawlers, and utilizes Behavior Trees to visualize the progress of clearance tasks across the entire swarm without getting bogged down in individual vehicle manipulation.

A central part of the software will be a plugin to document the work. The plugin database is shared with the munition disassembly station (platform or shore based).

- **Individual Visual Control Stations (UXO Expert Stations):** Every individual crawler and ASV is paired with its own dedicated visual control station.
 - **Function:** This is the designated workplace for the certified UXO expert responsible for a specific robot. It operates entirely independently of the fleet manager station, allowing multiple experts to work in parallel on different targets.
 - **Software (SCS 2 - High-Res Payload & Compliance):** Features an independent OpenMCT instance focused entirely on low-latency WebRTC 4K video feeds, localized sonar, and precise manipulation controls for that specific vehicle. It allows the expert to perform the legally mandated visual identification, manipulate the UXO, and authorize the "Red Button" protocol (arming/aborting) without interfering with the rest of the fleet. A background compliance logger records the specific video, telemetry, and operator commands to a tamper-proof database for legal certification.

This software will also include a plugin for documentation, connected to the same database.

Tier 2: The Gateway Leader (ASV Tether Hub)

The ASV acts as the physical, positioning, and data hub.

- **Positioning Engine:** Fuses RTK-GPS, IMU, and USBL data to calculate absolute crawler positions, broadcasting this down the tether.
- **Tether Management System (TMS):** Runs a dedicated ROS 2 node monitoring the paid-out length and tension of each winch. Using algorithms like REACT (Real-time Entanglement-Aware Coverage Path

Planning) or CoralGuide, the ASV calculates catenary curves to prevent the tethers of multiple crawlers from crossing or snagging (Laranjeira, et al., 2022; CoralGuide Framework, 2025).

Tier 3: The Benthic Swarm (Semi-Autonomous Crawlers)

- **Hardware:** Tracked marine crawlers equipped with NVIDIA Jetson edge computers, DVL, IMU, cameras, and manipulators.
- **Autonomy Level ("Guarded Motion"):** The crawler uses its ROS 2 Nav2 stack to autonomously execute path planning and obstacle avoidance around rocks and debris. However, it operates under strict constraints: it will automatically halt 1 meter from a suspected UXO target and await a direct "Confirm" or "Arm" command from its dedicated human Expert at the Visual Control Station (Ashfords, n.d.).
- **The "Red Button" Protocol:** To satisfy safety regulations, the system utilizes a high-frequency heartbeat over the tether. If the crawler misses consecutive heartbeats from its assigned Visual Control Station (e.g., a 500ms latency spike), it instantly enters a "Safe Hold" mode, halting all tracks and manipulators.

Critical Technical Implementations

Decentralized Leader-Follower Swarm Logic

It is important to note that this Leader-Follower behavior is exclusively applicable in configurations where two or more crawlers are tethered to a single ASV or conventional support vessel. In such multi-crawler setups, the robots operate using swarm logic to minimize ASV movement and prevent tether entanglement. The ASV (Leader) maintains a steady heading. Each Crawler (Follower i) is assigned a formation slot (x_i, y_i) relative to the leader.

The crawler calculates its target global position:

$$X_{\text{target}} = X_L + x_i \cos(\theta_L) - y_i \sin(\theta_L)$$

$$Y_{\text{target}} = Y_L + x_i \sin(\theta_L) + y_i \cos(\theta_L)$$

This mathematical relationship allows the multi-robot platoon to sweep a large corridor simultaneously, with the Nav2 stack handling micro-deviations for local obstacles (Kabanov, A., et al., 2024).

Optical Wireless Fallback

Tethers present an entanglement risk. If a tether snaps, the crawler must not be lost. The system integrates short-range Underwater Optical Wireless Communication (UOWC) (e.g., blue/green lasers or acoustic modem) as a fallback. If the physical link drops, the crawler can establish an emergency data link with the ASV to download a safe recovery trajectory to a standby or pickup location (Kyocera, 2025).

Obstacle and UXO Identification in Murky Waters

Semi-Autonomous navigation and obstacle identification & avoidance are difficult in areas with limited optical sight. Feasibility strongly depends on acoustic sensor technology and target recognition software way beyond the scope of this project.

Hydra Software Architecture

The proposed software architecture is built with decentralized planning and control in mind. A Fleet Manager station will host an instance of a web-based user interface built with OpenMCT allowing monitoring, planning and

mission dispatch for all vehicles in the fleet. Figure 8 displays an overview of the HYDRA software, including proposed operating levels and units within. Each Expert UXO station offers direct and manual control over its corresponding vehicle. Both the fleet manager and UXO expert interfaces communicate with the remainder of the stack over network interfaces, so instances of the programs may run on one or multiple computers, on the mother ship or on shore.

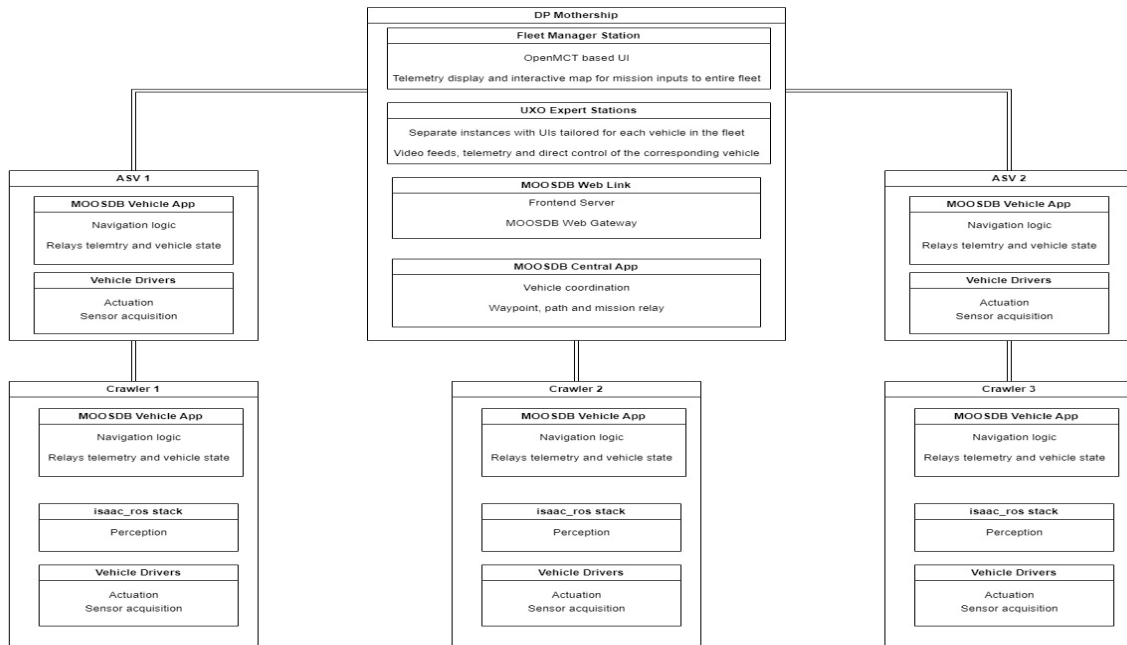


Figure 8: Overview of the proposed HYDRA software architecture.

The navigation planning logic will be built on the open-source set of modules MOOS-IVP. This will consist of a central MOOS app running on the mother ship for vehicle coordination and dedicated MOOS apps running on each vehicle for executing navigation logic (Figure 8). Waypoints and missions dispatched from the fleet manager are relayed down to the vehicles via MOOSDB and each vehicle is capable of independently executing its mission.

Each crawler also makes use of the `isaac_ros` stack for perception and obstacle recognition. Any new obstacles discovered are relayed back to the central MOOS app and made available for the entire fleet to consider in navigation planning.

The proposed software architecture may also be reused for the project CAMMera as the planning and navigation segments make no distinction between vehicles and it is solely the vehicle drivers that require unique per vehicle implementations.

AI-Accelerated Development Strategy

Developing a system as complex as Hydra traditionally takes years. We propose a “rapid prototyping” workflow utilizing AI agents to accelerate development and enforce architecture.

The Workflow: Antigravity and Claude Code

1. **Architectural Grounding (CLAUDE.md / AGENTS.md):** The project root contains context files acting as the system's constitution. These files instruct the AI on the tech stack (ROS 2 Humble, Vue.js), coding standards, and critical safety rules (e.g., "All movement commands must pass through the Tether Entanglement Service") (Anthropic, 2025; Modular, n.d.).
2. **Planning (Google Antigravity):** The lead engineer uses Google Antigravity, an agent-first IDE powered by Gemini 3 Pro. Antigravity excels at generating architectural artifacts and task lists, breaking down complex nodes (like the VDA5050 to ROS 2 bridge) into manageable plans (Urano10, 2026; Google Developers, 2025).
3. **Implementation (Claude Code):** **Claude Code**, running in the terminal, executes the plans. Powered by Claude 3.5 Sonnet/Opus, it excels at deep codebase understanding, writing the C++/Python ROS 2 nodes, and automatically generating corresponding unit tests (Anthropic, n.d.).
4. **Verification:** Antigravity's built-in browser automation agents test the OpenMCT frontend changes in real-time, providing visual artifacts (recordings/screenshots) of successful UI modifications without requiring manual human clicking (Google Developers, 2025; ZDNET, 2025).

By treating AI as orchestrated agents constrained by rigorous documentation, development time can be reduced by up to 60% while maintaining high reliability (Brosque, C., & Fischer, M., 2022).

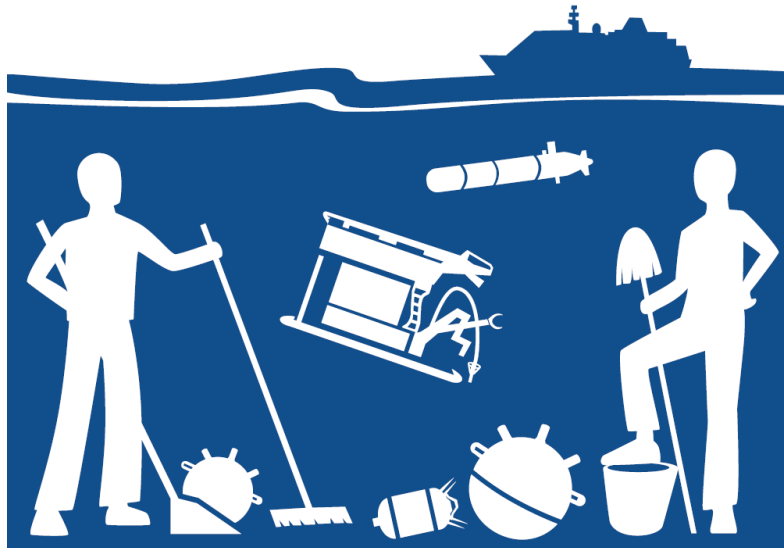
Conclusion

The remediation of millions of tonnes of submerged munitions is a monumental task that cannot be achieved only through manual labor or legacy surveying and salvaging techniques. It requires a paradigm shift toward supervised, multi-robot autonomy.

The Hydra architecture proposed in this report provides a software blueprint for this shift. By logically separating the system into Self-Contained Systems (SCS), it combines the rigorous compliance capabilities of traditional software, the human-centric visualization of OpenMCT, and the advanced robotic orchestration of Isaac ROS. It addresses the physical realities of tethered operations through entanglement-aware path planning, ensuring legal compliance without sacrificing the scalability of swarms. Ultimately, by leveraging AI-assisted development tools, we aim to rapidly develop and deploy these systems to help secure our oceans, protect human life, and enable a sustainable blue economy.

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MMinE-SwEEPER

Milestone Report

Milestone No. 19: Planning of trials in artificial 'mine gardens'
Milestone No. 20: Application for ship time and cruise planning



Funded by
the European Union

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1 Importance of trials, field work and research cruises

Within the MMinE-SwEEPER project testing equipment and technologies as well as trying and comparing different workflows and survey strategies is of great importance for WP3, 3, 6 and 8. We planned for trials in a) artificial mine gardens, b) known munition dumping areas and 3) in areas where real exploration still needs to be done. All partners will see that respective trial and cruise time will be made available through national possibilities. The following trial areas have been proposed in the proposal: CMRA test site in La Spezia, Italy; Eckernförde Bay, Germany. Other artificial mine gardens are currently setup near Rostock as part of the Digital Ocean Lab¹. It is the ambition of MMinE-SwEEPER to test equipment in very well-known environments that allow detailed comparisons. In this respect several ways exist that allow partners to apply for test time e.g. at CMRE or for cruises in the Baltic Sea, the North Sea or the Mediterranean and Atlantic.

2 Ways of applying for test and research cruises for partners

Applying for test and cruise time is different depending on the facility used (test site or research vessel) and the country you apply in. Within the project the following countries are typically able to apply for ship time in the frame of MMinE-SwEEPER: Poland, Belgium and Germany.

Mine Gardens

CMRE La Spezia, Italy: The NATO test site at CMRE in La Spezia runs a mine garden in the harbor close to the CMRE facilities. In 2024 GEOMAR and VLIZ visited the site performed AUV-based magnetic studies and hydroacoustic sub-bottom surveys. Every year the area is redesigned to the user needs. For 2025, the layout of the targets is still being discussed, MMinE-SwEEPER partners are in direct contact to CMRE representatives.

Eckernförde Bay, Germany - Baltic Sea: WTD-17 runs a test site with buried mines in Eckernförde Bay. The site belongs to WTD-71 and can be used in cooperation with WTD-71 partners. Logistics can be provided at site (hanger, crane). If ships are needed, these have to be provided from different sources (e.g. RV LITTORINA from GEOMAR).

Digital Ocean Lab, Germany – Baltic Sea: The site near Rostock is currently set up and does include infrastructure buried in and placed on the seafloor. Mines are/will be placed at certain location as well. The final state of construction still needs to be evaluated by the partners, but it would be an additional alternative for testing.

Research cruises

France: Colleagues from SHOM can apply for ship time to SHOM itself; however, the topic of investigation marine munition still needs to be discussed with the military branch of SHOM, who currently see respective studies from non-military people critical due to security issues. During the

¹ <https://www.oceantechnologycampus.com/en/our-offers/test-sites/digital-ocean-lab>

Poland: Colleagues from IOPAN have relatively easy access to the Polish research vessel RV Oceania. Requests for ship-time, for up to 14 days cruises can be made in October, in year prior to planned cruise. Typically, one or two Baltic cruises are requested, for period in spring and fall. In summer, the vessel is unavailable in the Baltic, as it conducts Arctic expedition. Typically, such expedition starts on first week of June and lasts until 1st week of September. IOPAN is also involved in other EU-funded munition projects and already applied for ship-time in 2025 (OC_APR25 cruise and OC_Nov25 in the frame of MUNIMAP) and will apply for MMinE-SwEEPER related ship-time in the Baltic Sea in 2026 and 2027.

Belgium: Normally, shiptime for RV Belgica can be applied by colleagues from VLIZ, typically for 2 weeks per year (application in June/July for the following year). However, for the moment being no applications can be done for RV Belgica as due to legal issues the vessel is not sailing (and it is not known yet when this matter will be resolved). In addition to RV Belgica, shiptime can also be applied by VLIZ colleagues for RV Simon Stevin, typically for 5 days (application in June/July for the following year). The Simon Stevin is a smaller vessel, with limited accommodation for equipment and people (max 8), and operating in the southern North Sea only.

Germany: In Germany ship-time on governmental research vessels needs to be applied for via the 'Portal Deutsche Forschungsschiffe'² in Germany who collect and review research proposals for the German research fleet (RV AKOR, RV. MARIA S MERIAN, RV HEINCKE). This involves a 20-page research proposal discussing the state of the art, the objectives and a rather detailed research cruise including station time and list of the needed equipment (e.g. large RIVs or AUVs). Other, smaller vessels e.g. RV LITTORINA from GEOMAR can be applied for within the institute and are scheduled every half year. If days are not scheduled or are given back, they can be used on short notice. This makes testing e.g. in Eckernförde Bay rather flexible.

3 Actions taken to promote joined tests in artificial mine gardens

On 23rd January 2025 a number of project partners had an online meeting to discuss joined field activities and test. The minutes of this meetings are attached. Discussions show that GEOMAR is planning to go for field trials at CMRA La Spezia to test and advance intelligence of their AUVs with magnetic sensors. For 2025 there is currently no ambition by other partners to go to La Spezia. This is also related to planning of this year's test-layout that is still ongoing at CMRE. It was discussed to think about visiting REPMUS in Portugal but no clear commitments have been made. GEOMAR was asked to check the state of the Digital Ocean Lab Site for tests at a later stage. Other topics have been discussed, mainly dealing with trails and test data set acquisitions during the upcoming AL628 cruise in March 2025.

2 <https://www.portal-forschungsschiffe.de/en/cruise-proposals.htm>

4 Granted and submitted research cruise proposals

Germany: So far, two cruise proposals have been submitted to the ‘Portal Deutsche Forschungsschiffe’. The **COMMS proposal** has already been granted with three individual cruises happening in 2025 and 2026 (see Table 1). Another proposal, ShIPPeR, was submitted early 2025 and will be evaluated soon. The proposal has originally been submitted to serve as data acquisition cruise for the BALTWRECK project, however, hydroacoustic mapping and optical investigations are part of the cruise work and MMinE-SwEEPER scientist are involved in the work and can apply and test MMinE-SwEEPER workflows and approaches. The two RV ALKOR proposals are attached to this report. In 2025, a proposal for a research cruise on a large research vessel e.g. Maria S. Merian to go to Norwegian dump sites will be handed in at GPF of Germany. Preparations for this proposal have to start in the first half of 2025 with partners from FFI, VLIZ, AU and GEOMAR. It will be tried to get potential Swedish partners on board to also investigate wrecks with chemical munition in the Skagerrak.

Table 1. Already schedules and planned cruises to the Baltic Sea.

Cruise	Date	Submitted / planned; schedules
AL628	March 2025	Scheduled for 13 th to 28 th March 2025 (COMMS proposal)
AL642	October 2025	Scheduled for 14 th to 29 th October 2025 (COMMS proposal)
ALXXX	September 2026	Granted, but exact dates still need to be defined (COMMS proposal)
ALXXX	Spring to Summer 2026	ShIPPeR
RV OCEANIA	April 2026	OC_APR25, Scheduled for 22-30 April
RV BELGICA		tbd
RV Marie S. Merian	2027	This cruise proposal still needs to be written and submitted. Partners from FFI, VLIZ and GEOMAR will join forces

5. Appendices

1. Minutes of the WP10 Task 10.1 meeting on 23rd January 2025
2. Cruise proposal COMMS, submitted by GEOMAR and approved for three cruises
3. Cruise proposal ShIPPeR, submitted by GEOMAR, waiting for evaluation

Workpackage / Task: WP10 / Task 1.1 -> Milestone 19

Meeting time: 23rd January 2025 13:00 – 14:15 / Webex

Participants: WTD-17 (Holger Schmaljohann), IQUA-Robotics (Tali Hurtos), VLIZ (Tine Missiaen, Thomas Mastdagh), GEOMAR (Marc Seidel, Jens Greinert), IOPAN (Jacek Beldowski)

General: The discussion started by presenting the possibility again to perform test in La Spezia. Marc Seidel from GEOMAR is currently preparing test at this site for AUV-based magnetic studies. He told (and others were also aware of it), that the plan for trails at CMRE for this year is not finalized yet. We quickly concluded that at the moment only GEOMAR is planning to go to La Spezia and that additional data for VLIZ should be acquired (see below -> extra meeting to discuss details). Longer discussions included the upcoming AL628 cruise to Lübeck Bay in March 2025. IOPAN and WTD-71 will join this cruise. IQUA-Robotics does not have time to join but is interested in data to use in WP6; GEOMAR runs a Sparus AUV with SSS and Oculus Sonar for acquiring data (see below). The idea of joining REPMUS 2025 was brought up. IQUA and WTD-17 most likely will go again in 2025, GEORMA is thinking about to go as well. Data exchange through the north.io cloud was discussed and GEOMAR already uploaded additional data and gave access to them. The location Digital Ocean Lab in Rostock Germany was discussed as well. IOPAN mentioned that ship time is also available through RV OCEANIA. GEOMAR as WP10 leader will continue asking partners about their plans for sea trials and cruises.

Specific topics that need action:

Who asks	Topic	Who has to act
VLIZ	VLIZ asked GEOMAR to get in contact with CMRE to see if they can place several magnetic objects less than 2m distance from each other (a small cluster of objects with known magnetic properties)	GEOMAR asks
VLIZ	During AL628, AUV LUISE is asked to acquire high-res magnetic data of a pile of munition objects from different altitudes. Such data are needed by the subcontractor of VLIZ (Davy Depreiter) for inverse magnetic modelling	GEOMAR tries to get some good data sets during the cruise
GEOMAR	Who will and want to join REPMUS 2025	All think about joining and getting in contact with their respective NAVYs
GEOMAR	Building a new dipole chain that can be deployed on demand by project participants	GEOMAR checks if such a chain can be build
GEOMAR	GEOMAR just updated a SPARUS AUV with a forward-looking Oculus Sonar; IQUA Robotics has the SoundTiles software for processing -> can GEOMAR get a trial version of the software	IQUA Robotics

COMMS

CONMAR, MuniRisk & MMinE-SwEEPER: Joined cruises for munition-related studies in the Baltic Sea

Cruise proposal for RS ALKOR (primary use)

Prof. Dr. Jens Greinert (chief scientist) perm.	Dr. Aaron Beck (deputy) perm.	Mareike Kampmeier (deputy) temp.
12.04.1968, German GEOMAR Helmholtz-Centre for Ocean Research Kiel FB2, Marine Geosystems Wischhofstr. 1-3, 24148 Kiel Phone: 0431-600-2590 E-Mail: jgreinert@geomar.de	23.10.1981, American GEOMAR Helmholtz-Centre for Ocean Research Kiel FB2, Marine Biogeochemistry Wischhofstr. 1-3, 24148 Kiel Phone: 0431-600-1289 E-Mail: ajbeck@geomar.de	06.02.1988, German GEOMAR Helmholtz-Centre for Ocean Research Kiel FB2, Marine Geosystems Wischhofstr. 1-3, 24148 Kiel Phone: 0431-600-2561 E-Mail: mkampmeier@geomar.de

1 Motivation

This proposal applies for three cruises to the Baltic Sea with the general topic of **munition-related research**. For the first time **it combines three projects** that deal with this topic. To secure the needed resources and from the very beginning align time lines of these three projects this proposal merges all the respective needs. The main incentive is the **CONMAR-C** project, the second Phase of the CONMAR¹ project as part of the sustainMare Mission². As part of CONMAR we applied for the three MECOMM-BS cruises AL590 (March 2023), AL603 (October 2023) and AL615 (October 2024).

The second project is the EU project **MuniRisk** that addresses the munition problem on stakeholder level in the entire Baltic Sea with three distinct areas for field investigations related to planned offshore wind farms, west of Bornholm (Bornholm Energy Island³ offshore Poland (Ślupsk Bank Offshore Windfarms) and the ELWIND⁴ project between Estonia and Latvia. The third **MMinE-SwEEPER** project is the largest of the three projects and aims on knowledge compilation and transfer, stakeholder involvement, technical munition detection and identification technologies and the generation of solutions on European level, not focusing on the Baltic Sea as the CONMAR-C and MuniRisk. Nevertheless MMinE-SwEEPER will also work in the Baltic for testing technology and European cooperation, e.g. between Denmark, Germany and Poland.

¹ <https://conmar-munition.eu/>

² <https://www.sustainmare.de/>

³ <https://www.energiobornholm.dk/en>

⁴ <https://elwindoffshore.eu/>

All three projects start around the same time September to December 2024, and thus fieldwork - specifically for GEOMAR as partner and coordinator (CONMAR-C and MMinE-SwEEPER) – needs to be planned and organized jointly. **We thus apply for three cruises** that have re-occurring monitoring parts within CONMAR-C, cover additional areas in MuniRisk and have an additional focus on technical developments and multinational cooperation in MMinE-SwEEPER. In the following the cruises will be named COMMS-25a, COMMS-25b and COMMS-26, indicating the planned years of the cruise.

1.1 State of the art and preliminary work

1.1.1 State of the Art

Marine munition is a threat mainly towards five different aspects, these are a) the construction of marine infrastructure, b) the safe travel of ships, c) the environment due to its release of toxic substances, d) the occasional findings of munition on shore and e) the potential misuse of explosives. Since 2011 German scientist study particularly the impact of marine munition (chemical as well as conventional) on the environment. Since 2016 the focus is on conventional munition in the German North and Baltic Sea with the aim of understanding and establishing potential threats of marine munition towards the environment. In this respect investigations on the one hand dealt with investigating actual munition occurrences (where, what, how much) and the release of the toxic explosive munition components as TNT, RDX, DNB as well as metabolites of it (e.g. 2- or 4-ADNT). Such kind of work has been undertaken by German scientist from AWI, GEOMAR, Thünen, IOW, Senckenberg am Meer, Uni Rostock, UKSH in different projects among them those coordinated by the applicant (see below), but also others like DAIMON I & II⁵, NorthSeaWrecks⁶, or the UBA project TATTOO⁷ undertaken by UKSH.

Currently the applicant is coordinating the DAM project CONMAR as part of the sustainMare Mission. The recently submitted 2nd Phase of CONMAR-C is the main driver behind this cruise application, with two additional EU projects as co-initiatives that need ships time in the Baltic Sea. All three proposals are very likely to be funded/extended; the two EU projects (MMinE-SwEEPER, MuniRisk) are in the final stages of signing the consortium agreement and funding CONMAR-C as part of the 2nd Phase of sustainMare is very likely. All three proposals are attached to this application and the CONMAR-C and MMinE-SwEEPER proposals have a rather detailed state-of-the-art description. Also, the recently submitted proposal for cruise AL609 (March 2024) had a long State-of-the-Art description and also the currently submitted proposal for AL615 (Oktober 2024, proponent Mareike Kampmeier) has a similar long and updated chapter. Because of this, we do not want to cite the same general content again and will only give only specific knowledge for this proposal.

1.1.2 Previous and running projects of the proponents

GEOMAR investigates marine munition in the Baltic Sea since 2016 when the BMBF funded project **UDEM**⁸ started. UDEM investigated ecological aspects and monitoring technologies to derive a base understanding if and to which extend marine munition has an influence on the ecosystem and what the actual scale is. An important output was the “Practical Guide for Environmental Monitoring of Conventional Munitions in the Seas”⁹ which gave an indication about the scale of contamination and the problem for the first time. GEOMAR was

⁵ <http://www.daimonproject.com/>

⁶ <https://www.dsm.museum/forschung/wissenschaftsteam/north-sea-wrecks>

⁷ <https://www.umweltbundesamt.de/publikationen/umid-012024>

⁸ <https://udem.geomar.de/de>

⁹ https://oceanrep.geomar.de/id/eprint/48842/1/geomar_rep_ns_54_2019.pdf

able to secure two parallel technology projects through the EMFF; **BASTA**¹⁰ and **EXPLOTECT**¹¹, both of which could successfully be finished in 2022. BASTA aimed at advancing the approach for munition detection both on local and a larger scale. The project worked on advancing data acquisition through ultra-high-resolution 3D sub-bottom profiling (SBP) and intelligent autonomous underwater vehicle (AUV) based magnetic mapping as part of an adaptive and iterative survey approach. EXPLOTECT in the same funding scheme successfully developed an automated analyzing system for munition compounds, which is currently further developed in its successor project **AMMOTRACe**¹². Parallel, the proponents run the **ProBaNNt**¹³ that has AI-driven decision support for munition object handling, as well as technical developments for optical and acoustic 3D reconstructions as main aims. AMMOTRACe and ProBaNNt are both funded through the MarTERA initiative. Two additional HGF funded validation projects aim at developing software for AI-based object detection in spatial data (MBES, SSS; **ValidITy**¹⁴) as well as advancing autonomy of AUVs for automated magnetic object detection (**SAM**¹⁵; further development from the BASTA project). Next to these very technical projects, GEOMAR is coordinating the current **CONMAR**¹⁶ project as one of five projects in the sustainMare Mission of the DAM. As outlined above, this proposal is part of the second CONMAR phase -> **CONMAR-C**.

1.1.3 Previous cruises to the topic by the proponents

As part of all these past and ongoing projects GEOMAR lead the following RV POSEIDON and RV ALKOR cruises with the focus in munition studies (POS530, AL548, AL567, AL583, AL590, AL603, AL609) and joined two RV HEINCKE cruises to the North Sea (HE622, HE635). Further GEOMAR run many one-day or smaller RV LITTORINA cruises to the North and Baltic Sea between 2017 and 2024.

1.2 Integration in national and international programmes

The three cruises are deeply imbedded in the three parallel running projects CONMAR-C, MuniRisk and MMinE-SwEEPER. It should be highlighted that **internationalisation and the cooperation between European countries have very high priority for all of these projects**. All have explicit stakeholder dialogue work packages and the ambition to strengthen European cooperation. Successful German lead cruises will help to strengthen this cooperation and will highlight the expertise of the German marine science and our science coordination expertise. At the same time **other international projects** are ongoing in which the proponents are not directly involved but are associated with, these are **MuniMap**, **REMARCO** and **BaltWreck**. MuniMap again has a focus on evaluating environmental/ toxicological impacts in German, Polish and Lithuanian waters from munition hot spots. It is run by IOPAN from Poland, who are partners in MMinE-SwEEPER (UBA as CONMAR-C partner is also partner in MuniMap). In parallel BaltWreck lead again by Poland is targeting a number of ship wrecks within the southwest Baltic Sea, with the aim to establish the degree of contamination but also investigate possible remediation possibilities. Similarly, the REMARCO project (a successor of the

¹⁰ <https://www.basta-munition.eu/>

¹¹ <https://www.exploTECT.eu/de>

¹² <https://www.geomar.de/en/ammotrace>

¹³ <https://www.probannt-munition.eu/>

¹⁴ <https://validity-project.eu/>

¹⁵ <https://sam-project.eu/>

¹⁶ <https://conmar-munition.eu/>

NorthSeaWrecks project) is investigating wrecks in the North Sea with other European partners. AWI, a partner in CONMAR-C is coordinating REMARCO. Furthermore, GEOMAR and CONMAR-C partners are closely cooperating with the **BMUV “Sofortprogramm Munitionsbergung”** and as part of this CONMAR-C aims at performing environmental monitoring studies and assessments to evaluate the impact of different removal and remediation methodologies. First activities will happen in Lübeck Bay in July-August 2024, and the parallel applied cruise AL622 by M. Kampmeier aims at investigating the environmental impact and recoveries after the munition removal. The two cruises in 2025 will continue investigating the environmental changes after munition removal.

2 Objectives and work program

The three cruises of COMMS-25a, COMMS-25b and COMMS-26 have three **overarching objectives**:

- 1) **Investigate environmental implications of marine munition in the Baltic Sea**, including conventional munition hot spots and isolated occurrences (i.e. munition dump sites in the Schleswig-Holstein waters) but for the first-time work in potentially chemical munition contaminated areas (around Bornholm Basin and Little Belt).
- 2) **Develop technological further development of automated, AUV-based seafloor mapping approaches** for the detection and identification of munition objects.
- 3) **Foster international cooperation** and support decision making processes in the Baltic Sea with respect to offshore wind installations and other planned infrastructure.

2.1 Detailed Objectives

For each of the above-mentioned overarching objectives a number of specific objectives can be named which are of importance for one or more of the three cruises. Each objective links to one or more of the three projects CONMAR-C = CO; MuniRisk = MR; MMinE-SWEEPER = MSW

Objective 1: Investigating environmental implications of marine munition in the Baltic Sea

- 1.1. Survey the seafloor with geophysical methods (MBES, SSS, SAS) in unknown areas of potential munition contamination in the western and eastern Baltic Sea, to increase our knowledge about munition hotspots. (CO, MR, MSW)
- 1.2. Survey the water column and sediment for contamination with explosive munition components as TNT, RDX, DNB as well as its metabolites as 4- or 2-ADNT and others. (CO, MR, MSW)
- 1.3. Perform detailed optical investigation of potential munition objects with ROV and AUV (CO, MR, MSW)
- 1.4. Perform magnetic surveys around potential munition objects to support its identification as magnetic object and investigate potential magnetic objects in the subseafloor (CO, MR)
- 1.5. Perform for the first-time sampling of sediment in potentially chemical warfare agent (CWA) contaminated areas; implement sampling strategies for CWA (CO, MSW)
- 1.6. Sample and analyse fauna in a screening like fashion from munition contaminated areas (CO, MR)

- 1.7. Continue monitoring measurements of water, sediment and fauna near the cleared munition pile areas in Lübeck Bay (BMUV Sofortprogramm; CO)
- 1.8. Repeat biomonitoring efforts with mussel moorings at dedicated monitoring locations in Kiel Bight and Lübeck Bay (CO)

Objective 2: Further development of automated, adaptive and cooperative AUV-based seafloor mapping approaches

- 2.1. Continue to further develop autonomous behavior of AUVs with magnetic sensors (MSW)
- 2.2. Increase AUV autonomy through real-time analyses of optical and sonar camera data with the aim of object detection and identification (MSW)
- 2.3. Increase AUV autonomy by real-time analyses of multibeam and sidescan data (object detection) with a adaptive survey approach (MSW)

Objective 3: Foster international cooperation

- 3.1. Use the planned cruise to establish contacts with Latvian, Estonian and Swedish scientists and authorities (MR, MSW)
- 3.2. Undertake cooperative investigations and joined exercises with German and Polish authorities with respect to general interventions of munition threats and handling of chemical munition incidents (MSW)
- 3.3. Transfer knowledge and perform training to authorities (civil and military) of Baltic Sea states (visits at sea during research is performed) (MSW)
- 3.4. Strengthen the cooperation among Baltic Sea states with respect to marine munition as threat to the environment and OWF installation by using governmental initiatives as HELCOM, the Baltic Sea Parliamentary Conference (BSPC) and the Council of Baltic Sea States (CBSS) (MR, MSW)

2.2 Work program

The work program at sea for all three projects is similar but does vary with respect to the main working areas and percentage between monitoring efforts, new areas that need surveying first, technical test as well as international cooperation.

2.2.1 Working area, stations, and profiles

The proposed cruises cover wide parts of the southern Baltic Sea. We have a total of 11 working areas that we plan to visit repeatedly during each cruise or only once. In addition to well-known conventional munition dumping grounds (MDG; Kolberger Heide, Falshöft, Lübeck Bay; Figure 1), we plan to investigate two known dump grounds of chemical warfare agents (CWA; Little Belt and Bornholm); the Bornholm CWA area has been investigated before by Polish colleagues. Further we have a number of yet unknown areas where initial surveying is essential. These areas correlate with national/international efforts of building offshore wind farms (OWF) and are thus of great interest to national authorities, the Baltic Sea states in general and the EU; the OWF area Bornholm 50Hertz/Energinet, Slupske Bank PGE, Latvia ELWIND and Estonia ELWIND. The two final areas are of interest because of conventional munition in two wrecks (Estonia Wrecks) and potential environmental contamination at a dump site just outside the Swedish EEZ (Utö). The working areas and the main work planned to be undertaken are explained below.

1. Kolberger Heide MDG

The Kolberger Heide area just 1.5h steaming from GEOMAR in Kiel has been well investigated since 2016 during many cruises. We have a very good overview of existing conventional munition objects ranging from piles of sea mines to clusters of depth charges or ground mines to isolated torpedoes and other munition objects. Further the Kolberger Heide is a contamination hot spot with large chunks of open explosives and thus will be regularly sampled for water and sediment. Due to this knowledge and the proximity to GEOMAR, the Kolberger Heide is an ideal testing area of equipment as it is needed for studies within the MMinE-SWEEPER project. Because of this the area will be visited during each cruise as first area.

2. Falshöft MDG

Similar to Kolberger Heide, many previous cruises worked in Falshöft where the seafloor is more sandy and isolated large munition objects like torpedo heads and depth charges are well known. The area has known for its stone reefs where boulder size rocks can be misinterpreted as munition objects and vice versa. WTD 71 uses this area for many years as test site for AUV-based SAS studies and with data acquired by GEOMAR, this area is ideal for testing change detection approaches and automated target identification. Falshöft will be studied during both cruises in 2025 with a focus of technical test and AUV deployments.

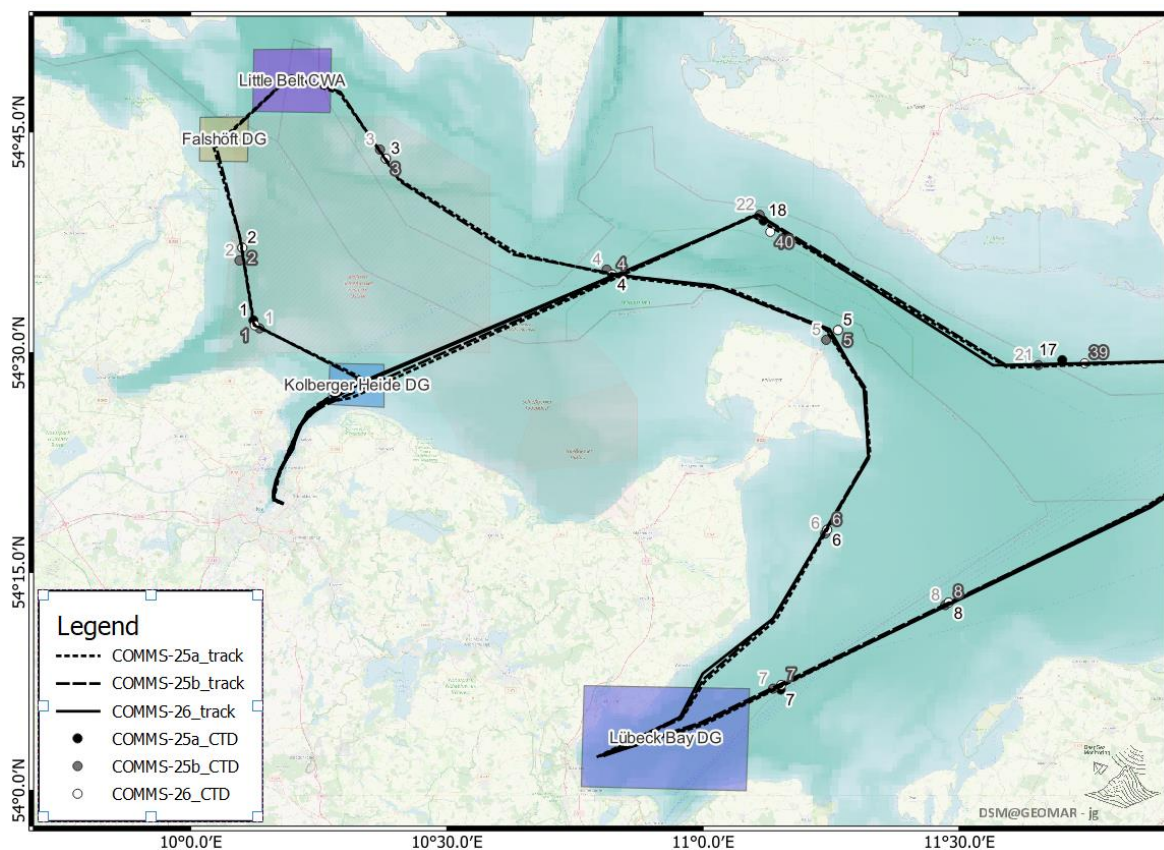


Figure 1: Overview of working areas in German waters and the Little Belt CWA area. CTD sampling occurs between the working areas as continuation of the monitoring in this region.

3. Little Belt CWA

The Little Belt area has only been sampled once before by the proponents CTD during AL603 by means of CTD. No detailed seafloor investigations occurred so far. This area is known to be used as dump ground for CWA when munition was transported from Flensburg into this area. The slightly deeper water depth and proximity to the Flensburg harbor caused that this

area was selected for CWA munition. Most of the German CWA munition was actually dumped in the Skagerrak. Prior to the cruise and as part of stakeholder discussion in the MuniRisk and MMinE-SwEEPER project we will get involved with Danish authorities (mainly the Navy) to discuss details about this area and the state of knowledge at authority level. This discussion is part of the two mentioned projects and will start immediately after the projects started in 2024. Work in this area will include longer survey activities to identify potential hotspots of munition followed by more detailed investigations by AUV and ROV. In case suitable sediment sampling sites for sediment are identified, we will bring respective authorities and the needed equipment for dealing with CWA on board the vessel (see 2.2.3 Special requirements). It is planned that the Little Belt CWA area is investigated during COMMS-25a and -25b, for about 70h and 26h, respectively.

4. Lübeck Bay MDG

The Lübeck Bay area is - similarly to Kolberger Heide - very well studied. The area has two main dump sites, Haffkrug and Pelzerhaken, which both have munition piles of small caliber munition boxes, grenades, bombs and depth charges as well as isolated objects of such kind. More than 200 of such munition piles with a spatial extend of up to 30 by 70m have been identified and investigated in the past. Seven of these piles will be removed as part of the BMUV Sofortprogramm 'Munitionsbergung', with clearance starting in July-August 2024. COMMS-25a and 25b are thus also planned to monitor the environmental changes/adaptations after removal of munition has taken place and a wet-storage for some of this munition has been established. During AL609 we performed a very dense sampling around the seven piles that will be cleared (100 x 100m raster of 3 by 3 with CTD, VanVeen grab and TV-Mini-MUC sampling). It is our ambition to repeat the same sampling scheme during both cruises. The current schedule of the "Sofortprogramm" envisions that a munition disposal platform is operating by the end of 2026. During COMMS-26 we thus plan to monitor the impact of operating such a platform in Lübeck Bay with a focus on sediment plume distribution and potential contamination with munition compounds during retrieval of the wet storage baskets and the release of discharge water from the munition disintegration process. These environmental investigations are part of the CONMAR-C project.

Further, Lübeck Bay is an ideal area for testing autonomy of AUVs and combined AUV operations with systems that autonomously communicate to each other and adapt their joined mission plan. During all three cruises respective tests will be undertaken as part of the MMinE-SwEEPER project.

5. Bornholm 50Hertz/Energinet OWF

The area SW of Bornholm is a dedicated offshore wind farm area (Figure 2). Near that area CWA encounters are reported. North of the area there is a dedicated CWA relocation spot, in case fishermen accidentally have CWA grenades in their net. In close cooperation with Aarhus University we will have stakeholder dialogues with respective local authorities, NGOs and the government as part of the MuniRisk project. Until the cruise COMMS-25a we will also get in contact with 50Hertz from Germany and Energinet from Denmark to discuss locations for investigation with the aim of independently investigating the potential implications of munition removal and CWA encounters during the construction phase of the OWF. These studies are planned of COMMS-25a with a total of about 62 hours. These studies are part of the MuniRisk project.

6. Bornholm CWA

West of Bornholm a very known CWA dump sites exists that has been filled with about 35,000 tons of munition between 1947 and 1948. The large number of encounters of CWA munition indicates that munition might have not only been dumped inside the designated area and that fishing activities spread munition (grenades but also barrels with CWA) over a larger area. Our working area is at the northern border of the larger CWA dumpsite. Here, colleagues from IOPAN did AUV and ROV based investigations in the past and discovered KC250 German areal bombs filled with diphosgene. We will use this location as start for our survey activities in the area (about 49h are planned for this) combined ship-based surveys (MBES and towed SSS) but also AUV and ROV deployments during cruise COMMS-25b. Depending on the results found, we plan to perform sediment sampling to investigate the degree of contamination with CWA. Sampling will be only performed if authorized personal is on board the vessel; we plan to collaborate with the Polish Navy/Coast Guard for this purpose, who are partner in MMinE-SWEEPER. Depending on the finding, studies will be extended and completed during COMMS-26.

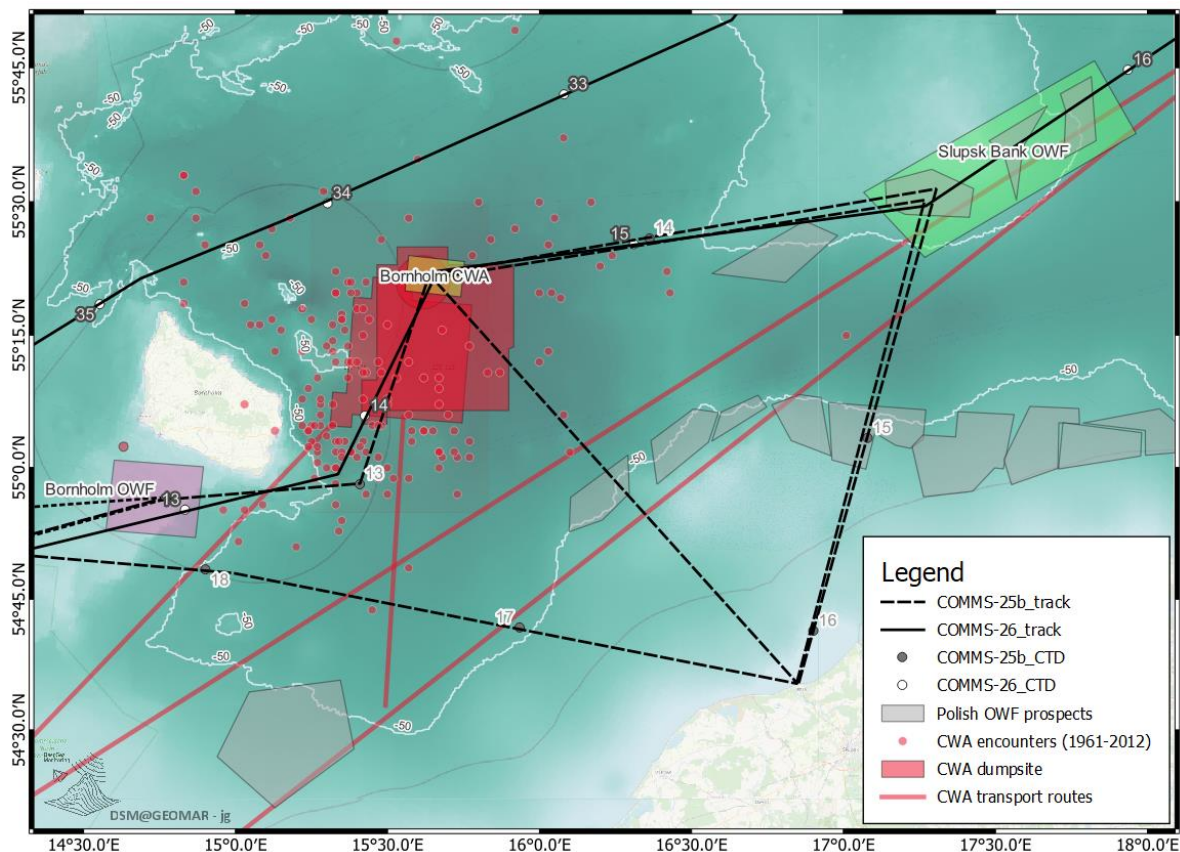


Figure 2: Working areas around and east of Bornholm. A CWA dump site is known from the Bornholm Deep. In the past several encounters of CWA have been reported (source HELCOM). Project partner IOPAN.

7. Slupske Bank OWF

The area of the Slupske Bank is a dedicated OWF area from Poland that currently invite European companies for tenders. The Slupske Bank area is of interest because it falls on the old main transport route for CWA from Wolgast to the dumping ground in the NE laying Gotland Deep dumpsite (Figure 2). Some of the OWF park sites in this area are already taken by the Polish Investor PGE; prior the cruise and with help of our Polish partners from IOPAN we will get in contact with them and discuss useful target locations to establish a potential environmental threat from conventional but also CWA munition. Studies in this working area

include substantial survey time during COMMS-25b and -26, as well as AUV and ROV deployments. Sampling is planned for both cruises, but CWA sampling will only occur during COMMS-25b where the Bornholm CWA and the Slupske Bank OWF area will be sampled directly after another, with dedicated authorities on board.

8. & 9. Latvia & Estonia ELWIND & OWF

Similar to the Polish area, Latvia and Estonia also plan OWF projects; the ELWIND project is jointly been undertaken between Latvia and Estonia (Figure 3). We plan to perform first munition related environmental studies in both areas. Ship-based surveying, AUV and ROV deployments will be performed after discussions with the OWF company ELWIND and the authorities/Navy of Latvia and Estonia. We will sample specific locations for water and sediment. Discussion as part of the MuniRisk and MMinE-SWEEPER project might result in a 'diplomatic' harbor call of the countries. All this will be part of the discussion and stakeholder interactions of both projects.

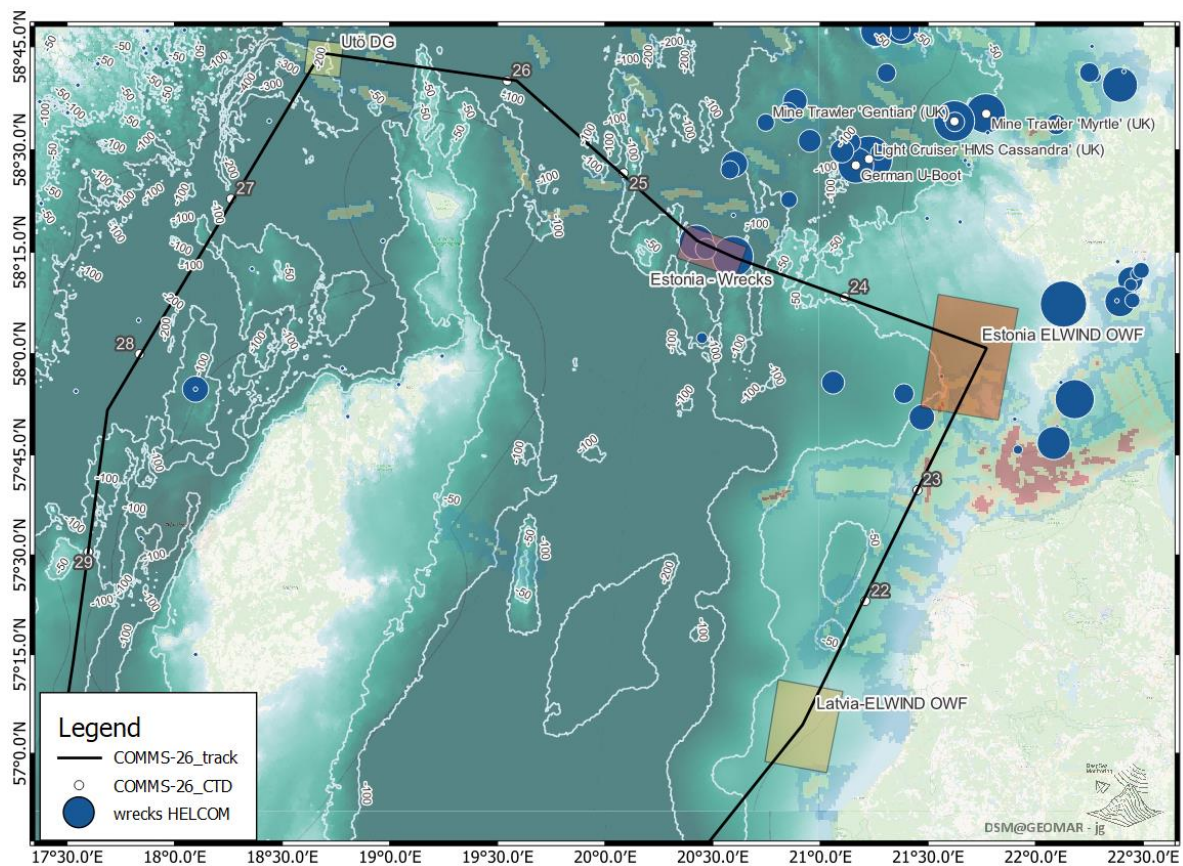


Figure 3: Overview of the four northern most working areas during COMMS-26. Blue circles show wreck positions; the circle size indicates the length of the wreck. The blue-yellow-red shading indicates the density of WWII mine barriers. Particularly, the NE' Baltic Sea was heavily mined, with a hot spot towards the entrance of the Gulf of Riga.

10. Estonia Wrecks

The HELCOM data bases also presents a data set of ship wrecks in the NE part of the Baltic Sea. The wreck density is very high in this area because of the intense WWII activities (as also indicated by the density of mine barriers). Two larger nameless wrecks of 80m and 60m length (NIMETU 186 and 195) lie in 122m and 132m water depth. We will investigate both wrecks to see if they are a potential contamination hot spot of conventional munition and oil. Both are listed in the HELCOM data base to need sonar and diver clarification. This is what we intend

to do during the cruise. Depending on the time needed we might inspect other wrecks in the area, many of them still unidentified. Several larger vessels have been identified in the area with some of them slowly leaking oil into the environment (e.g. Light Cruiser HMS Cassandra; 25 nmi towards NE).

11. Utö MDG

The deepest area during all the cruises will be close to the Swedish shooting range Utö in about 250m water depth. Prior to the cruise we will seek more information from the Swedish authorities. What we plan is a 44h investigation with ship-based MBES and SSS mapping followed by AUV and ROV deployments during COMMS-26. These investigations and the prior discussion with Swedish authorities will be part of the MuniRisk and MMinE-SWEEPER project.

12. Water sampling in the Baltic Sea

In general, little is known about munition about water column contamination with conventional explosives. Studies that have been undertaken in German waters since 2018 do not exist elsewhere. This is why we aim for a general screening of the Baltic Sea while we are transiting between working areas. Such kind of sampling can be undertaken during night with a minimum of crew effort, and has been frequently undertaken during past cruises. A total of 18, 22 and 40 CTD stations will be undertaken during COMMS-25a, -25b and -26, respectively.

The tables below give a summary of the work performed in each working area of the three cruises. Also highlighted is the main project and the country in which the work will be done. All environmental investigations will be feedback to the CONMAR-C project. Technical testing links to MMinE-SWEEPER and the cooperation with other countries relates to CONMAR-C and MuniRisk. Performing sampling of potentially CWA contaminated sediment does need detailed prior discussion with local authorities; these discussions and the appropriate coordination between countries are part of the MMinE-SWEEPER project.

COMMS-25a (March 2025) – 14 days in total

Working area	Main work & purpose	Projects	Country
Kolberger Heide MDG	Technical testing: AUV autonomy, high res acoustic cameras, cooperative surveying, real-time object detection Environment: Monitoring of contamination hotspots	MMine-SWEEPER (CONMAR-C)	Germany
Falshöft MDG	Technical testing: AUV autonomy, high res acoustic cameras, cooperative surveying, real-time object detection	MMine-SWEEPER	Germany
Little Belt CWA	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV Environment: water sampling	CONMAR-C, (MuniRisk)	Denmark
Lübeck Bay MDG	Technical testing: AUV autonomy, high res acoustic cameras, cooperative surveying, real-time object detection Environment: Monitoring with respect to the BMUV “Sofortprogramm” – changes after munition recovery and wet storage installation	MMine-SWEEPER, CONMAR-C	Germany
Bornholm OWF	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV, Environment: Water sampling and sediment sampling as baseline study for fact-based discussion with NGOs and authorities Collaboration: Support international cooperation on scientific, industry and governmental level	MuniRisk (CONMAR-C)	Denmark

COMMS-25b (September 2025) – 14 days in total

Working area	Main work & purpose	Projects	Country
Kolberger Heide MDG	Technical testing: AUV autonomy, high res acoustic cameras, cooperative surveying, real-time object detection Environment: Monitoring of contamination hotspots	MMine-SwEEPER (CONMAR-C)	Germany
Little Belt CWA	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV Environment: water sampling, sediment sampling	CONMAR-C, (MuniRisk)	Denmark
Lübeck Bay MDG	Technical testing: AUV autonomy, high res acoustic cameras, cooperative surveying, real-time object detection Environment: Monitoring with respect to the BMUV "Sofortprogramm" – changes after munition recovery and wet storage installation	MMinE-SwEEPER CONMAR-C	Germany
Bornholm CWA	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV, subseafloor evaluation of munition occurrence Environment: Water sampling and sediment sampling to further establish the risk of CWA contamination in the area	CONMAR-C MMinE-SwEEPER	Denmark
Slupsk Bank OFW	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV, subseafloor evaluation of munition occurrence Environment: Water sampling and sediment sampling to further establish the risk of CWA contamination in the area Collaboration: Support international cooperation on scientific, industry and governmental level	MuniRisk MMinE-SwEEPER	Poland

COMMS-26 (October 2026) – 21 days in total

Working area	Main work & purpose	Projects	Country
Kolberger Heide MDG	Technical testing: AUV autonomy, high res acoustic cameras, cooperative surveying, real-time object detection Environment: Monitoring of contamination hotspots	MMine-SwEEPER (CONMAR-C)	Germany
Lübeck Bay MDG	Environment: Monitoring env. impacts of the munition disposals platform as part of the BMUV "Sofortprogramm" Technical testing: AUV autonomy, high res acoustic cameras, cooperative surveying, real-time object detection	CONMAR-C MMinE-SwEEPER	Germany
Slupsk Bank OFW	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV subseafloor evaluation of munition occurrence Environment: Water sampling and sediment sampling to further establish the risk of CWA contamination in the area Collaboration: Support international cooperation on scientific, industry and governmental level	MuniRisk MMinE-SwEEPER	Poland
Latvia ELWIND OWF	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV Environment: Water sampling and sediment sampling as baseline study for fact-based discussion with NGOs and authorities Collaboration: Support international cooperation on scientific, industry and governmental level	MuniRisk CONMAR-C	Latvia
Estonia ELWIND OWF	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV Environment: Water sampling and sediment sampling as baseline study for fact-based discussion with NGOs and authorities Collaboration: Support international cooperation on scientific, industry and governmental level	MuniRisk CONMAR-C	Estonia

Estonia Wrecks	Surveying: Survey and inspection wrecks with ROV and AUV Environment: Investigate potential environmental contamination Collaboration: Support international cooperation on scientific and governmental level	CONMAR-C MMinE- SwEEPER	Estonia
Utö MDG	Surveying: Surveying for munition objects, inspection of objects with ROV and AUV Environment: Water sampling and sediment sampling as baseline study for fact-based discussion with NGOs and authorities Collaboration: Support international cooperation on scientific and governmental level	CONMAR-C MMinE- SwEEPER	Sweden

2.2.2 Deployment of equipment

All three cruises use a wide variety of equipment for sampling, survey, and inspections; these are briefly detailed below. Station times that keep the ship busy and thus need to be considered for the overall length of the time needed, are based on experience during many years. AUV deployment time will be much longer, as we typically do other things (including leaving the AUV survey area) while an AUV is deployed.

Ship-based and towed survey equipment

Ship-based **MBES** and **SAS** mapping will be performed with moonpool installed systems (i.e. RESON T51 or Kraken SAS). Both systems have been used before for the same topic. The newly acquired SAS was tested during AL609 but still needs adaptations. This will be done during the upcoming cruises AL615 and the applied for AL619 in October 2024. We are confident that the SAS can be used as MBES replacement for 2025 and 2026. If this is not possible a T51 will be rented as in the previous years. In addition, we will use a **towed SSS** to (EdgeTech from AWI) which will give a better resolution in greater water depth, i.e. in the Bornholm Basin. The SSS will be towed behind the vessel in about 10m altitude. SAS and SSS can operate in parallel so that no additional station time needs to be scheduled. The survey speed will be about 3 knots.

Depending on sea state, we will use the towed video sled **XOFOS** to record high resolution images and in parallel scan the seafloor with a) the Norbit MBES or b) the Marine-Sonic SSS system. This will be done when AUVs cannot be deployed, but video and still camera footage is needed. In such cases we will also install the Norbit or Marine-Sonic system on the XOFOS, typically they are part of the GIRONA 500 AUVs ANTON and KALLE. The tow speed with XOFOS is only 0.5kn. The XOFOS is a backup system and only planned for cruise COMMS-25a in Falshöft to acquire some additional information for a better habitat characterization in this area.

Water sampling for chemical analyses

Water samples will be collected with a **SeaBird 911 CTD with 12 10l Niskin bottles**, depending on the scope, sampling will occur along a transect through the Baltic Sea or in a 3 by 3 square of 100m by 100m in size around the removed munition piles in Lübeck Bay. Other sampling schemes depend on the findings. Typically, we will sample water along the transect lines in at least 2 depths (close to the bottom, above the pycnocline). We plan 20 minutes for each CTD deployment.

Sediment sampling for chemical and biological studies

Sediment samples will be taken either by **VanVeen grab** if biota will be samples as well or by **TV-mini-MUC** if porewater information and a sediment profile is needed. Both gears have been used very successfully in munition contaminated areas. The video capability of this device allows avoidance of munitions during collection of sediments. Sediment will be

sampled for biological analyses and chemical pore water analyses. Benthic community composition will be analyzed microscopically. Porewater will be extracted from the collected sediment cores for analysis of dissolved MC, and the residual sediments will be analyzed to provide a historical record of MC contamination. Sediments taken for biological studies will be separated by sieving and assessed for community composition. Based on experience we plan 20 minutes for each deployment be it TV-mini-MUC or VanVeen grab. This time has been proven as very good average during past cruises, where we had about 100 of such stations. With respect of sediment sampling in CWA contaminated areas, see 2.2.3 Special requirements.

Biomonitoring with Mussel Moorings

For several years now the UKSH uses mussel moorings for many years to investigate the uptake of MCs in fauna. A simple anchor, rope and flotation body mooring will be deployed with a rope or acoustic release near the clearance locations, ideally at the down current side. The moorings will be deployed in the Lübeck Bay area to continue sampling as part of the CONMAR-C project and in parallel to the BMUV "Sofortprogramm" activities (removal and destruction of munition in Lübeck Bay). The exact position needs to be discussed with the companies who perform the operations at the particular location. Two bags with mussels will be attached to the mooring at the anchor and 1m above the seafloor. The moorings will be recovered during smaller follow-up cruises about 1 to 2 months after deployment. A total of 14 moorings will be deployed during COMMS-25a and -25b.

Onboard MC analyses

We will perform ad-hoc analyses of munition compounds (explosives only) on board the vessel. We will use the **Xplotector** system, which is a shipboard (ex situ) system that includes two modules: a fluidics system that performs online preconcentration of explosive compounds (TNT, RDX, ADNT, DNB) from seawater for direct analysis, and (2) an analytical system that separates the target compounds by HPLC and detects them by electrospray-ionization or atmospheric pressure chemical ionization mass spectrometry (ESI/APCI-MS) and UV spectrophotometry. The system is fully automated from sample collection to data analysis via custom software. The prototype system has been demonstrated on several previous ALKOR cruises.

Underwater positioning and data communication / USBL

Parallel to the MBES/SAS, a USBL transponder will be installed in the moonpool (Evelogics). AUV navigation and communication will use the USBL and the ROV will use the USBL for navigation. All deployments will be live monitoring using either the BELUGA or OFOP software in which ships and USBL-transponder positions location can be seen (AUV, ROV, TV-mini-MUC, CTD).

Remotely Operated Vehicle (ROV)

GEOMAR owns two small ROVS which have been successfully used in the German Baltic Sea (water depth down to 30m) to gain a good 3D impression of the munition object, its exact locations and the munition layering. We will deploy the small **ROVs Kapt'n BlauBär** (BlueROV) or **ROV BlackBear** (Deep Trekker) from GEOMAR that have been very successfully used on previous cruises. We will use the water sampling capabilities of BlauBär for additional detailed sampling next to open explosives. Acquired data include exact navigation and video footage from individual object will be compared to previous observations, i.e. to define a better munition compound dissolution rate. In deeper water we will use the **ROV FALCON** from IOPAN, that has been used before, e.g. in the 80m deep Bornholm Basin or Lübeck Bay as part of studies in the joined ProBaNNt project. Deployment time of the ROVs is given in hours. Exact number and length of ROV dives depend on the findings during the cruise.

Autonomous vehicles

Of great importance for the MMinE-SwEEPER project are technical advancements in AUV autonomy. Partners from GEOMAR, IQUA-Robotics, WTD71, FFI, University Tromsø and IOPAN are working on different aspects in this regard. Several AUVs will be used, tested and jointly operated during all planned three cruises. They will be used for dedicated mapping tasks but also for testing new robotic capabilities. For all AUV deployments we will use USBL navigation and modem capacities. The following AUVs are planned to be used. Almost all have been successfully deployed from RV ALKOR in the past. Only the Ocean Server Iver-2 from IOPAN was not used on RV ALKOR so far, but it is a small and manageable AUV.

GEOMAR:	GIRONA500 AUVs LUISE, ANTON, KALLE, GIRONA SPARUS; Hydroid 6000 AUV Abyss
German Federal Police:	Atlas SeaCat
WTD71:	AUV-SeeOtter & Atlas SeaCat
IOPAN:	Ocean Server Iver-2

In the past we very successfully used GEOMARs GIRONA 500 AUVs for optical and magnetic mapping of munition dump sites. AUVs will be deployed in parallel and depending on their particular mission will use cameras, magnetic or acoustic sensors for their investigations. As outlined in the MMinE-SwEEPER proposal, **technical developments aiming at more autonomy and real-time decision making with adaptive mission planning are key to the project. Thus, we need to plan sufficient trial time in all three applied cruises.** These trials will mainly be done in areas of which scientists have a very good knowledge already, as Falshöft, Kolberger Heide or Lübeck Bay. The use of the large AUVs Abyss and SeeOtter will be planned in advance. All other AUVs (including SeaCat) can be reasonably handled easily and do not need much deck space.

2.2.3 Special requirements

Sampling in conventional munition contaminated areas: We are well aware that sediment sampling or any kind of bottom contact in munition contaminated areas can be dangerous. In the last years, we acquired great knowledge of how to conduct sampling in such areas and are constantly in contact with e.g. the EOD of Schleswig-Holstein and munition clearance companies such as SeaTerra. In German waters we acquired the needed data and are capable to acquire new on-the-spot data that allow a clear verification if a certain area of seafloor has munition objects or not. With our technological expertise we are as advanced as official German EOD entities and commercial companies to detect and identify munition. In this respect, we are very confident to work safely, also in unknown waters that we only scanned during the respective cruise.

Sampling in chemical munition contaminated areas: With our partners from IOPAN (Poland) we are considering sediment sampling within chemical munition contaminated areas of the Bornholm CWA working area and might encounter similar munition objects in Slupske Bank OWF area as well. If chemical munition is present in this area we cannot answer right now, but the old rout for dumping CWA in the Gotland Deep dumpsite makes encounters generally possible.

Before cruise COMMS-25b we will acquire the most recent data from Danish and Polish authorities as part of the two MuniRisk and MMinE-SwEEPER project. Both have a strong ambition to foster international collaboration. In any case, working in potentially chemical

contaminated area will see a rigorous preparation with respect to data gathering, contacts to local authorities and plans for potential decontamination. Respective procedures will be defined well in advance during discussions with Reederei Briese and the captain and crew of the ship. When working in Polish waters dedicated personal from the **Polish Maritime Office in Gdynia** will conduct any chemical sampling and handling of the samples afterwards. Established procedures exist on the Polish side that have been used in the past on their research vessel RV OCEANIA. The German Federal Police is leading a respective task in the MMinE-SWEEPER project that aims at coordinating such international activities; in this project plans exist for joined operation between the German and Polish authorities and we will further evaluate if this sampling could be used as a first joined exercise in the MMinE-SWEEPER project. It is very clear that without dedicated personnel on board, we will NOT sample sediment in CWA areas.

Crew exchange and guests: Due to the potential need of embarking technical personal for CWA sampling during COMMS-25b, we are planning two port calls in the city of Ustka which is rather close to the Slupsk Bank OWF area. Transit and crew exchange time in Ustka has been considered in the planning. If Ustka is not possible for exchange, the next harbour would be Kolobrzeg; the transit would be longer and needed to come from the survey time in the Slupsk Bank OWF working area.

It is likely that also in the Latvia and Estonia working areas visitors want to come to the ship. We aim for organising these visits via an exchange at sea, supported by local authorities (most likely the military or coast guard). Well in advance before the cruise we will clarify if political reasons emerge that make a port call more favourable. The proximity to harbours for both ELWIND OWF areas would make a port call possible (Latvia ELWIND OWF to Ventspils ~ 25 nmi; Estonia ELWIND OFW to Kuressaare ~ 40 nmi).

Particularly in Lübeck Bay we will have day visitors, e.g. mayors from the Lübeck Bay area, politicians or press who are all interested and seeing the progress of the munition clearance. Furthermore, we will exchange scientific and technical personnel by replacing those from the first part of the cruise who worked on technical advancements of AUVs as part of the MMinE-SWEEPER project, with those who work on environmental aspects and in the MuniRisk project. In the past, the Federal Police in Neustadt was very helpful in executing the transport to and from the vessel, so that we did not need an extra port call.

2.2.4 Work days at sea

We planed the three cruises based on our experience from the previous cruises to munition dump sites and contaminated areas. Deployment times for CTDs and sediment sampling are given above, the need for survey time, test time and ROV inspections is based on experience. Survey times are estimated on the area that need to be covered (1h survey time = 3 nmi with 40m coverage => 0.22 km² => 470m by 470 m). **A more detailed description of the station time is given in Table 1 in the Appendix.**

COMMS-25a

Area	Station	Stations (h)	Transit (h)
Transit	In total 450 nmi with 9kn		50
Kolberger Heide	MBES/SSS, AUV survey, AUV testing, ROV, CTDs, MIC/VVG	47	
Falshöft	AUV survey, AUV testing, ROV, CTDs, XOFOS	35.3	

Little Belt CWA	MBES/SSS, AUV survey, AUV testing, ROV	64	
Lübeck Bay	AUV survey, AUV testing, ROV, CTDs, MIC/VVG, mussel mooring	71.2	
Bornholm OWF	MBES/SSS, AUV survey, ROV, CTDs, MIC/VVG	62	
Stations during transit	18 CTDs	5.4	
Hours in total		= 284.9	= 50

COMMS-25b

Area	Station	Stations (h)	Transit (h)
Transit	In total 860 nmi with 9kn		95.6
Kolberger Heide	AUV survey, AUV testing, ROV, CTDs, MIC/VVG	27	
Little Belt CWA	MBES/SSS, AUV survey, AUV testing, ROV	26	
Lübeck Bay	AUV survey, AUV testing, ROV, CTDs, MIC/VVG, mussel mooring	49.8	
Bornholm OWF	MBES/SSS, AUV survey, ROV, CTDs, MIC/VVG	49	
Slupske Bank OWF	MBES/SSS, AUV survey, AUV testing, ROV, CTD, MIC/VVG	69	
Stations during transit	22 CTDs	6.6	
Crew exchange	in Ustka, Poland		12
Hours in total		= 227.4	= 107.6

COMMS-26

Area	Station	Stations (h)	Transit (h)
Transit	In total 1110 nmi with 9kn		123.2
Kolberger Heide	AUV survey, AUV testing, ROV, CTDs, MIC/VVG	27	
Lübeck Bay	AUV survey, AUV testing, ROV, CTDs, MIC/VVG, monitoring munition platform	49.6	
Slupske Bank OWF	MBES/SSS, AUV survey, AUV testing, ROV, CTD, MIC/VVG	67	
Latvia ELWIND OWF	MBES/SSS, AUV survey, AUV testing, ROV, CTD, MIC/VVG	63	
Estonia ELWIND OWF	MBES/SSS, AUV survey, AUV testing, ROV, CTD, MIC/VVG	63	
Estonia Wrecks	MBES/SSS, AUV survey, AUV testing, ROV, CTD, MIC/VVG	55	
Utö MDG	MBES/SSS, AUV survey, AUV testing, ROV, CTD, MIC/VVG	44	
Stations during transit	40 CTDs	12	
Hours in total		= 380.6	= 123.2

2.2.5 Arrival and departure

Arrival and departure for all cruises is planned to be Kiel; this is because of logistic reasons. For all cruises we envision exchange of technical personnel as well as guests in Lübeck Bay where we have a good agreement with the German Federal Police to support with a shuttle service at sea. For cruise COMMS-25b and COMMS-26 we plan port calls in Poland to exchange scientific and technical personal, but also embark personnel for working with CWAs. We plan for one of such port calls during COMMS-25b and COMS-26.

2.2.6 Measures to conduct responsible marine research

All measures will be taken with regard to the Declaration of Responsible Marine Research, the Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area, and the Mitigation measures for the operation of seismic and hydroacoustic sources with pulsed sound emissions. During all cruises we will use high frequency, low energy hydroacoustic systems like the SAS towed SSS (300 to 800 kHz). If we bring a multibeam it will also have high frequency (800 kHz; Reson T51) Hydroacoustic cameras (1.9MHz) and sensors on the AUVs are also high frequency systems; they will run in low energy settings due to their proximity to the seafloor (SSS of AUVs SeaCat and Abyss is 300 kHz; AUV KALLE runs a dual frequency system of 800 kHz to 1,9 MHz). The USBL navigation and data communication for the AUVs (38kHz) will work with the lowest possible energy during operation. All these systems can and will be started with low energy (soft start). Mammals, particularly porpoises, could be scared away in such a way. During the entire cruise, we will pay attention to any sightings of mammals in the working area and also follow the news as they often report on sightings and longer stays of mammals close to shore. During measurements, no harmful chemicals will be released. For biological sampling, we will use a small MUC, 0.1 m² van Veen grab to sample endofauna communities. This is standard gear that provide the possibility to collect data comparable to previous studies. Because both tools are rather small, with respect to sediment and fauna distribution, we will sample only the absolute needed amount of biota from the environment, which will be handled accordingly to current ethical standards valid for EU research institutions.

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4 Funds available or requested

Funds for additional technical personnel, consumables and analyses will be made available through the related and funded research projects CONMAR-C (BMBF), MuniRisk (HEU) and MMinE-SWEEPER (HEU). Additional funding for GEOMAR technicians as well as consumables will be applied for through the “GEOMAR-Schiffstopf”. CONMAR-C has a total funding of 3.79MEUR of which 1.4MEUR go to GEOMAR; MuniRisk has a total funding of 2MEUR of which 377kEUR go to GEOMAR; MMinE-SWEEPER has a total budget of 5.9MEUR of which 1.8MEUR go to GEOMAR. Only MuniRisk will support funds for consumable, all other consumables will come through inhouse funding.

5 Cruise participants

The cruises will be occupied with personnel from different institutions and nations. For some berths we cannot name the final person at the moment. For each cruise we plan an exchange of scientists and technicians in Lübeck Bay. **Permanent employed participants are indicated with a '#'**. Next to German participants we will have scientists from Poland, Norway and Denmark as well as technicians from robotic company IQUA from Spain. GEOMAR and Senckenberg scientists who do not have a permanent position are employed in currently employed in CONMAR and will be employed in CONMAR-C from December onward. **In the Appendix are the lists for each leg of cruise COMMS-25b and COMMS-26.**

COMMS-25a

Leg-1; Kiel – Lübeck Bay (# = permanent employed)

#	Participant	Status	Institute	Discipline
1	Jens Greinert #	Scientist	GEOMAR	Chief Scientist ; AUV, video analyses
3	Mareike Kampmeier	Scientist	GEOMAR	Co-Chief Scientist SAS/MBES, sediment sampling, video analyses
2	Aaron Beck #	Scientist	GEOMAR	CTD operation, water sampling, MC chemistry
4	Marcus Krüger	Scientist	GEOMAR	Data Management, CTD
5	Tim Weiß #	Technician	GEOMAR	USBL Navigation, data processing
6	Marc Seidel	Scientist	GEOMAR	AUV magnetics & autonomy
7	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
8	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
9	Andrey Vedinin	Scientist	Senckenberg	biological sampling
10	NN	Technician	IQUA / ES	AUV Sonar Camera, AUV autonomy
11	Holger Schmaljohann #	Scientist	WTD71	AUV SeaOtter, change detection
12	Paul Lademann #	Technician	WTD71	AUV SeaOtter

Leg 2; Lübeck Bay – Kiel (# = permanent employed)

#	Participant	Status	Institute	Discipline
1	Jens Greinert #	Scientist	GEOMAR	Chief Scientist ; AUV, video analyses
3	Mareike Kampmeier	Scientist	GEOMAR	Co-Chief Scientist SAS/MBES, towed sidescan, sediment sampling
2	Aaron Beck #	Scientist	GEOMAR	CTD operation, water sampling, MC chemistry
4	Marcus Krüger	Scientist	GEOMAR	Data Management, video analyses
5	Tim Weiß #	Technician	GEOMAR	ROV operations, USBL Navigation, data processing
6	Jochen Mohrmann	Scientist	GEOMAR	SAS/MBES surveying, video processing
7	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
8	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
9	Hans Sanderson #	Scientist	Uni Aarhus	Ecology
10	NN	Scientist	Uni Aarhus	Ecology
11	Jacek Baldowski #	Scientist	IOPAN	ROV & AUV operation
12	Milosz Grabowski #	Scientist	IOPAN	ROV & AUV operation

6 Data and sample handling

The cruises are part of the DAM Mission CONMAR-C and thus data management will follow the rules the participating institutes and centers of DAM agreed on. The attached "Leitantrag" of **CONMAR-C** details the data handling/data management; data managing and data sharing has a dedicated work package in the CONMAR project. During the cruise we will use a

specifically setup GEO-Node data base on the ship to not only record D-SHIP data, but immediately generate metadata for sampling stations but more importantly generate information on sub-samples for which analyses will be generated in onshore labs. As can be seen from the MuniRisk and MMinE-SwEEPER projects, data management with the strong purpose of data sharing of sensitive and security relevant data is of great importance. Primarily data will be stored either at GEOMAR to use the Ocean Science Information System (OSIS) as a central information and research data sharing utility of the project or at the respective institutes. GEOMAR will make meta data available through a GeoNode instance running on GEOMARs servers. This makes metadata and final data available to the data portal at DAM (marine-data.de) through the CONMAR-C Viewer as federated approach. This federated approach is already running and can be used. It is automatically updated with D-SHIP data. Using the GeoNode instances will be of great value to the different projects.

The final goal of course is to publish as many data as possible. Data managers at GEOMAR and in CONMAR-C are active PANGAEA data curators and can assist researchers during preparation of their sample archival and data publication procedures in a World Data Center (e.g. PANGAEA). Links to data publishers or principle investigators provide contact information for external scientists.

As part of the MMinE-SwEEPER project we are investigating other means of sharing data that national authorities have seen as sensitive and secret information. This is particularly true for exact locations of munition objects on the seafloor. As part of MMinE-SwEEPER methodologies and procedures will be developed for exchanging sensitive data and perform cloud-based computing for AI-supported object detection. During the projects we will learn how such sensitive data can be shared and used in a European or bilateral approach.

7 Appendix

7.1 Detailed overview of station time per gear and working area

Table 1: Overview of the station time in each working area for all three cruises.

COMMS 25a (March 2025)				COMMS 25b (October 2025)				COMMS 26 (October 2026)					
		hours total	334.9			hours total	335.0			hours total	503.8		
		days	14.0			days	14.0			days	21.0		
Area	Working time per gear	h		Area	Working time per gear	h		Area	Working time per gear	h			
Kolberger Heide MDG	ship based survey (MBES, SSS)	8		Kolberger Heide MDG	AUV survey deployments	6		Kolberger Heide MDG	AUV survey deployments	6			
	AUV survey deployments	8			AUV technical testing	12			AUV technical testing	12			
	AUV technical testing	18			ROV deployments	4			ROV deployments	4			
	ROV deployments	6			6 CTDs	2			6 CTDs	2			
	6 CTDs	2			6 MIC / VVG	2			6 MIC / VVG	2			
	6 MIC / VVG	2			transits in area	1			transits in area	1			
	transits in area	3			AUV survey deployments	8			AUV survey deployments	4			
	Fahlsjöf MDG	AUV technical testing	16		Little Belt CWA	AUV technical testing	8		Lübeck Bay MDG	AUV technical testing	12		
AUV survey deployments		8		ROV deployments		6		ROV deployments		4			
ROV deployments		6		3 CTDs		1		7 x 3 CTDs		6.3			
CTD		0.3		3 MIC / VVG		1		7 x 3 MIC / VVG		6.3			
XOFOS		2		transits in area		2		Monitoring of munition platform		14			
Little Belt CWA	transits in area	3		Lübeck Bay MDG	AUV survey deployments	8		Slupsk Bank OFW	transits in area	3			
	ship based survey (MBES, SSS)	36			AUV technical testing	18			ship based survey (MBES, SSS)	40			
	AUV survey deployments	12			ROV deployments	4			AUV survey deployments	12			
	AUV technical testing	8			7 x 3 CTDs	6.3			ROV deployments	8			
	ROV deployments	6			7 x 3 MIC / VVG	6.3			6 CTDs	2			
Lübeck Bay MDG	transits in area	2		Bornholm CWA	14 mussel moorings	4.2		Latvia ELWIND OWF	6 MIC / VVG	2			
	AUV survey deployments	12			transits in area	3			transits in area	3			
	AUV technical testing	24			Slupsk Bank OFW	ship based survey (MBES, SSS)	24			Estonia ELWIND OWF	ship based survey (MBES, SSS)	36	
	ROV deployments	6				AUV survey deployments	12				AUV survey deployments	12	
	7 x 5 CTDs	10.5				ROV deployments	8				ROV deployments	8	
	7 x 5 MIC / VVG	10.5				3 CTDs	1				6 CTDs	2	
14 mussel moorings	4.2		6 MIC / VVG	2			6 MIC / VVG	2					
Bornholm OWF	transits in area	4		Slupsk Bank OFW		transits in area	2		Estonia Wrecks		transits in area	3	
	ship based survey (MBES, SSS)	36			ship based survey (MBES, SSS)	42		ship based survey (MBES, SSS)		36			
	AUV survey deployments	12			AUV survey deployments	12		AUV survey deployments		12			
	ROV deployments	6			ROV deployments	8		ROV deployments		8			
	6 CTDs	2			6 CTDs	2		6 CTDs		2			
	6 MIC / VVG	2			6 MIC / VVG	2		6 MIC / VVG		2			
transit time (450 nmi with 9kn)		50		2 x crew exchange Ustka Poland		12		transits in area		3			
	CTDs during transit (18)	5.4			transit time (860 nmi with 9kn)	96			transits in area	1			
					CTDs during transit (22)	6.6			ship based survey (MBES, SSS)	36			
								AUV survey deployments	8				
								ROV deployments	6				
								6 CTDs	2				
								6 MIC / VVG	2				
								transits in area	2				
								transits in area	2				
								transit time (1110 nmi with 9kn)	123				
								CTDs during transit (40)	12				

6	Marc Seidel	Scientist	GEOMAR	AUV magnetics & autonomy
7	Jochen Mohrmann	Scientist	GEOMAR	AUV sonar cameras & autonomy
8	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
9	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
10	NN	Technician	IQUA	AUV Sonar Camera, AUV autonomy
11	Holger Schmaljohann #	Scientist	WTD71	AUV SeaOtter, change detection
12	Paul Lademann #	Technician	WTD71	AUV SeaOtter

Leg 2; Lübeck Bay - Kiel (# = permanent employed)

#	Participant	Status	Institute	Discipline
1	Jens Greinert #	Scientist	GEOMAR	Chief Scientist; AUV, video analyses
3	Mareike Kampmeier	Scientist	GEOMAR	Co-Chief Scientist SAS/MBES, towed sidescan, sediment sampling
2	Björn Raupers	Scientist	GEOMAR	CTD operation, water sampling, MC chemistry
5	Tim Weiß #	Technician	GEOMAR	ROV operations, USBL Navigation, data processing
7	Jochen Mohrmann	Scientist	GEOMAR	AUV sonar cameras & autonomy
8	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
9	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
6	Jacek Baldowski #	Scientist	IOPAN	ROV & AUV operation
4	Milosz Grabowski #	Scientist	IOPAN	ROV & AUV operation, surveying
10	NN	Scientist	IOPAN	ROV & AUV operation, surveying
11a	NN AUV #	Technician	GEOMAR	AUV Abyss operation (disembark in Ustka)
12a	NN AUV #	Technician	GEOMAR	AUV Abyss operation (disembark in Ustka)
11b	NN	Technician	Polish Maritime Office	CWA handling (embark in Ustka)
12b	NN	Technician	Polish Maritime Office	CWA handling (embark in Ustka)

COMMS-26

Leg 1; Kiel – Lübeck Bay (# = permanent employed)

#	Participant	Status	Institute	Discipline
1	Jens Greinert #	Scientist	GEOMAR	Chief Scientist; AUV, video analyses
3	Mareike Kampmeier	Scientist	GEOMAR	Co-Chief Scientist SAS/MBES, towed sidescan, sediment sampling
2	Björn Raupers	Scientist	GEOMAR	CTD operation, water sampling, MC chemistry
4	Marcus Krüger	Scientist	GEOMAR	Data Management, video analyses
5	Tim Weiß #	Technician	GEOMAR	ROV operations, USBL Navigation, data processing
6	Marc Seidel	Scientist	GEOMAR	AUV magnetics & autonomy
7	Jochen Mohrmann	Scientist	GEOMAR	AUV sonar cameras & autonomy
8	NN AUV	Technician	GEOMAR	GIRONA 500 AUVs operation
9	Prasad Lokukaluge #	Scientists	Uni Tromsø	AUV autonomy
10	NN	Technician	IQUA	AUV Sonar Camera, AUV autonomy
11	NN	Technician	IQUA	AUV Sonar Camera, AUV autonomy
12	Holger Schmaljohann #	Scientist	WTD71	AUV SeaOtter, change detection

Leg 2; Lübeck Bay – Kiel (# = permanent employed)

#	Participant	Status	Institute	Discipline
1	Jens Greinert #	Scientist	GEOMAR	Chief Scientist; AUV, video analyses

3	Mareike Kampmeier	Scientist	GEOMAR	<u>Co-Chief Scientist</u> SAS/MBES, towed sidescan, sediment sampling
2	Aaron Back #	Scientist	GEOMAR	CTD operation, water sampling, MC chemistry
4	Tim Weiß #	Technician	GEOMAR	ROV operations, USBL Navigation, data processing
5	Jochen Mohrmann	Scientist	GEOMAR	AUV sonar cameras & autonomy
6	Gabriel Nolte #	Technician	GEOMAR	ROV operations, USBL Navigation, data processing
7	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
8	NN AUV #	Technician	GEOMAR	GIRONA 500 AUVs operation
9	NN	Student	GEOMAR	Survey support, water sampling
10	Jacek Baldowski #	Scientist	IOPAN	ROV & AUV operation
11	Milosz Grabowski #	Scientist	IOPAN	ROV & AUV operation, surveying
12	NN	Technician	IOPAN	ROV & AUV operation, surveying

SHIPPeR

Shipwreck Investigation for Pollution Prevention and Remediation in the Baltic Sea

Cruise proposal for RV ALKOR (primary use)

Dr. Aaron Beck (Chief Scientist)	Dr. Ralf Prien (Deputy Chief Scientist)	Professor Jacek Beldowski
23.10.1981, American GEOMAR Helmholtz-Centre for Ocean Research Kiel FB2, Marine Biogeochemistry Wischofstr. 1-3, 24148 Kiel Phone: 0431-600-1289 E-Mail: ajbeck@geomar.de	10.3.1964, German Leibniz-Institut für Ostseeforschung Meereschemie Seestr. 15, 18119 Rostock phone: +49 381 5197372 email: ralf.prien@io-warnemuende.de	30.10.1974, Polish, Institute of Oceanology PAS, ul. Powstańców Warszawy 55, 81-712 Sopot, Poland Phone: +48 667 653 000 Email: hyron@iopan.pl

Project description

1 Motivation

This proposal applies for one cruise covering the Baltic Sea from Germany to Lithuania, and addresses the environmental threat of shipwrecks with their associated fuels and munitions. The proposed research cruise primarily serves the fieldwork needs of BALTWRECK¹, a 3.8 M€ project funded by the EU South Baltic Interreg program that seeks to prevent pollution of the Baltic Sea by munitions, hazardous fuel, and other dangerous remains of shipwrecks by jointly developing, demonstrating, and implementing national wreck management programs. The BALTWRECK consortium includes Poland, Germany, Lithuania, and Sweden, and the proposed fieldwork spans across the first three of these countries. The proposed cruise is requested for late spring/early summer 2026, and links to additional fieldwork that is currently being planned by BALTWRECK project partners IOPAN (R/V Oceanograph; summer 2025) and IOW (R/V Elisabeth Mann Borghese; autumn 2026).

In addition, the proposed cruise activities dovetail with three concurrent research projects focused on the topic of marine munitions, and will leverage synergies and expertise available in these projects to ensure the proposed cruise generates the greatest added value. The first project, CONMAR-II² is the second phase of a project investigating environmental impacts of munitions in German waters of the Baltic and North Seas, with a goal to prioritize recommendations for remediation. The second project MUNI-RISK³ addresses environmental risks from munitions throughout the Baltic Sea with three areas for field study related to planned offshore wind parks: west of Bornholm (DK), the Słupsk Bank (PL) and a project on the border of Estonia and Latvia. The third and largest project, MMinE-SwEEPER⁴ is particularly focused on technical munition detection and identification technologies and the generation of EU-level solutions. MMinE-SwEEPER has a broad geographical view, with fieldwork also including the northeast Atlantic Ocean and Mediterranean Sea.

1 <https://www.imp.gda.pl/en/projects/interreg-programmes/baltwreck/>

2 <https://conmar-munition.eu/>

3 <https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/projects-details/43392145/101173075/EMFAF?order=DESC&pageNumber=1&pageSize=50&sortBy=title&keywords=MUNI-RISK&isExactMatch=true>

4 <https://cordis.europa.eu/project/id/101167839>

1.1 State of the art and preliminary work

1.1.1 State of the art

Shipwrecks in the Baltic Region

As of 2005, there were an estimated 8569 potentially polluting shipwrecks in the world's oceans, of which 1583 were oil tankers (Michel et al., 2005). Approximately 75 percent of these wrecks sank during the Second World War. In fact, the highest historical rate of ship loss for both military and commercial vessels worldwide occurred during WWII, with over 7800 ships and vessels estimated to have sunk during the wartime period (Monfils 2005; Monfils et al. 2006). More than 70 years later, these wrecks are a major source of potential pollution and represent a global marine pollution risk (Michel et al., 2005; Alcaro et al., 2007). There are an estimated nearly 1000 wrecks in the Baltic Sea with often unknown or significant quantities of fuel on board (both as own fuel, as well as cargo) (Hac, 2004). There are about 17,000 shipwrecks along the coast of Sweden alone, and the Swedish Maritime administration classified 3,000 of these as possibly hazardous for the environment, 300 as hazardous for the environment and 30 as an acute environmental threat (HELCOM 2024). Similar detailed data is not available for all countries in the Baltic region, although limited available information shows the vast extent of shipwrecks in the area (Fig. 1).

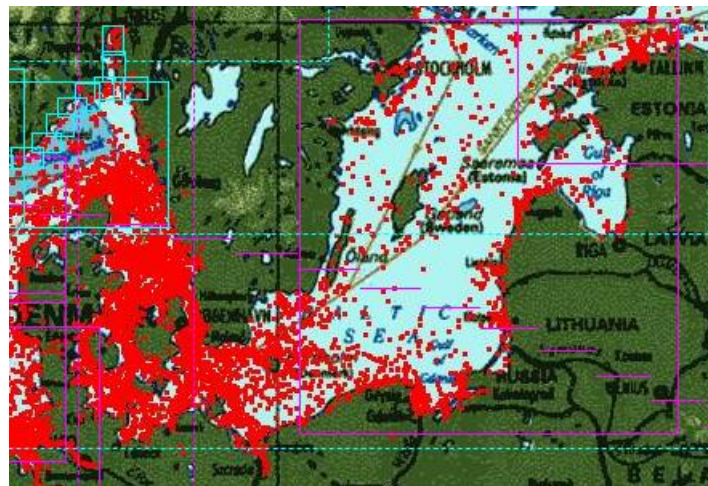


Figure 1. Map of wreck locations in the Baltic region. From Wrecksite 2024.

Hazardous fuels in shipwrecks

The oil pollution threat of submerged wrecks has been recognized in recent years (Michel et al., 2005; Landquist et al., 2013; Goodsir et al., 2019). This emerging risk is associated with large volumes of fuel oils (estimated between 2.5 and 20 million tonnes), remaining within nearly 9000 wrecks on the ocean floor (Michel et al., 2005). The majority of these wrecks occurred during WWII, and have been submerged for more than 80 years. With corrosion rates on the order of 0.1 mm per year, shipwrecks face an increasing risk of structural collapse (Melchers, 2021, Moore, 2015; Macleod, 2016). For example, assessment of a WWII-era shipwreck in the UK indicated that the wreck condition in 2022 had only moderate risk of oil release, whereas this risk is expected to be high by 2031 (Hill et al., 2022). Oil leakage is often difficult to predict, with small breaches allowing substantial leaks to occur (Fig. 2a). Unmonitored and unmanaged shipwrecks therefore pose a substantial risk to the marine environment (Landquist et al., 2013; Etkin et al., 2009; Michel et al., 2005).

Although the hazard of oil leaks from shipwrecks is well-known, approaches for risk assessment and management strategies are still in a developing phase. Existing assessments lack an evaluation of quantitative risk to local receptors under multiple oil spill scenarios. This can lead to an under- or overestimation of threats to the marine environment

and leads to incorrect prioritisation of shipwreck sites. The type and scale of oil leaks can occur as sporadic events or continuous releases of differing magnitudes (Etkin et al., 2009), which makes it difficult to predict the potential quantity and rate of release. It is nonetheless clear that as the wreck condition degrades, the likelihood of remaining oil being released will increase (Monfils, 2005). In some cases, incomplete or insufficient risk assessment can lead to negative environmental impacts and necessitate short-term reactions to mitigate potential disasters (Hill and Rodway-Dyer, 2024). In other cases, environmental pollution from the shipwreck has already progressed past the point where risk reduction by oil removal is no longer possible (e.g., Fig. 2b), and remediation of contaminated sediments is necessary (Hac, 2024).

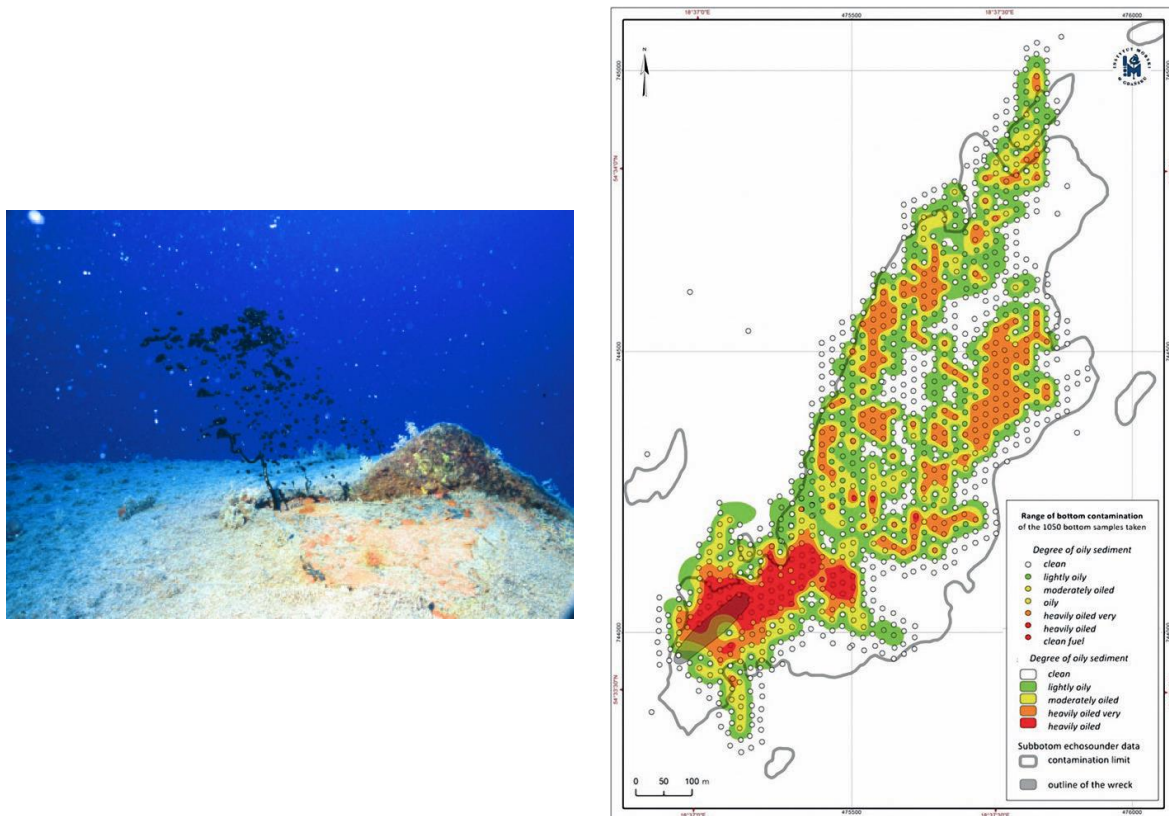


Figure 2. a) Image of oil leaking from the USS Mississinewa wreck in the southwest Pacific (from Michels et al., 2005). b) Oil contamination in sediments around the SS Stuttgart wreck in Gdansk Bay (from Hac, 2024).

Relic munitions in shipwrecks, disposal sites, and unexploded ordnance

Coastal marine waters are contaminated globally with unexploded ordnance and intentionally dumped munitions (Beck et al., 2018), especially as a result of the two World Wars (WWI and WWII). German territorial waters of the North and Baltic Seas are estimated to contain some 1.6 million metric tons of munitions, including unexploded ordnance, dumped munitions, and munitions in shipwrecks (Böttcher et al., 2011). The total amount of underwater munitions in the Baltic region and globally is much higher, although an exact accounting is impossible due to a lack of precise records (Benn et al., 2010; Brewer and Nakayama, 2008). This makes it difficult to predict locations with increased risk of biological exposure to toxic munition-associated chemicals from both chemical and conventional munition, although it is clear that hotspots such as munitions dumpsites and shipwrecks represent primary sites of environmental exposure.

Munitions in shipwrecks are gaining increasing recognition as a poorly constrained source of toxic chemicals to the marine environment, and one that is often in association with other

chemical pollutants such as fuel oils. This multi-exposure condition represents a particularly high risk to ecological receptors. Perhaps the most well-known shipwreck full of munitions is the SS Richard Montgomery, an American ship that sank in the Medway Channel, not far from London, England. The Montgomery wreck contains more than 3,000 tons of munitions, but is in an unsalvageable condition, and now represents a worst-case scenario for management (Alexander, 2019; Wyse and Leary, 2016). Recent investigations of the V 1302 “John Mahn” shipwreck showed that munitions in the wreck are indeed leaking explosive chemicals, and that the chemicals accumulate in fish and mussels near the shipwreck (Maser et al., 2023).

Underwater munitions contain toxic and carcinogenic chemicals of conventional explosives and chemical warfare agents (Tornero and Hanke, 2016), and there is growing concern of environmental risks due to chemical release and exposure to marine organisms and humans (Sanderson et al., 2010; Beldowski et al., 2017; Barbosa et al., 2023). The release of toxic munitions compounds (MC) into the seawater increases as a function of corrosion and contact with seawater (Wang et al., 2013), and food web exposure to MC depends on environmental factors affecting corrosion and dissolution (Lewis et al., 2009; Pennington et al., 2008). It is possible that these substances persist for several decades in the environment (Darrach et al., 1998). TNT accumulates in aquatic invertebrates and therefore may enter the higher trophic food chain (Beck et al., 2022). Indeed, dumped munitions and shipwrecks act as habitat structure for macrofauna such as fish (Fig. 3), and this may lead to even greater biota exposure to toxic contaminants.



Figure 3. Still images of video captured with an ROV at munitions dumpsites in Lübeck Bay (southwest Baltic Sea) showing abundant cod fish. (Images: Deep Sea Monitoring, GEOMAR)

Political decision makers remain unsure of the best course of action with regard to munition remediation. The US Army has concluded that “monitored no-action” is the best current solution because munitions do not pose a substantial or immediate threat to the environment (Lotufo et al., 2021). In contrast, the German federal government has invested over 100M€ to begin a pilot program for removing and destroying underwater munitions (through the so-called Sofortprogramm or “Immediate Action” program; Mergener, 2024). These very different approaches demonstrate the challenge for political leaders to choose the best and most cost-effective response to legacy underwater contamination hotspots. The workplan of the proposed SHIPPeR cruise aims to collect samples and data for developing decision tools to guide policy makers in addressing such environmental threats.

Risk assessment and remediation of environmental hazards from shipwrecks and munitions

Environmental risk assessment consists of four primary steps: hazard identification, exposure assessment, dose–response, and risk characterization (Fahd et al., 2014). Water and sediment samples may constitute an important source of information on the extent of pollution and its impact on surrounding ecosystems. In particular, sediments sequester contaminants, including those emitted from shipwrecks (Rogowska et al., 2010; Rogowska et al., 2015), and are the final repository for sorbed and modified contaminants (Corazza et al.,

2012). Decision-making bodies therefore need a range of information to evaluate if it is necessary to remove fuel residues and munitions or undertake other remediation actions based on risk assessment and costs analyses (Rogowska and Namiesnik, 2012).

There are a range of possible remediation options for shipwreck-associated contaminants. The best solution is proactive removal of fuel oils and munitions before the chemicals leak into the environment (Hill and Rodway-Dyer, 2024; Mergener, 2024). However, this is not always possible, and chemical release is often already occurring when the wrecks are discovered (Hill et al., 2022). In situ capping has been proposed in some instances, including the Hg-leaking submarine U-864 in Norwegian waters (Kystdirektoratet, 2006), although this reduces the immediate environmental exposure but does not remove it entirely.

Bioremediation by enhanced natural attenuation has the potential to clean polluted sediments of chemical pollution, and typically uses artificially enhanced or selected microbial populations to degrade contaminants in situ (Ayilara et al., 2023). This has particular promise for shipwreck related fuel oils and explosives because it avoids disturbance of fragile structures that may accelerate contaminant release and leaves culturally sensitive sites intact. Studies of shipwreck sites have shown that natural microbial populations respond to fuel oil contamination and sediments in such locations contain a higher abundance of taxa known to degrade oil contaminants (Landuyt et al., 2022). Munition contaminants in sediments are also associated with unique microbial communities (Janssen et al., 2021), and these have been shown to remove TNT contamination under enhanced natural attenuation conditions (Kundu et al., 2023).

1.1.2. Previous and ongoing work by the proponents

1.1.2.1 Shipwreck investigation

Current wreck investigation methods include 3-D reconstruction of the wreck site with shipboard acoustic mapping methods such as sidescan or multibeam echosounder. This large-scale mapping is then followed by detailed investigation with an AUV carrying sidescan sonar and a magnetometer. Optical images may also be acquired with the AUV, with individual still images stitched together into a larger 2-D photomosaic. A map of bottom currents in the vicinity of the wreck is usually compiled based on ADCP measurements. Based on the acoustic, optical, and magnetic imagery, direct inspection is conducted by ROV, allowing groundtruthing of the wreck structure and condition. Discrete samples of sediments, water and biota are collected in close proximity around the wreck with an ROV mounted sampler that allows for precise sampling transects along and across the bottom current axes that potentially represent contamination transportation pathways (Fig. 4).

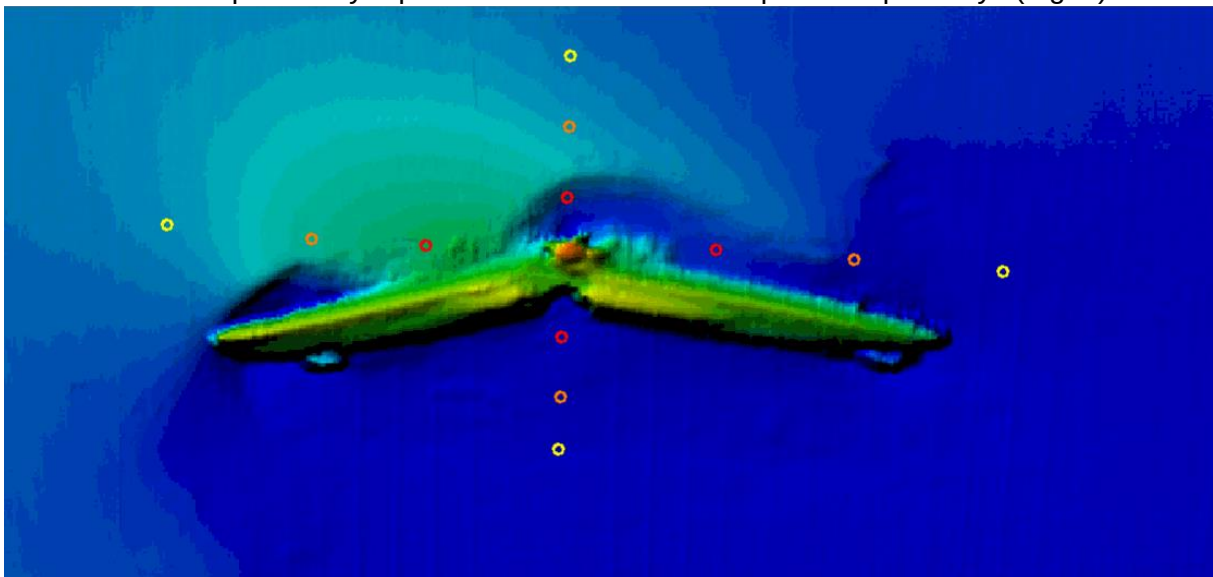


Figure 4. Example of high-resolution sediment sampling strategy around a shipwreck in Gdansk Bay (Image: IOPAN).

1.1.2.2 Investigation of chemical contamination from underwater munitions

Current methods for measuring munition chemicals such as TNT in marine samples are extremely time- and labor-intensive. Delays of weeks to months are typical between sample collection and laboratory analysis, and analyses require expensive and sensitive instruments. We developed a novel shipboard lab-in-a-box system, the “Xplotector” (Fig. 5a), during the ExPlOTect project (EU EMFF; 2019-2022), which is now being deployed in a number of munitions-related research projects. The Xplotector automates sample processing and analysis, and is robust enough to take on board research ships. Each sample is analyzed in less than 15 minutes, providing immediate information about chemical contamination spread. The mass spectrometer in the Xplotector was upgraded as part of the VAMOS project (BMBF), and can now detect TNT concentrations in seawater as low as 0.1 ng/L. The upgraded Xplotector was tested in October 2023 on the CONMAR-led research cruise AL603. Results showed very low TNT concentrations in the Little and Great Belts (Fig. 5b), suggesting that high contamination found in the Kieler Bucht and Lübecker Bucht comes from local munitions, not from more distant sources. **Wider-scale regional mapping of MC in the Baltic Sea has not yet been conducted, so other, e.g., shipwreck-based point sources are not known.** Real-time chemical mapping allows essential rapid-response adaptation to field observations. For example, during AL603, regional-scale mapping was supplemented by sample collection in direct proximity to munition dumpsites and individual objects.

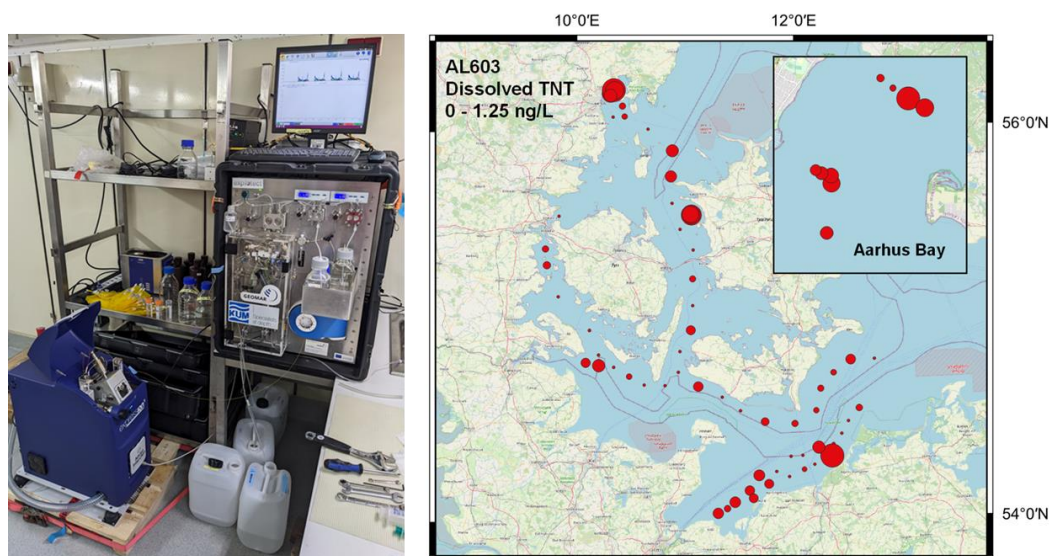
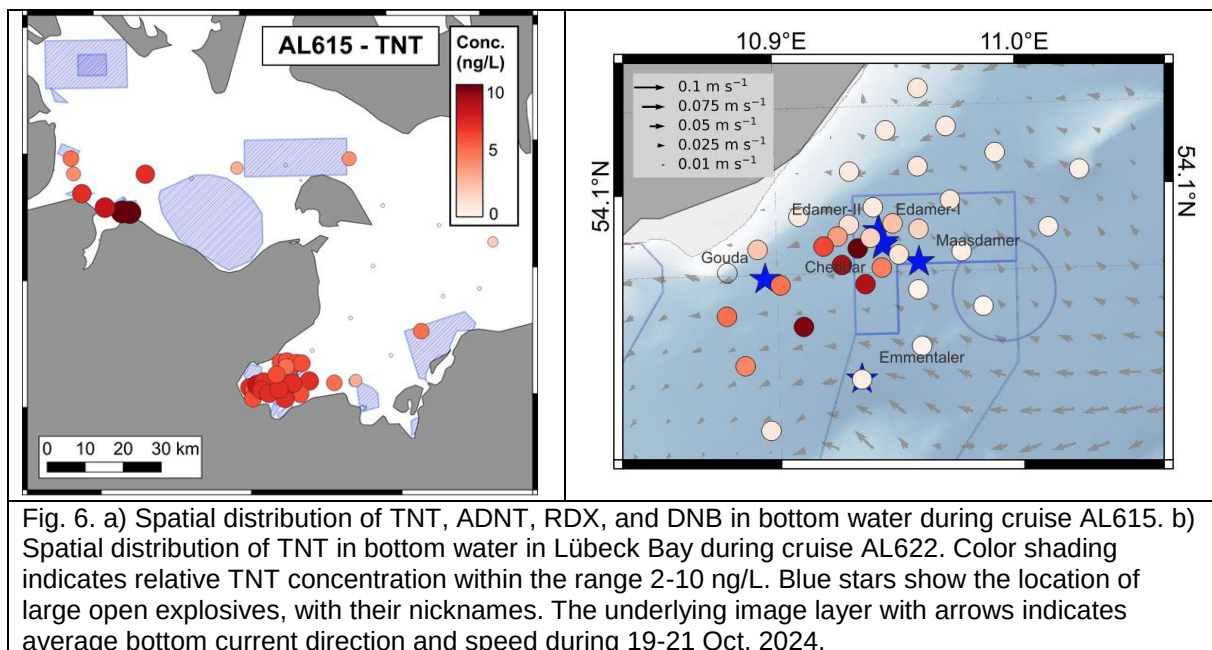


Figure 5. (left) Xplotector system in operation in the wet lab on AL603. (right) Map of dissolved TNT in bottom waters during AL603. Symbol size indicates concentration up to 1.25 ng/L.

The spatial distribution of MC during cruise AL615 (July 2024; Fig. 6a) matched that established during monitoring cruises over the previous six years (Arinaitwe et al., 2024). Dissolved TNT was highest near the munitions dumpsites in Kiel Bay and Lübeck Bay. High resolution sampling was conducted during cruise AL622 (October 2024) in the Pelzerhaken dumpsite subregion. Numerous large munitions with extensive areas of exposed explosive material have been identified in this region, and been nicknamed after various types of cheese given their similar appearance. Samples were analyzed on board with the Xplotector system. Results showed relatively low concentrations of dissolved TNT around the borders of the study region, and a zone of higher concentrations in the center and southwestern areas (Fig. 6b). Modeled bottom currents during the sampling period show slow current transport from the north and east toward the southwest. The spatial distribution suggests that these

open explosive objects represent the major MC source in Pelzerhaken, and currents carry a plume of dissolved MCs away from the objects.



1.1.3. Previous cruise work by the proponents

As part of past and ongoing munitions projects, GEOMAR has led and participated in numerous cruises in the Baltic Sea (POS530, AL548, AL567, AL583, AL590, AL603, AL609, AL615, AL622) and joined two RV HEINCKE cruises to the North Sea (HE622, HE635). In addition, GEOMAR has run many one-day or smaller RV LITTORINA cruises to the North and Baltic Sea between 2017 and 2024. To date, none of the GEOMAR-led cruises has focused on shipwrecks, although some expeditions to the Lübecker Bucht discovered and mapped the munitions-containing wreck *Wk_0132* that was selected for test remediation as part of the Sofortprogramm.

IOPAN has conducted multiple research cruises into munition dumpsites (S/Y Oceania, on average two cruises per year in the period 2010-2024) and several cruises dedicated to wreck pollution aboard S/Y Oceania (April 2023, October 2023, March 2024, October 2024) and R/V Oceanograf (November 2021, January 2022, March 2022). In addition, some proponents and participants in the planned cruise (IOPAN, ITP) participated in cruises aboard R/V Heincke for the North Sea Wrecks project (HE607, Sept 2021; HE613, Feb 2023). Within the scope of the AMMOTRACe project, IOW participated in a number of cruises to munitions dumpsites during development of their shipboard and in situ mass spectrometers.

1.1.4. Relevant previous work published by the proponents

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1.2 Integration in national and international programmes

A cross-border approach for management of pollution from shipwrecks is fundamentally necessary as it is not affected by international borders and can spread widely throughout the South Baltic. The problems/challenges of the project cannot be addressed without cross-border cooperation as chemical pollution from shipwrecks can potentially cause a massive ecological disaster that will affect communities throughout the South Baltic region. The BALTWRECK project gathers multidisciplinary actors around the marine pollution table: scientific units, agencies, SMEs and potential target groups as Associated Organisations. The draft of the future South Baltic Interreg Programme prioritises these activities, in particular: developing, demonstrating and implementing solutions for reducing pollution of the Baltic Sea by chemical munitions and conventional ammunition in and outside of wrecks, and other dangerous remains of sunken ships.

International cooperation within the BALTWRECK project fieldwork is built into cruise plans with multiple vessels visiting the same targets with different equipment. Two cruises

are planned aboard R/V Oceanograf – one covering wrecks in Gulf of Gdańsk and Lithuania, and another visiting wrecks on central Polish coast and Mecklenburg Bight. These cruises will take place in June and July 2025. One additional cruise in the late stages of the project is planned and will be applied for by IOW on the R/V Elizabeth Mann Borgehse.

We also plan to cooperate with other projects in the field, for example implemented by Finnish Environment Institute (SYKE) Dept. of Authority services, which leads the Wrecks-project at the Finnish Environment Institute. The project investigates suitable sites for wreck oil removal operations and searches archival data to determine potentially dangerous substances in the wrecks. The project will build a wreck registry which will be added to the MERT-system (owned by Finnish Border Guard). We also cooperate with the Sustainable and Prosperous Region, Council of the Baltic Sea States Secretariat (Sweden). The CBSS is an intergovernmental organisation for regional cooperation in the Baltic Sea Region where political dialogue is at the core of our activities.

1.3 Funding sources

Work on the proposed cruise will be primarily supported by the BALTWRECK project, which is funded through the South Baltic Interreg Programme. In addition, the cruise will generate samples and data for use in parallel related projects, including MMinE-SWEEPER, MUNI-RISK, MUNIMAP, and CONMAR-II.

2 Objectives and work program

2.1 Objectives

The SHIPPeR cruise focuses on six representative shipwrecks, two of each located in the EEZ of Germany, Poland, and Lithuania. Wrecks are chosen to target a range of different characteristics (e.g., age, condition, type of ship, type of contaminant) as far as possible, with the goal to include munitions and hazardous fuel oils. Work at these target sites has four overarching objectives:

1. Geophysical characterization of the shipwrecks and the surrounding seafloor, including wreck condition and target objects laying outside the wreck body (e.g., munition objects).
2. Geochemical investigation of water, sediments, and biota to assess chemical contamination spread and ecological exposure and application of eDNA metabarcoding approach for biodiversity assessment
3. Collection of sediments and water for land-based experimentation and development of remediation techniques for explosive chemicals and fuel-related compounds.
4. Promote international cooperation on shipwreck hazards in the South Baltic Region and support regional-scale solutions to border-transgressing pollution.

Details to the Specific Objectives:

Geophysical characterization of target shipwrecks

Each wreck will be inspected by acoustic and visual imaging to evaluate the current position and condition. This will be compared with reports from previous investigations of the wreck sites to evaluate any changes over time and to ensure a reliable baseline survey for subsequent sampling around the wreck. This approach follows previous successful expeditions (Bergmann et al., 2022).

Ship hull-mounted SAS imaging will be conducted first to provide detailed maps of the shipwrecks and surrounding area. Overnight mapping activities optimize shiptime use, and provide baseline site data for subsequent activities. These baseline data will be used to plan

AUV missions to image specific target areas of the shipwreck site by sidescan sonar, magnetometer, and optical photogrammetry.

Optical imaging will also be conducted by ROV to allow controlled inspection of points of interest, especially related to suspected munitions objects and fuel tanks. ROV-based imaging will be further used for 3-D reconstruction of the shipwrecks. The combination of geophysical mapping and reconstruction with chemical distribution maps will be a powerful approach to demonstrate the connection between wreck condition and environmental contamination. This is an important component for inclusion in the development of guidelines for wreck management and remediation.

Geochemical investigation of water, sediments, and biota to assess chemical contamination spread, and ecological exposure and biodiversity assessment

Water and surface sediments will be collected at high spatial resolution around the shipwreck sites using traditional sampling devices and ROV-based samplers. Vertical water sample profiles will be collected by CTD-mounted Niskin bottles on a 3x3 grid pattern across the wreck site. This approach has been demonstrated successfully for dumped munition piles during the German “Immediate Action” remediation program. Discrete water samples will be immediately analyzed with the shipboard Xplotector system (Esposito et al., 2023) to visualize spatial patterns and plan additional sampling work as necessary to capture contamination plumes.

Surface sediments will be collected on a similar spatial grid with a Van Veen grab sampler outfitted with an underwater camera to ensure safe sampling around hazardous objects. New methods are currently being developed to allow on-site chemical extraction of sediments and rapid analysis with the Xplotector system. Surface sediments will also be collected for analysis of eDNA to evaluate effects of shipwreck contamination on microbial biodiversity.

Settling sediments will be collected with a moored sediment trap (IOPAN) that will also serve as a platform for mussel biomonitoring and passive sampler deployment. To maximize deployment time, this mooring will be deployed by a wreck in DE waters at the start of the cruise (likely Torpedo boat T34) and recovered on the return transit to port. Collected sediments will be analyzed for target munition and fuel chemicals, and compared with surface sediments collected near the wreck.

Biota sampling will especially target macrofauna, including fish and mussels. Sampled organisms will be analyzed for general parameters (size, sex, age) and for a range of biomarkers targeting different animal health aspects: genotoxicity, cytotoxicity, oxidative stress, metal toxicity, and haematological condition. Fish will be collected by hand angling near the wrecks to collect organisms that use the wreck as habitat. This is also the optimal approach to collect organisms that are directly exposed to wreck-related contaminants. Mussels will be deployed on small moorings using established biomonitoring methods (e.g., Strehse et al., 2017; Appel et al., 2018). Short deployments are appropriate for munition compounds, whose short tissue retention time rapidly reflects recent exposure. Longer deployments will be conducted in association with the sediment trap deployment discussed above, or will be deployed for later recovery during other planned cruises.

Samples for land-based experimentation and development of remediation techniques

A major goal of the BALTWRECK project is to develop in-situ and ex-situ bioremediation technologies using dedicated external and autochthonous microbes to combat fuel and munition pollution. These technologies will apply both aerobic (using oxygen) and anaerobic (not using oxygen) microbial consortia. Laboratory development will focus on culturing microbial communities capable of degrading target compounds associated with fuels and explosives and construction of appropriate substrate platforms for field deployment of microbial consortia. This approach is also known as “Enhanced Natural Recovery”, but has

not been applied thus far to remediation of shipwreck related pollution. (*Note that field deployment of such consortia will **NOT** be conducted during the SHIPPeR cruise.*)

To determine and demonstrate the efficacy of the microbial remediation tool, field samples will be collected during the SHIPPeR cruise for bench-scale tests at the home laboratories. Real-world material is critical for these tests due to the complexity of chemicals found in shipwrecks and the inherent challenge of completely characterizing and replicating such material. Shipboard technologies (e.g., the Xplotector system) will provide on-site guidance to characterize the spatial spread of contamination and identify optimal locations for material collection. High spatial resolution water column mapping through CTD profiles (described above) will provide baseline data on water quality characteristics for the microbial consortia culturing.

Promote international cooperation on shipwreck hazards in the South Baltic Region

The SHIPPeR cruise workplan is oriented around target sites in three Baltic countries (DE, PL, LT), and this provides an excellent opportunity for international outreach and cooperation. This links directly to two specific goals of the BALTWRECK project: increasing awareness of shipwrecks and related pollution in the South Baltic region, and development and application of decision-guidance tools for wreck management. Stakeholder groups are engaged to co-design regional strategies addressing South Baltic wrecks challenges and integrate local insights into policy-making. Stakeholder engagement is also intended to facilitate exchange throughout the region to share best practices and lessons learned from field investigations, including the SHIPPeR cruise. To achieve this goal, the SHIPPeR timeplan includes port stops in Poland (Gdynia) and Lithuania (Ventspils). These port stops enable day visits by local scientists who are unable to participate in the entire cruise due to space limitations, as well as local politicians, NGOs, and media.

2.2 Work program

The planned work program is oriented around two target wrecks in each of the three project countries (DE, PL, LT). Three wrecks have been identified when possible to allow one back-up in case one of the two priority wrecks cannot be found or is determined to be unsuitable for the project goals. Target shipwreck types include both civilian ships containing fuel oils and WWI- & WWII-era military ships with both munitions and fuel oils. The workplan at each wreck location is expected to be similar, as described below the identification of the target wrecks.

Shipwrecks in DE EEZ

		
Destroyer Z28 (image: Koop and Schmolke, 2003)	Torpedoboat T35 (sister ship to T34; image: Harnack, 2004)	Minesweeper, 1943 (image: Wikipedia)

Destroyer Z28

This destroyer ship escorted convoys and laid minefields. Z28 was sunk near Saßnitz in shallow water by British bombers on 6 March 1945. Z28 weighed approximately 3,000 tons, and had an overall length of 127 m and a beam of 12 m.

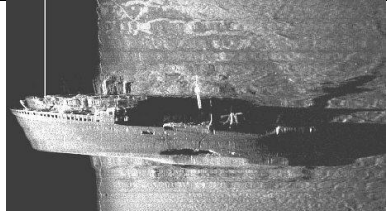
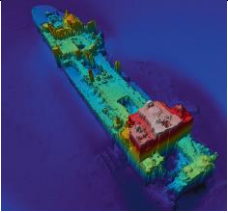
Torpedo boat T34

The German torpedo boat T34 was one of fifteen Type 39 torpedo boats built for the Kriegsmarine (German Navy) during World War II. It struck a mine laid by a Soviet submarine and sank off Cape Arkona November 1944. T34 weighed approximately 1,500 tons, and had an overall length of 103 m and a beam of 10 m. The ship's munition-related inventory included 6 torpedo tubes, 30–60 mines, 4 depth charge launchers

Minesweeper (TBD, Usedom)

This military minesweeper wreck is known to be present offshore the island of Usedom, but limited information is currently available. Further archival research is planned in 2025 to determine the exact position and probable pollutant load contained in the wreck.

Shipwrecks in PL EEZ

		
SS von Steuben (sidescan image: oceanlinersmagazine.com)	Supply Vessel Franken (multibeam image: Hac, 2024)	Class VIIC submarine similar to U768 (image: Deutsches U-Boot-Museum)

Passenger liner SS von Steuben

SS General von Steuben was a nearly 15,000 ton German passenger liner and later an armed transport ship of the German Navy that was sunk in the Baltic Sea during World War II. The ship served as a troop accommodation vessel, and from 1944 as an armed transport vessel. On 10 February 1945, while evacuating German military personnel, wounded soldiers, and civilian refugees during Operation Hannibal, the ship was torpedoed by the Soviet submarine S-13 and sank. The Steuben wreck was found and identified in May 2004 by the Polish Navy. The sister ship of the von Steuben is the SS Stuttgart, the wreck of which is a well-documented major source of fuel oil pollution (Hac, 2024).

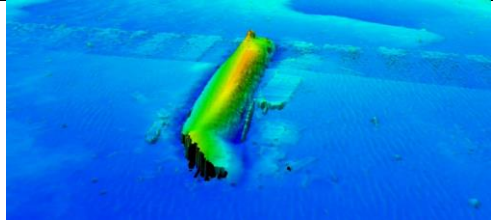
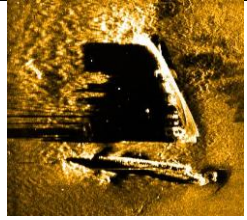
Tankership Franken

The German tankership Franken was sunk in April 1945, at the end of WW II. It was capable of carrying approximately 8,000 tons of fuel and 1,000 tons of munitions, and was used to fuel the German warships in the Baltic Sea. The Russian military sank the Franken near the Hel Peninsula off Gdańsk, Poland, and it is the largest identified wreck in Gdańsk Bay. The wreck is located near numerous Natura 2000 sites, reserves, and a colony of protected grey seals, making it of particular importance for remediation and environmental protection. An estimated 600 and 1000 tonnes of mostly heavy fuel oil, remains in the wreck (Hac, 2024). Previous investigation showed that an approximately 3 ha trough around the wreck is saturated with a large amount of heavy fuel (Hac, 2018).

Submarine U768

German submarine U-768 was a Type VIIC U-boat of Nazi Germany's Kriegsmarine during World War II, and was sunk in a collision with U-745 on 20 November 1943. U768 weighed approximately 1,000 tons, and had an overall length of 67 m and a beam of 6 m. Carried 14 torpedoes.

Shipwrecks in LT EEZ

		
Shipwreck 231123 (multibeam image: Fugro, 2023)	Submarine (W-19) (sidescan image: KU Institute of History and Archaeology of the Baltic Region)	

Shipwreck 231123

The shipwreck 231123 was recently discovered in 2023 in the maritime area of the Republic of Lithuania during geophysical seabed surveys for Lithuania's first offshore wind farm. The wreck lies at a water depth of 37.5 - 38 m and measures 70 x 12.5 m with a height of 5.5 m. The wreck rests with its keel upwards on a flat, sandy bottom in a N-S direction. The vessel was built in steel construction with welded, single-layer hull plating (the bottom of the vessel was probably double-layered). The remains of the bottom part of the hull are preserved in good condition. Large damage can be seen only in the bow section of the ship. No remnants of armaments or any distinctive pieces of equipment were spotted around the shipwreck. It can be assumed that the ship was built no earlier than the mid-1950s. The size and proportions of the vessel are similar to the trawler-type ships produced in the USSR since the 1960s, although civilian and military research and hydrographic vessels were also built on similar hulls.

Submarine W-19

In 2007, the sunken Soviet submarine W-19 was detected over 18.6 nautical miles offshore. The water depth at the wreck is 43 m; the bottom is smooth and sandy. The vessel has broken into two parts. The characteristic structural details including hydroplane guard, vertical rudder, one of the two propellers, torpedo tube opening, and longitudinal ballast tanks are characteristic of a type Щ (Щука) submarine.

2.2.1 Working area, stations, and profiles

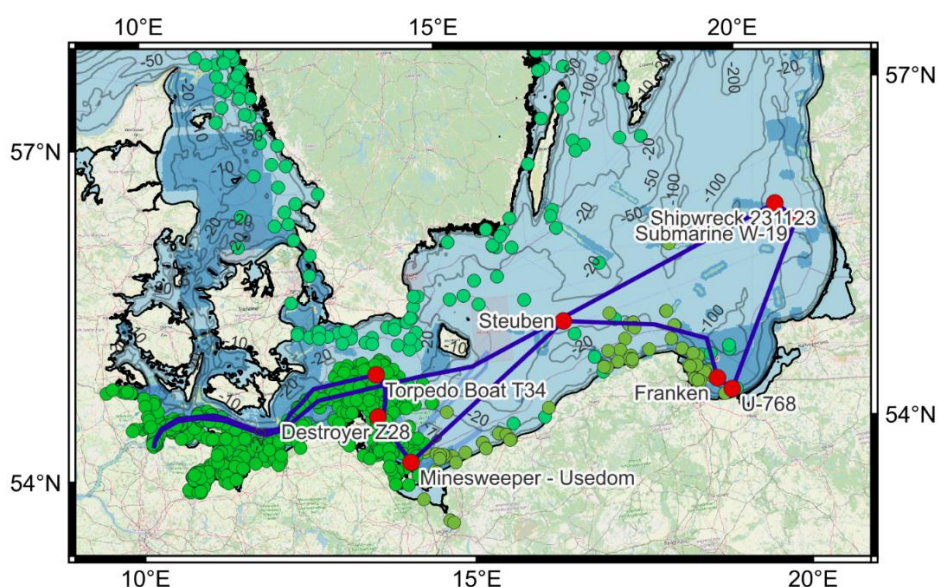


Figure 7. Map of the planned wreck investigation sites. The blue line indicates the planned shiptrack (starting and ending in Kiel). Green points are shipwreck locations from BSH, HELCOM, and Wraki Baltyku (wreck locations not available from all national EEZs).

Table 1. Specific data on the planned wreck investigation sites. All locations are in relatively shallow water depth (< 100 m).

Shipwreck	Country	Latitude	Longitude
Destroyer Z28	DE	54.506	13.653
Torpedo Boat T34	DE	54.888	13.667
Minesweeper - Usedom	DE	<i>TBD</i>	<i>TBD</i>
Steuben	PL	55.223	16.682
Franken	PL	54.539	18.966
U-768	PL	54.425	19.166
Shipwreck 231123	LT	56.018	20.281
Submarine W-19	LT	55.851	20.581

2.2.2 Deployment of equipment

Synthetic Aperture Sonar (SAS): GEOMAR recently upgraded infrastructure for seafloor investigations focusing on marine munition through the BMBF funded project VAMOS (Verbesserte Autonome Meeresboden Observations-Systeme; Grant 03F0942A). Part of this included acquisition of an SAS hydroacoustic mapping system, similar to sidescan sonars (SSS), but which has the advantage of a much higher and range-independent resolution. The SAS will be deployed through the moonpool. As a first activity at each location, we plan overnight surveys to map the shipwrecks and surrounding seafloor.

Sidescan Sonar (SSS): In addition to the ship-based SAS mapping, sidescan sonar mapping will be conducted with an AUV-based system (see below). The AUV-based system enables low-altitude, high resolution imaging of the wreck and surrounding seafloor.

Autonomous Underwater Vehicles (AUV):

An Iver2 autonomous vehicle equipped with sidescan sonar and magnetometer will be deployed to perform low altitude missions around the wreck locations for high-resolution acoustic imaging and identification of metallic objects scattered around the wreck positions. Simultaneously acquired sidescan and magnetic maps will provide critical information on the presence of buried metallic objects, and will guide sediment sampling.

USBL: Parallel to the SAS, the USBL transponder will be installed in the moonpool. AUV navigation and communication will use the USBL and the ROV will use the USBL for navigation. All deployments will be monitored live using OFOP software in which the ship and USBL-transponder positions location can be seen in real-time (AUV, ROV, CTD, etc.) to guide mission navigation.

CTD rosette: Water samples will be collected using rosette-mounted Niskin bottles equipped with sensors for water quality parameters (temperature, salinity, dissolved oxygen, etc.). Samples are typically collected with high vertical resolution (as close as 3 m intervals) to highlight gradients from the putative seafloor source. Profiles will be arranged in a 3x3 grid pattern across the wreck site to capture the 3-D structure of contamination plumes emitted from the shipwrecks.

The Xplotector is a shipboard (ex situ) system that includes two modules: a fluidics system that performs online preconcentration of explosive compounds (TNT, RDX, ADNT, DNB) from seawater for direct analysis, and (2) an analytical system that separates the target compounds by HPLC and detects them by electrospray-ionization or atmospheric pressure chemical ionization mass spectrometry (ESI/APCI-MS) and UV spectrophotometry. The system is fully automated from sample collection to data analysis via custom software. The prototype system has been demonstrated on several previous ALKOR cruises. The Xplotector will be used during SHIPPeR to allow near real-time mapping of dissolved munition chemical distribution around the target shipwrecks.

Van Veen grab: Surface sediment will also be collected with a camera-guided 0.1 m² Van Veen grab. Sediment subsamples will be analyzed for adsorbed MCs and fuel-related compounds. Sediment grab sampling will be guided by real-time video to ensure safety around hazardous objects.

Remotely Operated Vehicle (ROV): To gain a good 3D impression of the wrecks and surrounding objects, we will deploy a small ROV SAAB SEAEYE Falcon, which we have used very successfully on previous cruises. We will use the water sampling capabilities for additional detailed sampling next to targets of interest. Acquired data include exact navigation and video footage that serves as base-line when compared to footage acquired during other planned fieldwork.

Fish collection: The uptake of MC and fuel-related chemicals into fauna is one of the great concerns related to shipwrecks. We plan to collect fish by hand angling, which can be performed directly above shipwrecks, with no risk to damage the wreck or accidentally encounter munitions. Here, in addition to bottom dwelling flat fish (flounder, dab, plaice), Baltic cod (*Gadus morhua*) living near shipwrecks will be targeted. Fish tissue will be immediately sampled or stored frozen at -20 or -80 °C for later analysis, as appropriate.

Mussel Moorings/Passive Samplers: The UKSH has used mussel moorings for many years to investigate the uptake of MCs in fauna. A simple anchor, rope and flotation body mooring will be deployed with a rope or acoustic release near the clearance locations, ideally at the - current side.

2.2.3 Special requirements

Ship visits for outreach and communication activities: A major goal of the BALTWRECK project is outreach to promote and enhance international cooperation within the South Baltic Region. We therefore plan port visits in PL (Gdynia/Gdansk) and LT (Klaipeda), and to invite day visitors from news media, politicians, NGOs, and local scientists to observe research work on at least one day in each of these locations. Additional outreach activities are planned in Kiel before and after the cruise.

Sampling near shipwrecks and in munition contaminated areas: We are well aware that sediment sampling or any kind of bottom contact near shipwrecks and in munition contaminated areas can be dangerous. The cruise proponents have acquired great knowledge of how to conduct sampling in such areas during research work over more than 10 years. We have established procedures (e.g., preliminary surveys, video-guided sampling) to acquire new on-the-spot data that allow a clear verification of risks related to wrecks and munitions before any physical samples are collected.

It is also important to consider that shipwrecks represent cultural heritage sites and may contain human remains of ship's crew casualties. Preservation of cultural heritage, as well as archeological documentation of the site will be secured by participation of archeologists in the BALTWRECK project who specialize in underwater archeology. Sampling activities are only planned to be non-invasive with respect to the shipwrecks, and necessary permits will be applied for from national authorities. Additional documentation from the field campaigns will be delivered to the National Maritime Museum in Gdańsk and will be shared with the Warsaw University department of archaeology.

2.2.4 Work days at sea

We apply for 20 days of ship time. Table 2 gives an overview of the planned station time per deployment, transit time, and time for exchange of day visitors. The working time at each location will be approximately constant; the total working time at sea is 18 d (including transits between stations); 54 h are transit between Kiel and the first and last investigation sites; an additional 25 h have been allocated for port calls and day visitors (only at non-DE sites; similar

outreach is planned at the start and end of the cruise in Kiel). Based on previous experience, station time is calculated including the time for the deployments, with an approximately 10% time buffer added to station time in the cruise duration plan for exact positioning of the ship, etc.

Workplan at each shipwreck site

	Number stations	Time per station	Total time (h)
Geophys pre-mapping	1	8	8
Water sampling	9	0.5	4.5
Sediment sampling	20	0.25	5
AUV deployment/recovery	3	2	6
ROV	3	3	9
Angling/fishing	1	3	3
Mooring deployment/recovery	3	1	3
Guest transfer	1	5	5
		Total	ca. 43.5

Cruise duration planning

Start time	Duration (h)	Activity	Transit (nmi)
Day 01 08:00	23.50	Mobilization/Loading - Kiel	
Day 02 07:30	12:00	Depart Kiel	
Day 02 08:00	13.6	Transit	136
Day 02 21:36	40	Torpedo boat T34	
Day 04 13:36	3.4	Transit	34
Day 04 17:00	40	Destroyer Z28	
Day 06 09:00	5	Transit	50
Day 06 14:00	40	Minesweeper - Usedom	
Day 08 06:00	11	Transit	110
Day 08 17:00	48	Steuben	
Day 10 17:00	10	Transit	100
Day 11 03:00	48	Franken	
Day 13 03:00	5	Transit	50
Day 13 08:00	48	U-768	
Day 15 08:00	11	Transit	110
Day 15 19:00	48	Shipwreck 231123	
Day 17 19:00	5	Transit	50
Day 18 00:00	48	Submarine W-19	
Day 20 00:00	5	Transit	50
Day 20 05:00	40	Transit	400
Day 21 21:00		Return Kiel	
Day 22 08:00	11	Demobilization	
Station time (h)	360	Transit total (nmi)	1090
Station time (d)	15.0	Transit time total (d)	4.54
		Transit first/last stations (d)	2.23
		Transit between stations (d)	2.31

2.2.5 Arrival and departure

The cruise start and end is planned in Kiel.

2.2.6 Measures to conduct responsible marine research

We state that all measures will be taken with regard to the Declaration of Responsible Marine Research (Appendix 1), the Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area (Appendix 2), and the Mitigation measures for the operation of seismic and hydroacoustic sources with pulsed sound emissions (Appendix 3). During measurements, no harmful chemicals will be released. Physical sampling will comprise water and sediment as well as a minimum of biota. Our activities will not lead to alterations and damage in the investigated ecosystems. Special care will be taken when starting acoustic measurements (soft-start). The data and samples will be made available to other researchers according to the strategy outlined in section 6. Biological material obtained during the planned expedition will be sampled according to Nagoya Protocol regulations.

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4 Cruise participants

The cruise will include a balance of personnel from different institutions and nations within the BALTWRECK project. We plan to host day visitors on at least one day each during fieldwork in PL and LT.

	Name	Status	Affiliation	Topic / Role*
01	Aaron Beck	Scientist	GEOMAR	Chief Scientist/Marine Chemistry
02	Ralf Prien	Scientist	IOW	Deputy chief scientist/Marine sensors
03	Jens Greinert	Scientist	GEOMAR	Marine geophysics
04	Tim Weiss	Scientist	GEOMAR	Marine geophysics
05	Jacek Beldowski	Scientist	IOPAN	Marine chemistry & geophysics
06	Miłosz Grabowski	Technician	IOPAN	ROV/AUV specialist
07	Sergej Suzdalev	Scientist	KU	Marine geochemistry
08	Aurelija Samuiloviene	Scientist	KU	Marine biodiversity
09	Ksawery Kuligowski	Scientist	IMP-PAN	Environmental engineering
10	Milda Stankevičiūtė	Scientist	NRC	Biodiversity and ecotoxicology
11	Lars Scheer	Technician	ITP	Toxicology
12	Uwe Wichert	Historian	MELUND/BLANO	Wreck & military specialist

5 Funding availability

Work on the proposed cruise is supported primarily by the BALTWRECK project (South Baltic Interreg). In addition, the SHIPPeR cruise will interface with three additional projects (MMinE-SWEEPER, CONMAR-II, and MUNI-RISK), as described in Section 1, providing additional resources and added value.

6 Data and sample handling

The final goal of course is to publish as many data as possible. Data managers at GEOMAR and in CONMAR are active PANGAEA data curators and can assist researchers during preparation of their sample archival and data publication procedures in a World Data Center (e.g. PANGAEA) Links to data publishers or principle investigators provide contact information for external scientists. Further, the Kiel Data Management Team (KDMT) maintains the Ocean Science Information System (OSIS) as a central information and research data sharing utility for marine research projects at GEOMAR and Kiel University. Comparable to PANGAEA it is publicly accessible and can be utilized by all cruise participants. OSIS merges information of expeditions, experiments and numerical models with peer review publications and available research data. The view of all information in OSIS is open to the public while access to actual data in ongoing research projects may be restricted for definable periods of time (moratorium). The submission status of data files including the responsible investigator as contact person is visible to the public and may foster collaborations with interested researchers.

During the cruise no permanent samples (e.g. sediment cores or rocks) will be taken, so that we do not foresee the need physical sample storage. However, if biota samples taken need to be stored for longer time they will be inventoried and stored at the respective institute. Data and information generated during geochemical, sedimentological analyses will be stored in OSIS/PANGAEA or respectively in the laboratory context at least until publication.

As knowledge about the exact location wrecks and munitions can be misused, bathymetric data and even images of bathymetric maps will not be made publically available with coordinates. However, data will be uploaded to the decision aid and wreck management tool that is being developed for the assessment of wrecks by the responsible institutions and governmental bodies. To ensure protection of these data, an advanced user management system will be implemented to restrict access to sensitive information while allowing a thorough risk assessment and site prioritization.

Preparation of station maps will be done by GEOMAR. Metadata information about the survey location can and will be made public via OSIS. The chief scientist and all principal investigators involved in this cruise will comply with the time schedule below regulating the availability of all information and all research data and where applicable also of physical samples resulting from this cruise. Following the cruise the KDMT will support and assist researchers in their data management activities.

6.1 Data Management time plan:

- 1 Availability of metadata in OSIS and PANGAEA (<https://portal.geomar.de/osis> or <https://www.pangaea.de/>) two weeks after completion of the cruise and related experiments.
- 2 Availability of measured data in OSIS (<https://portal.geomar.de/osis>) six months after completion of the cruise and related experiments.
- 3 Availability of data in PANGAEA (<http://www.pangaea.de> or as compilation at <http://www.pangaea.de/search?q=campaign:CRUISENAME>) three years after completion of the cruise and related experiments.

NOTE: Due to the sensitivity of the data position accuracy will be reduced and some data may not be possible to publish publicly.

Appendices:

Appendix 1: Declaration of Responsible Marine Research

Appendix 2: Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area

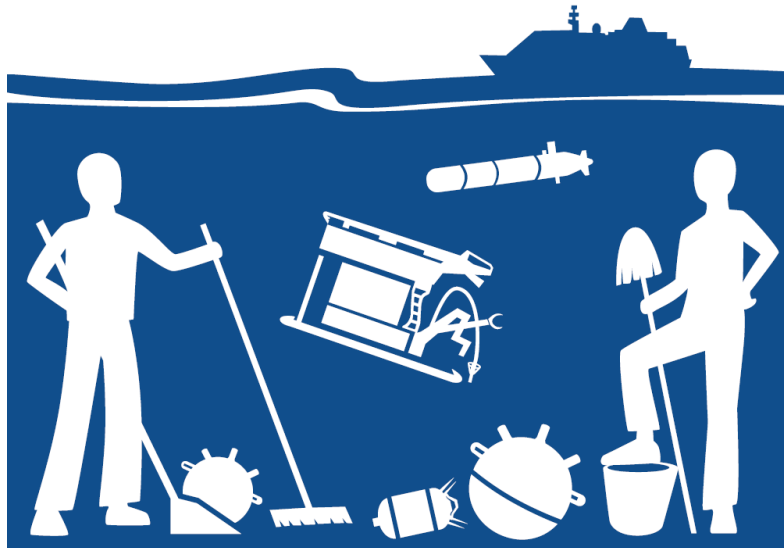
Appendix 3: Mitigation measures for the operation of seismic and hydroacoustic sources with pulsed sound emissions

Appendix 4: SHIPPeR cruise map

Appendix 5: BALTWRECK project summary

Appendix 6: BALTWRECK project proposal (EU South Baltic Interreg)

Appendix 7: Letter of confirmation from BALTWRECK coordinator



MMinE-SwEEPER

Milestone Report

Milestone No. 11.1: First training material (munition detection /
remediation and environmental studies)



Funded by
the European Union

Authors | Miłosz Grabowski, Ewa Korejwo, Jacek Bełdowski

Contributing organisations:



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Disclaimer

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This document contains information on MMinE-SwEEPER's core activities. Any reference to content in this document should clearly indicate the authors, source, organisation, and publication date.

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5. Appendix	8

1. Introduction

This presentation addresses the problem of dumped military munitions in the Baltic Sea and presents methods used to detect these objects and evaluate their environmental impact. Large quantities of conventional and chemical weapons remain on the seabed as a legacy of past military activities. These objects may pose risks to marine ecosystems, offshore infrastructure, and human safety. The study combines two complementary perspectives. The physical part explains how geophysical techniques are applied to locate, map, and identify underwater munitions. The chemical part focuses on environmental investigations that determine whether hazardous substances are released from these objects into the surrounding ecosystem. Together, these approaches form a complete workflow from detection to environmental risk assessment.

2. Geophysical Detection of Munitions

The physical section of the presentation describes how underwater munitions are detected and identified using modern geophysical survey techniques. Because large marine areas must be investigated safely, the process begins with non-invasive remote sensing methods capable of covering wide regions efficiently.

The workflow starts with survey planning and large-scale screening of the seabed. Side-scan sonar is presented as the primary search tool, producing acoustic images that reveal objects resting on the seafloor through variations in acoustic backscatter and shadow effects. These data allow rapid identification of potential targets and provide an initial overview of object distribution. Multibeam echosounders complement sonar imagery by measuring seabed bathymetry and generating detailed three-dimensional models. This method improves understanding of object size, orientation, and surrounding seabed morphology. Magnetometry is then introduced as an additional technique capable of detecting ferromagnetic objects, including targets buried beneath sediments, by measuring disturbances in Earth's magnetic field. For objects hidden below the seabed surface, low-frequency acoustic systems such as Synthetic Aperture Sonar and three-dimensional sub-bottom profilers are applied. These techniques enable imaging of subsurface structures and identification of partially or fully buried munitions. The presentation emphasizes that no single method provides complete information; therefore, data from multiple sensors are combined through data fusion to improve interpretation and target ranking. The final stage of the physical investigation involves direct observation using remotely operated vehicles equipped with cameras and acoustic navigation systems. Visual inspection confirms object identity and condition, while underwater photogrammetry allows precise three-dimensional documentation. Overall, the physical part demonstrates a structured detection chain that progresses from wide-area screening to detailed confirmation and documentation of hazardous objects.

3. Environmental Chemical Screening

The chemical section focuses on understanding the environmental consequences of dumped munitions after they have been detected. The presentation explains that the presence of ammunition on the seabed does not automatically indicate environmental contamination. Instead, environmental chemical screening is required to determine whether toxic compounds are actively released and whether they pose ecological risks. The study examines chemical warfare agents, explosive residues, and especially their degradation products, which often remain in the environment long after the original compounds have transformed. Because chemical agents undergo hydrolysis, oxidation, and biological degradation processes, stable breakdown products frequently serve as the most reliable indicators of past or ongoing contamination. Environmental monitoring therefore uses a multi-analyte strategy that allows researchers to detect both known substances and unexpected contaminants. Sampling procedures play a central role in environmental assessment. Samples are collected around suspected objects to evaluate contamination gradients and distinguish local impacts from natural background conditions. Sediments are treated as long-term archives of pollution, while pore water reflects the fraction of chemicals available to living organisms. Biological samples help evaluate potential transfer of toxic substances through the food chain. Due to safety risks associated with chemical ammunition, sampling operations are often performed using remotely operated platforms rather than divers. After collection, environmental samples may undergo preliminary onboard screening when suitable analytical equipment is available. However, only a limited number of research institutions operate ships equipped with such systems. Therefore, the most common approach is to collect and properly preserve samples during the expedition and transport them to specialized laboratories for detailed analysis. In these laboratories, advanced analytical techniques such as chromatography coupled with mass spectrometry are applied to identify contaminants at very low concentrations within complex environmental matrices. The presentation also discusses scientific and operational challenges related to environmental assessment. Conditions in the Baltic Sea, such as low oxygen levels and heterogeneous sediment distribution, complicate interpretation of contamination patterns. Analytical uncertainty, unknown degradation pathways, and limited reference materials further increase the difficulty of reliable risk evaluation. In addition, management decisions must balance environmental protection with safety considerations, since removal of munitions can sometimes cause greater chemical release than leaving them in place. As a result, long-term monitoring and risk assessment often represent the preferred management strategy.

4. References

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Online sources:

www.helcom.fi

www.eur-lax.europa.eu

5. Appendix

Slides of the first training materials

TRAINING MATERIALS:

MUNITIONS DETECTION AND ENVIRONMENTAL STUDIES



Funded by
the European Union

CONTEXT

Case study: Baltic Sea legacy problem

- The Baltic Sea is one of Europe's major legacy UXO regions.
- An estimated 360,000 - 385,000 tones of conventional munitions were dumped.
- Around 40,000 tones were chemical weapons; about 40% were warfare agents.
- Wrecks add fuels, bombs, mines, torpedoes and artillery shells.

360 - 385k t

Estimated conventional
munitions dumped

40k t

Chemical weapons in
the Baltic Sea record



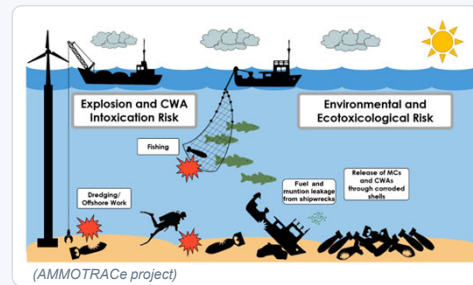
Picture: Bornholms Marinedistrikt



CONTEXT

How munitions reach the seabed

- Consequence of military conflicts.
- Post-war disposal programs scuttled ships loaded with chemical ordnance.
- Additional objects were lost during combat operations.
- Major dump areas of chemical munitions in the Baltic Sea include Kattegat, Skagerrak, Bornholm, Gotland and Gdansk deeps.
- Conventional munition and military shipwrecks scattered all around the Baltic Sea. Also, in coastal waters (e.g., Germany).
- Today, targets occur both exposed on the bottom, partly buried and fully buried in sediment.

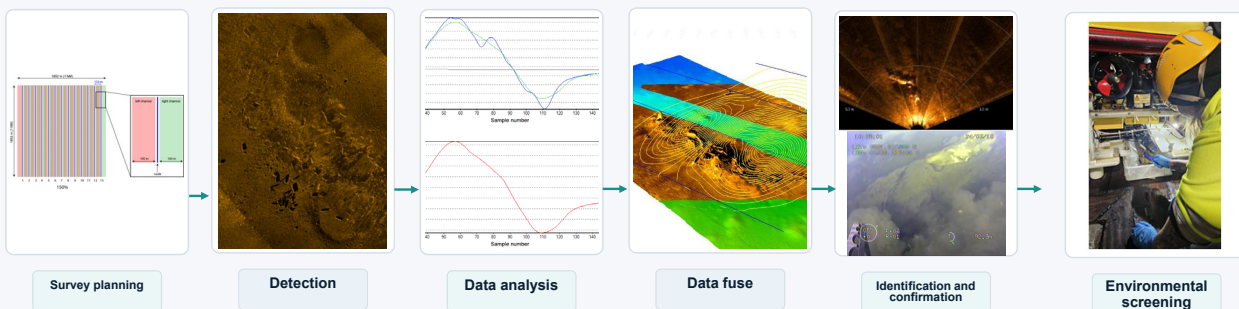


3

WORKFLOW

From wide-area screening to identification

The workflow moves from fast non-invasive screening to targeted visual confirmation and 3D documentation as well as environment screening.



- Screen large areas first.
- Rank targets before intervention.
- Use ROVs where confidence is highest.
- Perform environmental screening for final confirmation.

4

DETECTION – GEOPHYSICAL METHODS



01 – Side-scan sonar (SSS)

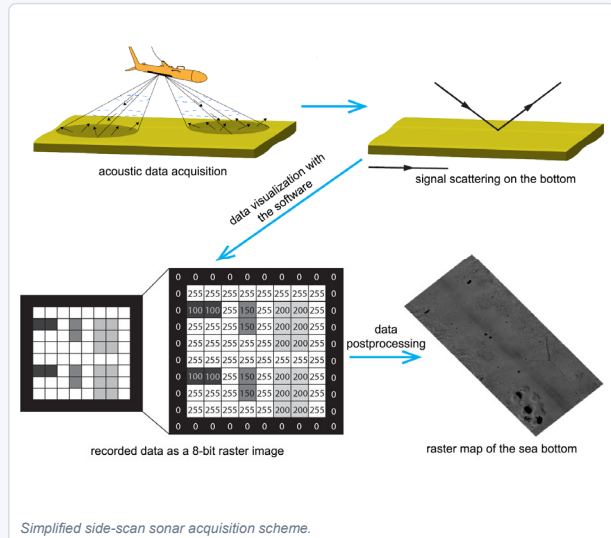
Detecting objects resting on the seabed.



SIDE-SCAN SONAR

Side-scan sonar: the primary search tool

- SSS images seabed backscatter rather than true elevation.
- It is highly effective for finding small bottom-resting targets.
- Object shadows help estimate height above the seabed.
- The method is fast, non-invasive and operationally mature.
- Side-looking acoustic pulses ensonify the seabed.
- Echo travel time and amplitude create a 2D raster image.
- Bright returns mark strong backscatter; shadows reveal relief.
- GNSS positions each line so mosaics can be georeferenced.
- Images resolution depend on angular geometry of the beam.



7

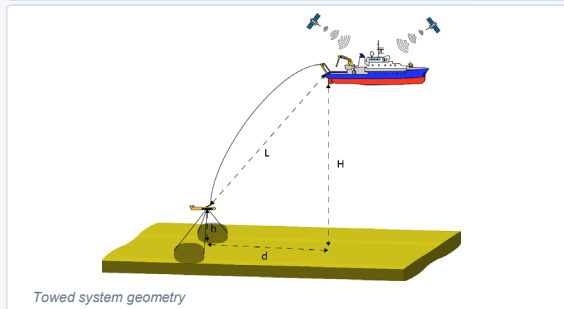
SIDE-SCAN SONAR

Example equipment: AUV/ROV-mounted side-scan configuration & towed systems

- Typical operating frequency ranges: 100 kHz – 1000 kHz. Also, dual-channel systems.
- Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) as a sonar platforms.
- AUV/ROV systems have more stable altitude.
- Towed systems are faster and covers large area but can be limited by vessel or cable.
- AUV/ROV SSS systems are more complex, and the costs of operation are higher.
- Platform choice depends on bathymetry and mission geometry.



Different size AUVs equipped with the SSS systems and towed system

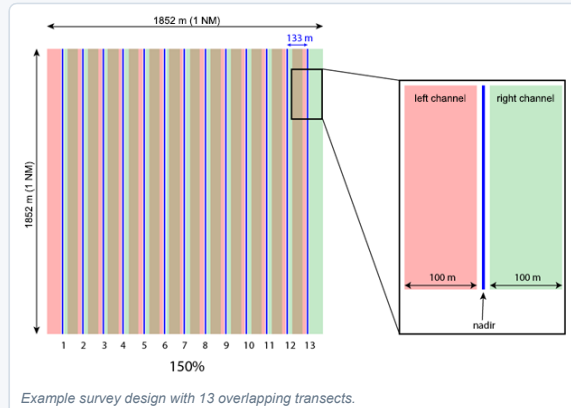


8

SIDE-SCAN SONAR

Survey design and resolution trade-offs

- Parallel transects with overlap are needed for full coverage.
- Higher frequency improves detail but shortens effective range.
- Along-track and across-track resolution vary with slant range.
- Dense line spacing is essential when searching for small targets.
- 100% overlap cover is minimum & 200% overlap cover is optimum.



150%

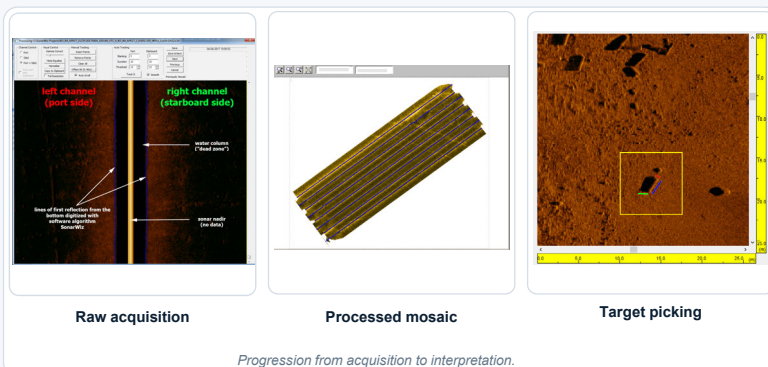
Example overlap in the survey plan

9

SIDE-SCAN SONAR

From raw lines to target candidates

- Clean and correct navigation, heading and tow (or cruising for AUV/ROV) altitude.
- Perform bottom tracking and slant-range correction.
- Apply gain normalization before mosaicking adjacent lines.
- Measure targets for length, width and height above the bottom.
- Detection can be manual, semi-automatic or AI-based.

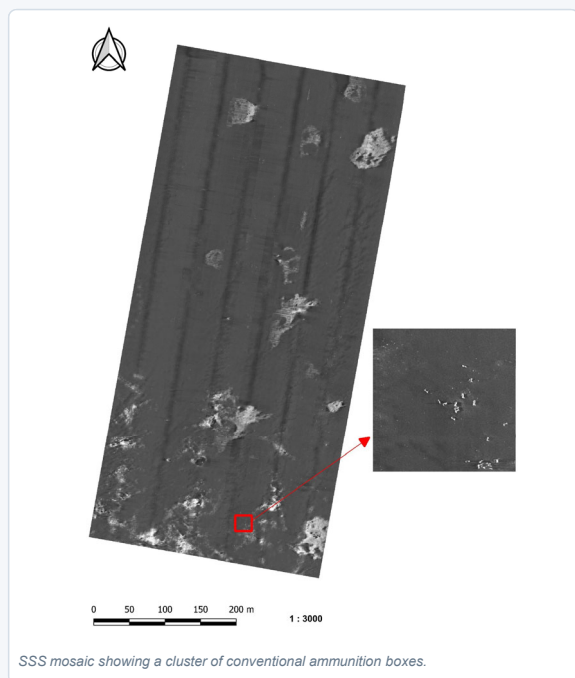


10

SIDE-SCAN SONAR

**Example result - Lubeck Bay:
ammunition crates on the seabed**

- The mosaic clearly resolves a cluster of military-origin objects.
- SSS separates targets from surrounding seabed texture quickly.
- It is well suited to screening dense object fields.
- But 2D imagery alone may still be ambiguous for identification.



11

02 – Multibeam echosounders (MBES)

Adding bathymetry with MBES.

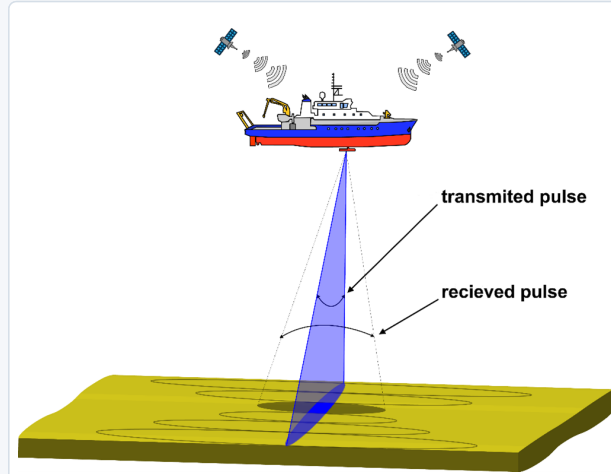


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MULTIBEAM ECHOSOUNDER

How MBES complements side-scan sonar:

- MBES measures depth with a fan of narrow beams.
- Hull-mounted, AUVs and ROVs installations are all possible.
- In shallow water it commonly operates at 200 - 700 kHz.
- Lower frequencies reach deeper water but reduce detail.



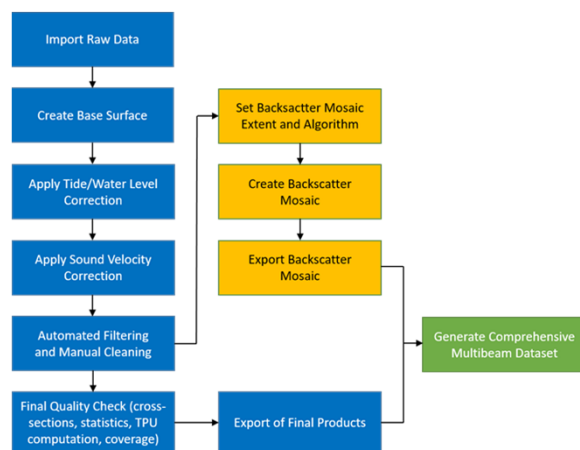
Fan-shaped acquisition geometry of a multibeam echosounder.

13

MULTIBEAM ECHOSOUNDER

MBES processing and final products:

- Apply patch-test calibration, motion correction and sound-speed correction.
- Remove erroneous soundings during quality control.
- Export point clouds, bathymetric grids, DTMs and backscatter mosaics.
- Typical final resolution ranges from 0.05 to 1 m.



Generalized MBES processing workflow.

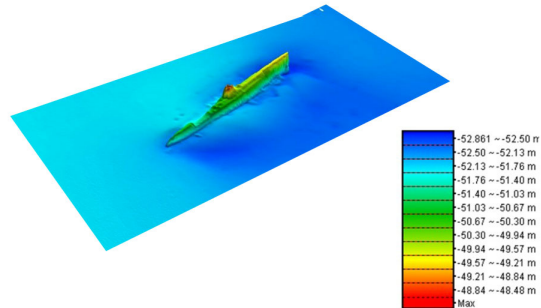
14

MULTIBEAM ECHOSOUNDER



What MBES adds in practice:

- MBES captures size, relief and orientation of submerged structures.
- It produces detailed 3D seabed and object geometry.
- Accurate sound-velocity profile, navigation and motion corrections are critical for depth quality.
- The method is especially useful for wrecks and complex relief.



MBES-rendered wreck morphology.

15

03 – Magnetometry (MAG)

Magnetic detection of Surface and subsurface targets.



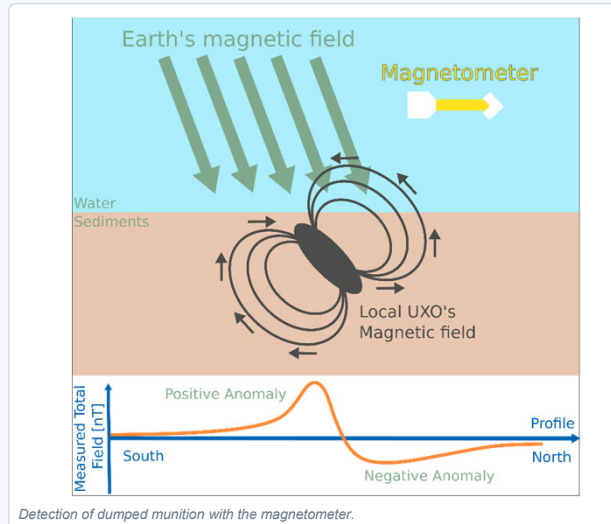
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MAGNETOMETER



Why magnetometers matter:

- Ferromagnetic objects perturb Earth's natural magnetic field.
- Targets include wrecks, debris, mines, bombs and shells (all metal-made).
- Marine magnetometers are passive and emit no pulses.
- They can be paired with sonar during the same survey.



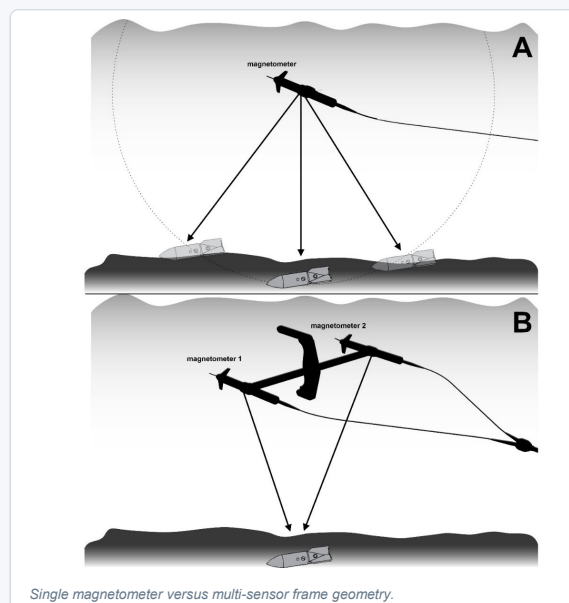
17

MAGNETOMETER



Single sensor or gradiometer?

- A single sensor (A) gives only approximate target location.
- Frame-mounted sensors (B) improve 3D localization.
- GNSS and USBL are used to position the tow body.
- Cesium systems sample fastest; proton systems slowest. Differences in resolution.



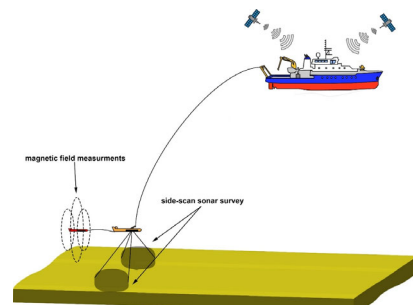
Single magnetometer versus multi-sensor frame geometry.

18

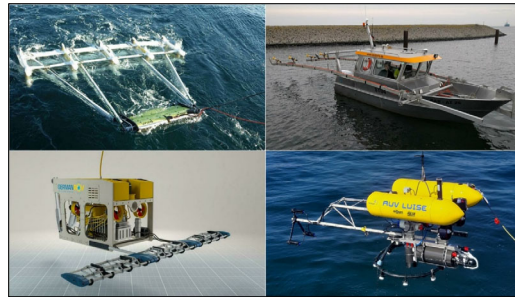
MAGNETOMETER

Different types of mounting platforms:

- Towed systems, also Remotely Operated Towed (ROTV) systems.
- ROV and AUV systems.
- Framed systems.
- Different detections results based on magnetometer height above object.
- Platform choice depends on bathymetry and mission geometry.



Simultaneous side-scan sonar and magnetometer towing arrangement.



ROTV, ship-framed magnetometer, ROV and AUV MAG systems.



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MAGNETOMETER

Acquisition rules that determine success:

≤ 10 m

Recommended line spacing for military targets

- Transect spacing controls the probability of finding small objects.

Low tow

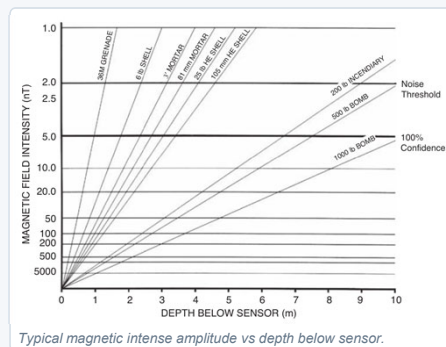
Keep the sensor as close to the seabed as safely possible

- Survey direction relative to magnetic-field variation affects detectability.

Stable altitude

Avoid abrupt height changes during towing

- Tow altitude matters as much as the sensor itself.



Typical magnetic intense amplitude vs depth below sensor.

Magnetometer Altitude above Object [m]	Total Field Amplitude Observed for Object Oriented S-N with only Induced Magnetization					
	Shell 105mm	Shell 155mm	Bomb 100lbs	Bomb 250lbs	Bomb 500lbs	Ground mine MKIV
2	11 nT	41 nT	75 nT	160 nT	300 nT	1,350 nT
3	3 nT	12 nT	23 nT	49 nT	91 nT	485 nT
4	<2 nT	5 nT	10 nT	21 nT	40 nT	223 nT
5	<1 nT	2.5 nT	5 nT	10.5 nT	20 nT	120 nT
6	<0.5 nT	<2 nT	3 nT	6 nT	12 nT	70 nT
	Clearly detectable at 3:1 SNR and distinguishable from geogenous objects					
	Still detectable at 2.1 to 3:1 SNR but mix-up with geogenous objects					
	Undetectable even at 2:1 SNR in good offshore magnetometer surveys					

Object detectability for different UXO types.

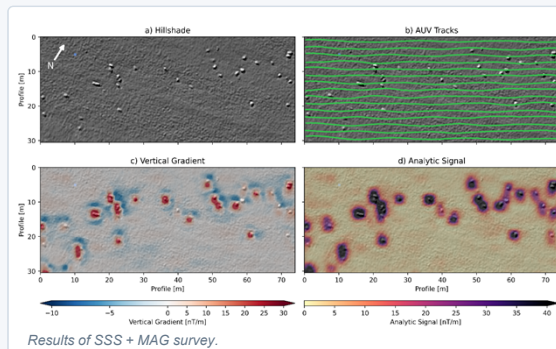
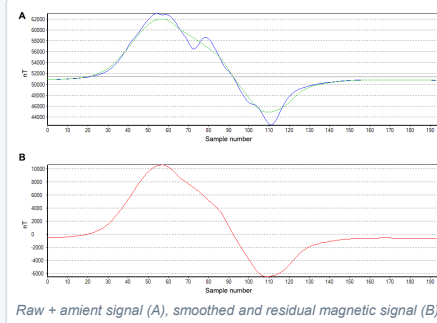


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MAGNETOMETER

From raw signal to residual anomaly:

- First verify navigation and altitude records.
- Subtract background field and internal instrument noise.
- The residual (analytical signal) isolates anomalies caused by ferromagnetic targets.
- Anomaly amplitude combined with tow distance can support mass estimates.

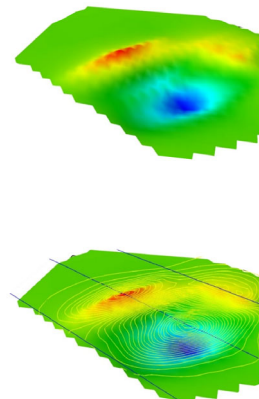
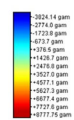


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MAGNETOMETER

3D anomaly maps and buried-target cues:

- Gridded residuals can be mapped as targets, contours or 3D surfaces.
- Anomalies may indicate wreck remains or smaller ferromagnetic targets.
- Magnetic highs and lows can flag objects concealed by sediment cover.
- Interpretation improves when compared with acoustic datasets.



3D residual-anomaly visualization over wreck remains.



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04 – Low frequency Synthetic Aperture Sonar (LF SAS) & 3D Sub-bottom profiler (3D SBP)

Detection of munition under the sea bottom.

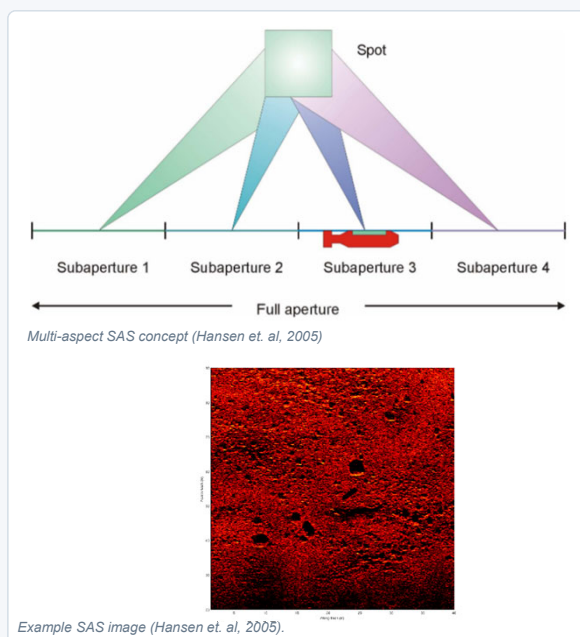


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LOW FREQUENCY SYNTHETIC APERTURE SONAR (LF SAS)

How does LF SAS image the seabed and objects buried within it?

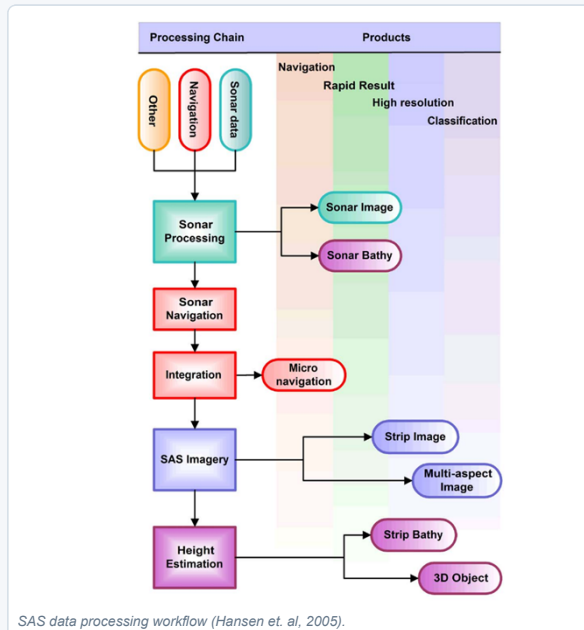
- SAS coherently combines successive pings into a synthetic aperture much longer than the physical antenna.
- This provides nearly constant along-track resolution, independent of range to the target.
- Operating below ~40 kHz improves sediment penetration and supports detection of buried objects.
- A typical configuration is an AUV-mounted and vessel hull-mounted.



LOW FREQUENCY SYNTHETIC APERTURE SONAR (LF SAS)

Measurement configuration and LF SAS data processing

- Measurements are conducted along parallel survey lines using an AUV or a surface vessel.
- Key supporting sensors include INS and DVL, as micronavigation requires a highly accurate trajectory.
- Processing includes DPCA, beamforming (TDBP / wave-domain), and autofocus.
- Outputs include SAS imagery, relative bathymetry, and data for target classification.
- When using low frequencies, the acoustic pulses penetrate the seabed and reach its subsurface layers.

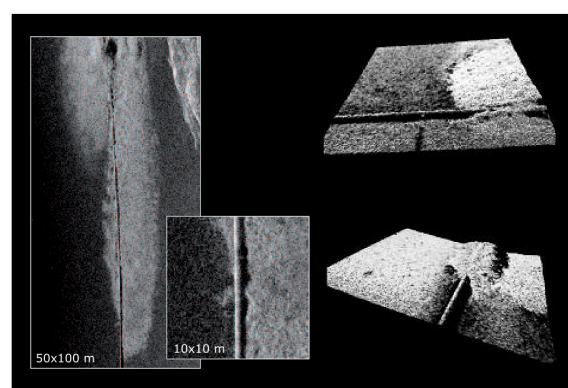


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LOW FREQUENCY SYNTHETIC APERTURE SONAR (LF SAS)

Applications, advantages, and limitations of LF SAS

- When using low frequencies, the acoustic pulses penetrate the seabed and reach its subsurface layers.
- LF SAS supports the detection of cables, pipelines, UXO, archaeological objects, and containers.
- In practice, it achieves centimeter-level resolution.
- It enables detection of objects approximately 1 m below the seabed surface.
- Performance is limited by navigation errors, seabed topography, sound speed variability, and sediment type.
- Example operating regime: 200 m swath per channel, platform speed at 2 m/s; for an object buried 0.5 m, the favorable height above the bottom window is 10–25 m.



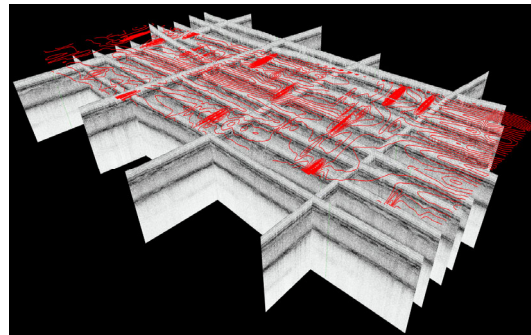
Pipeline inspection with SAS (kongsberg, HISAS 1030).

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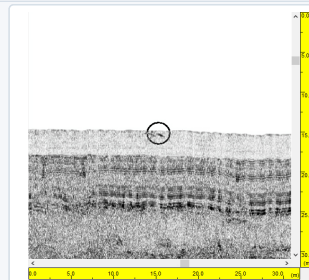
3D SUB-BOTTOM PROFILER (3D SBP)

Volumetric imaging of the subsurface using 3D SBP:

- 3D SBP builds a dense data volume of the shallow subsurface.
- The method is useful for locating buried objects, layer boundaries, archaeological structures, and other targets hidden within sediments.
- Buried targets produce a hyperbola in 2D and a hyperboloid in 3D; in tests, objects larger than 70 mm were detected.
- Vertical resolution up to 4 cm.
- The method works best up to about 12 m depth, and up to approximately 20 m at maximum.



3D SBP survey results with overlaid magnetometric contours



Buried object as a 2D hyperbola in SBP result



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3D SUB-BOTTOM PROFILER (3D SBP)

How does the parametric 3D SBP work?

- A parametric SBP emits two primary high-frequency (HF) waves (e.g., 100 kHz and 102 kHz); their difference generates a secondary low-frequency (LF) signal (e.g., 2 kHz).
- The secondary wave retains the narrow beam of the HF signal while achieving better sediment penetration.
- The example Quattro system has four transducers arranged in a line at 25 cm spacing and records four parallel profiles simultaneously.
- A 3D volume of the shallow subsurface is created from a dense grid of profiles.



Innomar Quattro parametric SBP system (Innomar, Quattro SBP)

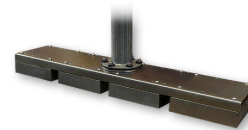
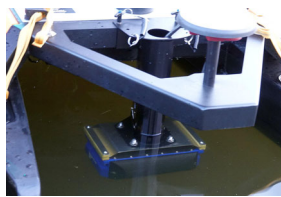


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3D SUB-BOTTOM PROFILER (3D SBP)

Measurement configuration and 3D SBP workflow:

- The transducer array operates from a surface vessel or USV, typically 0.5–1.5 m below the waterline.
- For 100% coverage, survey lines spaced at 1 m are required, which is why small and maneuverable platforms are preferred.
- GNSS RTK, MRU, and precise lever-arm and offset corrections are essential.
- Penetration is limited by coarse sands, gas in the subsurface, multiples in shallow water, and waves exceeding 0.5 m.
- Preparation of raw 2D SBP data: format conversion, coordinate interpolation, removal of positioning outliers, and optional tide corrections.
- After corrections, 2D sections are binned/interpolated into voxels, typically $25 \times 25 \times 1$ cm.



Innomar Quattro parametric SBP system mounted on the USV (Innomar)



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05 – Data fusion

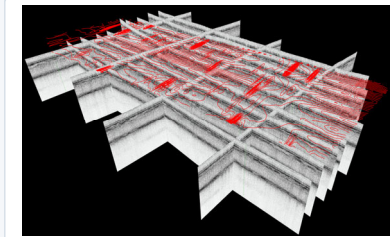
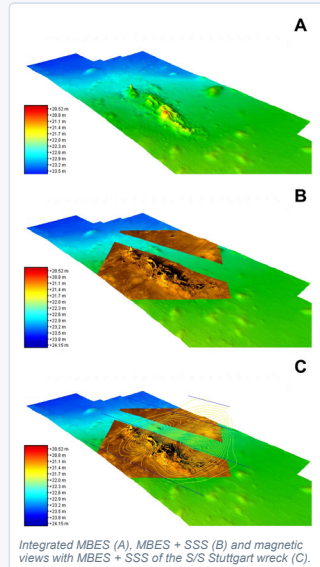
Fuse sensors before ROV inspection.



DATA SYNTHESIS

Sensor fusion: target ranking in 3D

- Common precise georeferencing lets different datasets align in 3D.
- Fusion combines morphology, backscatter, magnetic anomalies and sub-bottom data.
- It helps estimate hazard class, object dimensions and site condition.
- It improves ROV safety by exposing nets, wreck structure and obstacles.
- It also communicates results clearly to stakeholders and non-specialists.



3D SBP survey results with overlaid magnetometric contours

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DETECTION – DIRECT OBSERVATION



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06 – Visual inspection and photogrammetry

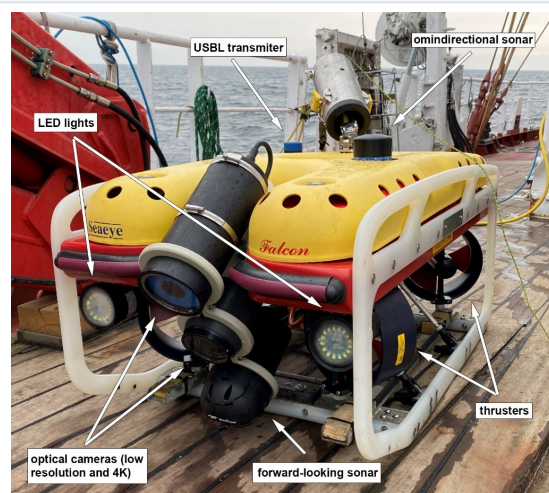
Direct observation using cameras mounted on underwater unmanned platforms.



ROV IDENTIFICATION

ROV identification closes the loop:

- ROVs provide the final verification step after remote sensing.
- Thrusters enable precise motion in X, Y and Z.
- USBL, compass, altimeters and DVL guide the last approach.
- HD or 4K cameras and lights support close inspection in darkness.
- ROVs can also carry acoustic or geophysical sensors.



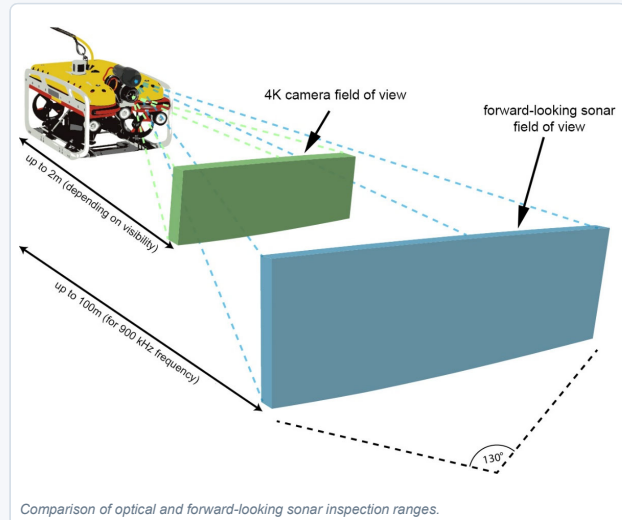
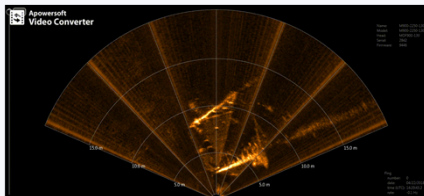
Inspection class ROV: Saab Seeye Falcon with key sensors indicated.



ROV IDENTIFICATION

Acoustic vision versus optical vision

- In turbid water, optics alone may miss small targets until very late.
- Forward-looking sonar extends detection range around the vehicle.
- Acoustic imagery guides the last approach to the object in low-visibility condition.
- Cameras then confirm morphology and condition at short range.

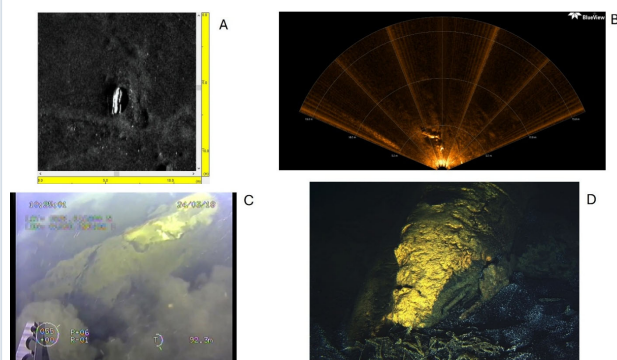


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ROV IDENTIFICATION

Example: KC-250 bomb in the Bornholm Deep - the inspection chain

- Geophysical methods (SSS / SAS + MBES + MAG) first marked the object on the seabed.
- The combined chain reduced uncertainty before intervention.
- ROV's forward-looking sonar localized it under poor visibility conditions.
- Low-resolution and 4K views enabled visual confirmation.
- Periodic ROV observations enables the assessment of the rate of object degradation on the seabed.



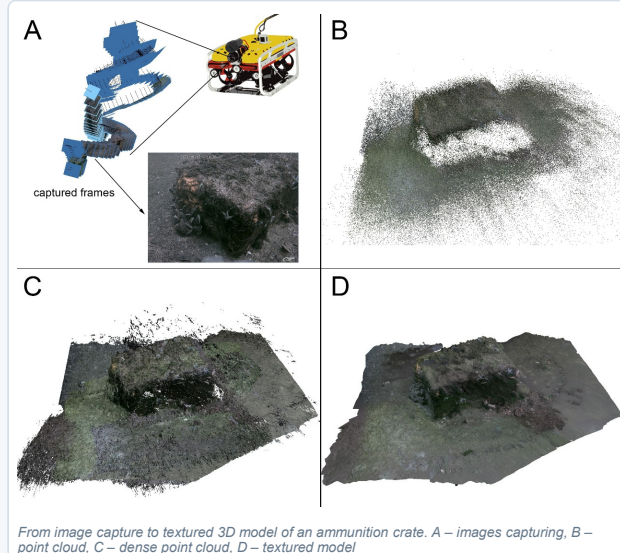
SSS, forward-looking sonar and camera views (SD & 4K) used to identify the KC-250 bomb.

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PHOTOGRAMMETRY

ROV / AUV underwater photogrammetry for 3D documentation:

- Thousands of overlapping images are captured around the target or above the seafloor.
- About 70 - 90% overlap is needed for reliable alignment.
- Processing creates a sparse cloud, dense cloud, mesh and textured model.
- Scale bars or navigation data convert the model to real dimensions.
- In favorable conditions the method can reach millimeter-level accuracy.

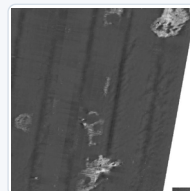


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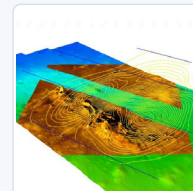
SUMMARY OF GEOPHYSICAL AND DIRECT OBSERVATION

Key takeaways:

- Start wide: SSS, MBES and magnetometer screen large areas quickly.
- For buried munitions, magnetic and subsurface planning must be performed.
- LF-SAS and 3D SBP gives information about semi-buried and buried objects.
- Interpret jointly: each sensor resolves a different part of the problem.
- Confirm late: ROV inspection turns targets into identified objects.
- Document fully: photogrammetry supports measurement and communication.
- Environmental screening gives final confirmation.



Search



Fuse



Document

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Further reading & references:

- **Drap et al., 2015.** *The ROV 3D Project: Deep-Sea Underwater Survey Using Photogrammetry. Application For Underwater Archeology.* ACM Journal on Computing and Cultural Heritage 8 (4), pp. 1 – 24
- **Grabowski et al., 2026.** *Detection and identification of munition in the sea.* In: Beldowski J., Gambin T., Turmus E. (eds) *Hazardous materials on the seabed: Monitoring and Assessment of dumped munition and wrecks in global context.* NATO Science for Peace and Security Series C: Environmental Security (submitted).
- **Hansen et al., 2005.** *Synthetic Aperture Sonar Processing for the HUGIN AUV.* Proceedings of IEEE Oceans 2005 Europe. 2: 1090 – 1094.
- **Holt 2019** *Marine Magnetometer Processing.* 3H Consulting Ltd., Plymouth
- **Shang et al., 2019.** *Obtaining High-Resolution Seabed Topography and Surface Details by Co-Registration of Side-Scan Sonar and Multibeam Echo Sounder Images.* Remote Sensing 11 (12), 1496
- **Song & Choi, 2016** *Underwater 3D Reconstruction for Underwater Construction Robot Base on 2D Multibeam Imaging Sonar.* Journal of Ocean Engineering and Technology 3 (30), pp. 227 – 233

Environmental chemical screening



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01 – Introduction

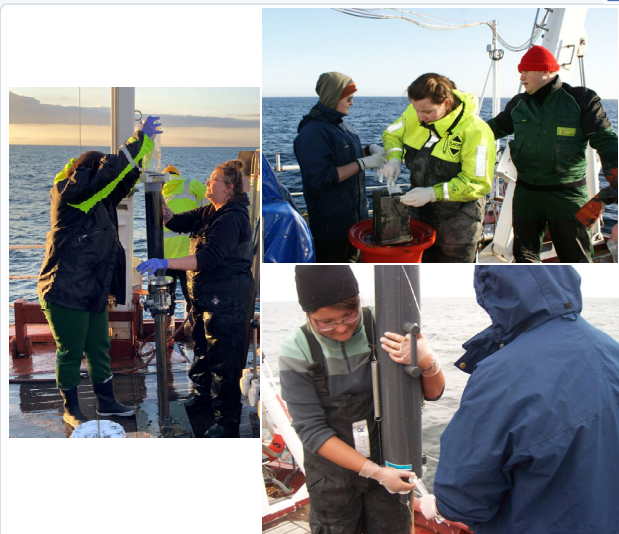
From detected objects to environmental impact.



ENVIRONMENTAL CHEMICAL SCREENING

From detection to environmental assessment:

- Geophysical detection confirms an object visually.
- Detection alone does not prove environmental threat.
- Ammunition presence $\neq$ automatic chemical release.
- Screening checks chemical release and spread in water.



Sampling activities (source: Jędruch; Korejwo)



ENVIRONMENTAL CHEMICAL SCREENING

Why environmental screening is needed:

- WWII ammunition corrodes slowly and unevenly.
- Corrosion processes are highly heterogeneous and difficult to predict quantitatively.
- Similar-looking objects can have different contamination.
- Only chemical monitoring shows real ecological risk.

Key environmental questions:

- Are toxic chemicals released ?
- Are chemicals available to organisms?
- How far does contamination spread?
- Are there biological effects from exposure?



Dumped objects (source: frontiersin.org; J. Ulrich)



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02 – Target compounds and analytes

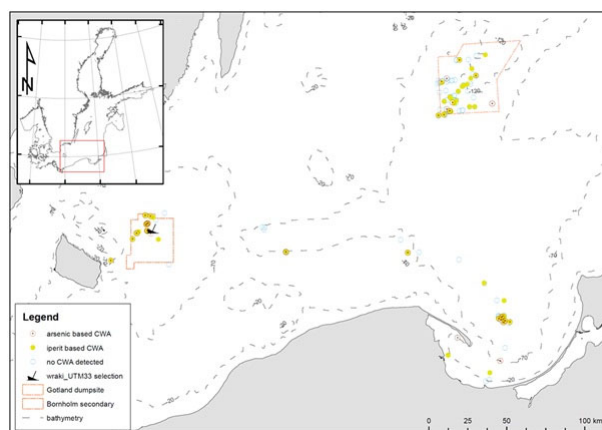
What are we actually looking for?



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Main classes of contaminants:

- **Sulfur mustard and its degradation products** – analyzed as intact chemical or derivatives (e.g., Thiodiglycol, Thiodiglycol sulfoxide, 1,4-Dithiane).
- **Phenylarsenic compounds** (e.g., Adamsite, Clark I/II, Triphenylarsine) – analyzed intact or as oxidized or modified forms.
- **Other chemical warfare agents and explosives** – including CN (α -Chloroacetophenone), Lewisites, and nitroaromatic explosives (e.g., TNT, dinitrotoluenes).
- Sulfur mustards and arsenic compounds are common in Baltic Sea ammunition.

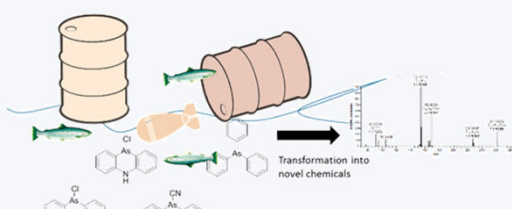


Detection of CWA in the Baltic Sea region (source: M. Szubska)

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Importance of degradation products:

- Primary chemical agents rarely found in water or sediment.
- They break down through hydrolysis, oxidation, biological processes.
- Corrosion promotes transformation of original agents into stable degradation products detectable in sediments and water.
- Environmental monitoring therefore relies primarily on transformation markers rather than parent compounds.



Proposed structure and elemental composition	Measured mass	Mass difference [ppm]	R _t [min]	Relative abundance of [M+H] ⁺ +2 peak (³³ S)*
PDCA-related chemical				
 dimethylphenylarsine sulfide C ₈ H ₁₂ AsS ⁺	214.98701	0.02052	1.96	3.97
Adamsite-related chemicals				
 10-hydroxy-5H-phenarsazinine-10-one C ₁₂ H ₁₁ AsNOS ⁺	291.97723	0.05111	2.57	4.44
 10-methyl-5H-phenarsazinine-10-one C ₁₃ H ₁₃ AsNS ⁺	289.99792	0.02315	2.92	4.16
Clark-related chemicals				
 diphenylthiarsinic acid C ₁₂ H ₁₂ AsOS ⁺	278.98196	0.10915	3.30	3.82
 methylphenylarsine sulfide C ₁₀ H ₁₄ AsS ⁺	277.00275	0.07746	3.41	3.93
Triphenylarsine-related chemical				
 triphenylarsine C ₁₈ H ₁₅ AsS ⁺	339.01842	0.30191	4.53	4.24

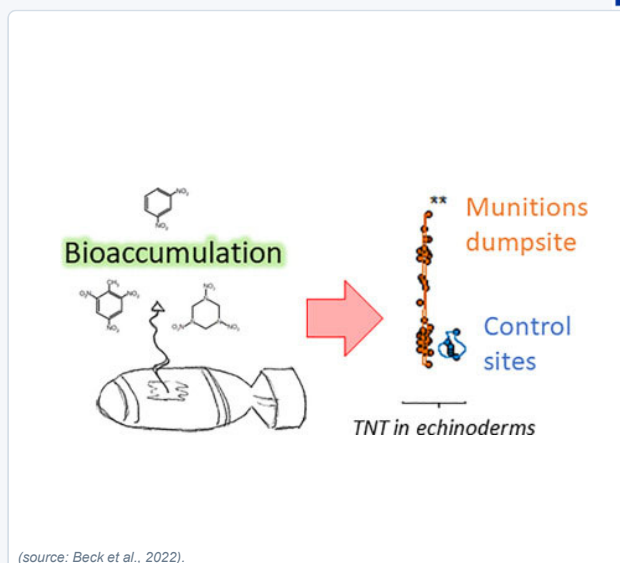
Proposed structures of novel sulfur-containing phenylarsenic chemicals in sediment (source: Niemikoski et al., 2020)

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ENVIRONMENTAL CHEMICAL SCREENING

Explosive Compounds in Marine Environments

- Conventional explosives such as TNT, RDX, and DNB are commonly detected near dumped munitions sites in marine environments.
- Transformation products (e.g., amino-DNTs, ADNTs, DANTs) often dominate environmental samples and serve as key monitoring markers.
- Explosives are highly toxic and persistent, posing risks to aquatic organisms, terrestrial plants, and potentially humans.
- Explosive compounds can accumulate in marine biota, posing ecotoxicological risks and potential food-web transfer.
- Environmental concentrations are typically low but widespread, indicating chronic contamination near disposal areas.



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03 – Sampling: matrices and safety

Sampling near hazardous legacy objects.



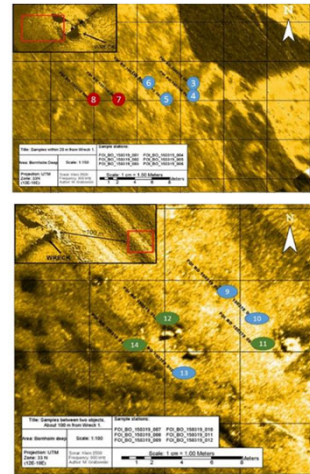
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ENVIRONMENTAL CHEMICAL SCREENING



Sampling design around munitions:

- Chemical release is typically localized near breached munitions
- Exposure is greater for objects lying in the water column compared with sediment-buried munitions.
- Hydrodynamics and water mixing strongly influence contaminant dispersion.
- Radial sampling around suspected objects ensures safe distance, accurate contamination gradients, and environmental representativity.
- Includes both direct-contact and reference zones.



Sampling positions near the wreck in Bornholm Deep (source: Söderström et al., 2017).

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ENVIRONMENTAL CHEMICAL SCREENING



Environmental matrices:

- Multiple environmental matrices are required to capture different exposure pathways.
- **SEDIMENTS:** Ammunition has been on the seabed for decades, with chemicals accumulating or migrating into sediments, making them a key contamination reservoir.
- **PORE WATER:** Dissolved or transformed chemicals in pore water represent the bioavailable fraction, posing immediate ecological risk.
- **ORGANISMS:** Benthic and local organisms accumulate contaminants, showing bioaccumulation and trophic transfer, which can impact humans and nearby species.



Sampling activities (source: Jędruch)

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ENVIRONMENTAL CHEMICAL SCREENING

Safety and operational constraints:

- Specialized PPE and strict decontamination protocols are mandatory for all personnel.
- The appropriate scope of information should be made available to different stakeholder groups interested in the topic, such as the fishing community and policymakers.
- Standard guidelines should be followed when working with submerged ammunition.
- Remotely operated vehicles are often used instead of divers.



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04 – From field to laboratory analysis

From seabed samples to chemical evidence.



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On-board screening:

- On-board analysis prevents sample alteration during transport
- Minimizing oxidation of sensitive chemicals.
- Early detection supports adaptive sampling near active release zones.
- Munition-derived compounds occur at ultra-trace concentrations due to slow dissolution and rapid dilution.
- Supports adaptive sampling close to suspected contamination sources
- Rapid screening helps identify freshly exposed or actively corroding objects.

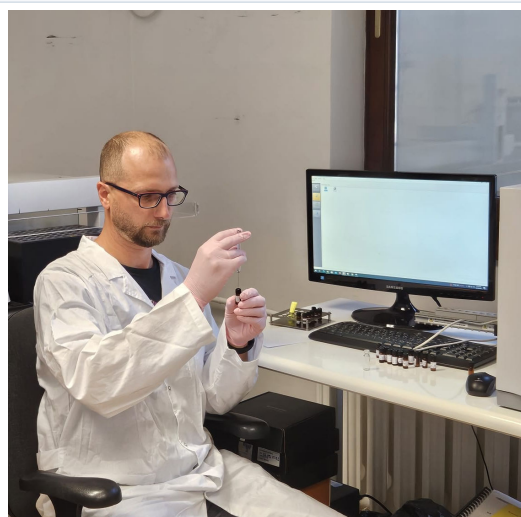


Examples of equipment used on-board (Griffin G510, HAPSITE Portable GC-MS, CE-C'D)
 (source: Szubska; Jędruch)

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Laboratory analysis:

- Predicted concentrations near munitions are often in the ng L^{-1} range, requiring highly sensitive analytical methods.
- Slow dissolution rates demand trace-level chemical detection strategies.
- Advanced chromatography + mass spectrometry (GC-MS/MS, LC-MS/MS).
- Laboratory confirmation is essential for distinguishing true contamination from background signals.



ICP-MS analysis (source: Jędruch)

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05 – Limitations and challenges

Scientific uncertainty meets environmental policy.



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ENVIRONMENTAL CHEMICAL SCREENING

Environmental limitations:

- Baltic Sea has low oxygen zones and low biological activity.
- Patchy contamination complicates regional risk assessment.
- Corrosion rates vary widely depending on oxygen availability, burial conditions, and material composition.
- Biological growth and mineral concretions may either accelerate or inhibit corrosion.
- Large uncertainties remain in predicting long-term chemical release from submerged munitions.



Dumped munition (source: IOPAN, FFI)



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Analytical challenges:

- Lack of certified reference materials.
- Unknown breakdown products present.
- Need to detect ultra-trace levels in complex matrices.
- Rapid field methods are available but still require optimization for environmental monitoring.
- Analyses of CWA can only be conducted by certified laboratories with special permits.
- Laboratories must be intercalibrated to ensure reliable chemical analyses.



Laboratory activities (source: Korejwo)

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Monitoring vs Remediation:

- Removing ammunition may release chemicals suddenly.
- Removal of sea-dumped munitions usually happens only when there is an immediate safety risk to people, ships, or infrastructure.
- Environmental risks alone do not require authorities to remove munitions, and environmental agencies are often not involved in the process.
- A common method is “blow-in-place”, where munitions are exploded underwater — it is cheaper but can seriously harm marine life and the environment.
- Scientific projects are working to develop and organize safer procedures for removing sea-dumped munitions.

Interreg
Baltic Sea Region
SUSTAINABLE WATERS
MUNIMAP

Co-funded by
the European Union

Interreg
North Sea
REMARCO

Co-funded by
the European Union

 CAMMera
Co-funded by
the European Union

 MUNI
RISK
Co-funded by
the European Union

Logos of projects working on sea-dumped munitions.

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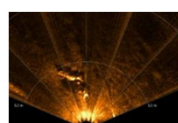
Further reading & references:

- **Beck et al., 2018.** *Spread, behavior, and ecosystem consequences of conventional munitions compounds in coastal marine waters.* *Frontiers in Marine Science* 5, 141.
- **Beck et al., 2022.** *Explosives compounds from sea-dumped relic munitions accumulate in marine biota.* *Science of the Total Environment* 806, 151266.
- **Beldowski et al., 2014.** *CHEMSEA Findings.* Gdańsk: Institute of Oceanology, Polish Academy of Sciences. ISBN 978-83-936609-1-9.
- **Beldowski et al., 2016.** *Chemical Munitions Search & Assessment – An evaluation of the dumped munitions problem in the Baltic Sea.* *Deep Sea Research Part II: Topical Studies in Oceanography* 128, 85-95.
- **Beldowski et al., 2018.** *Towards the monitoring of dumped munitions threat (MODUM): A study chemical munitions dumpsites in the Baltic Sea.* Springer, Dordrecht.
- **Chatterjee et al., 2017.** *Common explosives (TNT, RDX, HMS) and their fate in the environment: Emphasizing bioremediation.* *Chemosphere* 184, 438-451.
- **Gericke et al., 2026.** Legal aspects of marine munitions management in the Baltic Sea region – Volume I – Current status of national and international legislation. Umweltbundesamt, Dessau-Roßlau, Germany.
- **HELCOM, 2013.** *Chemical munitions dumped in the Baltic Sea: Report of the ad hoc Expert Group.* Baltic Sea Environment Proceedings. Helsinki Commission.
- **Marine Munitions in the Sea et al., 2025.** Fact sheets: Munitions in the Sea. Mmine-SwEEPER Project, European Union Horizon 2020.
- **Niemikoski et al., 2020.** *Identification of degradation products of sea-dumped chemical warfare agent-related phenylarsenic chemicals in marine sediment.* *Analytical Chemistry* 92, 4891-4899.
- **Valdez et al., 2018.** *Analysis of chemical warfare agents by gas chromatography0-mass spectrometry: methods for their direct detection and derivatization approaches for the analysis of their degradation products.* *Reviews in Analytical Chemistry* 37, 20170007.

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Key takeaways:

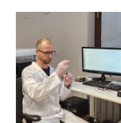
- Detection identifies dumped munitions; environmental screening determines their impact.
- Not every munition releases contaminants, therefore chemical verification is essential.
- Degradation products are often better indicators than original warfare agents.
- Environmental data directly support risk assessment and policy decisions.
- Environmental chemistry transforms detection into environmental understanding.



Detection



Sampling



Analysis



Decision

60

Thank you



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MMinE-SwEEPER

Milestone Report

Milestone No. 22: Digital news and newsletter and social media



Funded by
the European Union

Authors | Samar Ensenbach + Inken Preuss

Contributing organisations:



DOCUMENT TRACKING DETAILS

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Grant Agreement	No. 101167839
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Duration	31 March 2028
Project Coordinator	GEOMAR Helmholtz Centre for Ocean Research Kiel

Milestone Information

Milestone Name	Digital news and newsletter and social media
Milestone Number	22
Work Package (WP)	12
Related Task (s)	12.2
Milestone Beneficiary	GEOMAR
Author(s)	Samar Ensenbach, Inken Preuss
Due date	31.01.2025
Submission date	30.01.2025
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Dissemination level	Public

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Digital Project News

The following steps have been taken to ensure that all stakeholders are kept informed of the progress of the project:

- A newsletter registration option has been added to our website, and the first issue of the newsletter has been distributed to subscribers.
- A dedicated LinkedIn account and LinkedIn forum 'Munitions in the Sea' has been launched
- Our first project news articles have been published on the website and social media channels

Newsletter

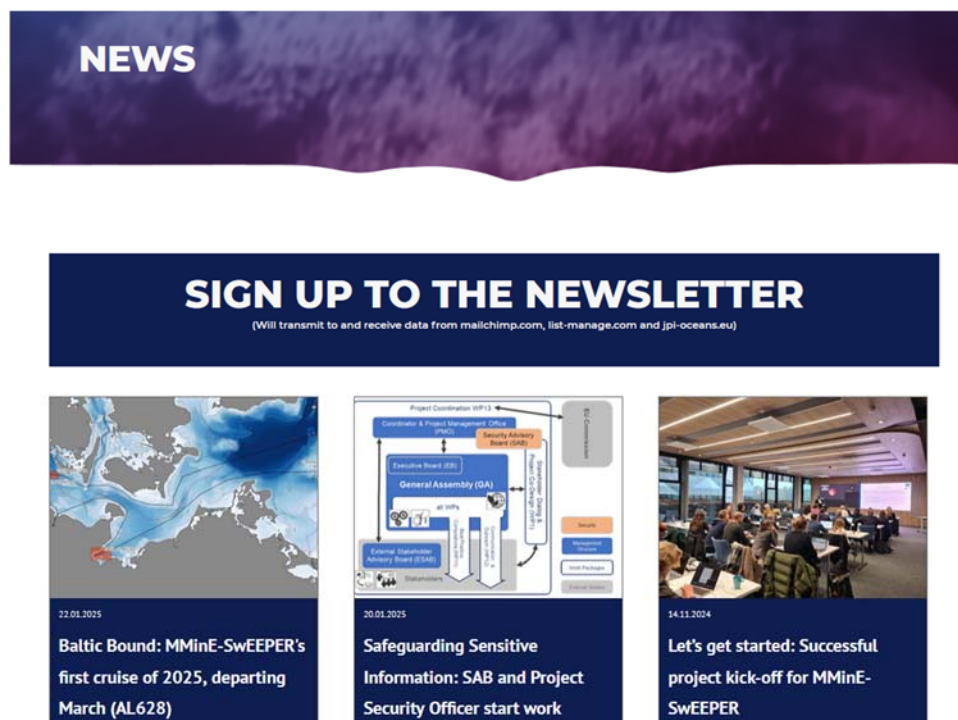
Published every two months, the MMinE-SWEEPER newsletter aims to keep stakeholders informed about the project's latest developments, achievements, and news, as well as providing updates on the broader topic of marine munitions.

The registration option for the newsletter has been integrated into the [project website](#) and the [JPI Oceans MMinE-SwEEPER](#) page making it easy for stakeholders and interested persons to sign up and stay up-to-date with the latest news.

The first newsletter was created by JPIO using mailchimp and sent to subscribers from 13 countries on 30 January 2025. It featured three recent news stories from our project website, and also linked to two relevant news articles from other munition projects. The first newsletter is included as an appendix to this report.

News on the project website

The first project news has been published on the [project website](#). The following screenshots were taken from https://mminesweeper-munition.eu/03_news/ on 29.01.2025 10:40-10:50.



News items are displayed as individual tiles, which open to reveal the full article when clicked.

Let's get started: Successful project kick-off for MMinE-SwEEPER

On 13-14 November 2024 the EU funded project MMinE-SwEEPER launched with a kick-off meeting at the GEOMAR Helmholtz Centre for Ocean Research Kiel. With a budget of almost six million euros, the project aims to develop safe strategies for removing unexploded ordnance from European waters. The meeting was attended by 43 participants from 20 partner organisations coming from nine European countries and focused on collaboration, sharing insights into key work packages and setting the stage for future efforts.

The MMinE-SWEEPER project officially launched with a kick-off meeting on 13 and 14 November 2024 at the GEOMAR Helmholtz Centre for Ocean Research in Kiel. It brought together 43 participants from 20 partner organisations across nine European countries. This marked the start of an ambitious initiative, funded by the European Commission through Horizon Europe with €5.9 million, which will run for 42 months, and aims to tackle the challenges posed by sea-dumped munitions in European waters.

Safeguarding Sensitive Information: SAB and Project Security Officer start work

The MMinE-SwEEPER project, which focuses on locating and detecting marine munitions, has established a Security Advisory Board to address security concerns related to sensitive information. The Board, chaired by a Project Security Officer, has begun meeting with partners to ensure the safe handling and distribution of sensitive information, with additional consultations planned to solidify the project's security framework.

Focusing on locating and detecting marine munitions MMinE-SwEEPER faces security concerns due to the sensitive nature of the information involved. To address these concerns, a Security Advisory Board has been established to advise the project's Executive Board and External Stakeholder Advisory Board on the handling of sensitive information. The Board, chaired by a designated Project Security Officer, ensures compliance with EU regulations on classified information and oversees the distribution of security-relevant data to external parties.

In particular, the Security Officer and the members of the Advisory Board were already appointed during the

Baltic Bound: MMinE-SwEEPER's first cruise of 2025, departing March (AL628)

Hands-on field research is a critical component of our project, enabling us to advance technology and conduct in-depth ecological investigations, as outlined in work packages 3, 4, 6, 8, and 10. On March 13th, we'll be embarking on research vessel ALKOR to conduct crucial fieldwork in German and Danish waters. Over the course of the cruise, we'll be testing cutting-edge mapping techniques, deploying intelligent AUVs, and measuring explosive concentrations in the Baltic Sea, with a focus on the area around and west of Bornholm. This collaborative effort will also support the objectives of the CONMAR and MUNI-RISK projects, with a dedicated week of research in Lübeck Bay, Germany.

On 13 March 2025, we will embark on a 14-day research cruise from Kiel to Kiel. This is the first of three granted cruises within the German funded cruise proposal COMMS (CONMAR | MUNI-RISK | MMinE-SWEEPER) submitted by GEOMAR in Kiel. The cruise will support different aspects of the three projects. For MMinE-SwEEPER, the main objectives are technical tests and trials and data collection for AI-based object detection and water analyses for a more conclusive data set on explosive chemicals in the western Baltic Sea (Figure 1).

News on Social Media

Instagram

The official kick-off of the MMinE-SwEEPER project was first announced on social media via the CONMAR project's Instagram account, managed by Samar Ensenbach (GEOMAR). This platform is mainly used to inform the German interested public about the topic of sea-dumped munitions.

The following screenshot was taken from https://www.instagram.com/p/DCgslkzCMYz/?utm_source=ig_web_button_share_sheet&igsh=MzRIODBiNWFIZA== on 28.01.2025 at 10:30.

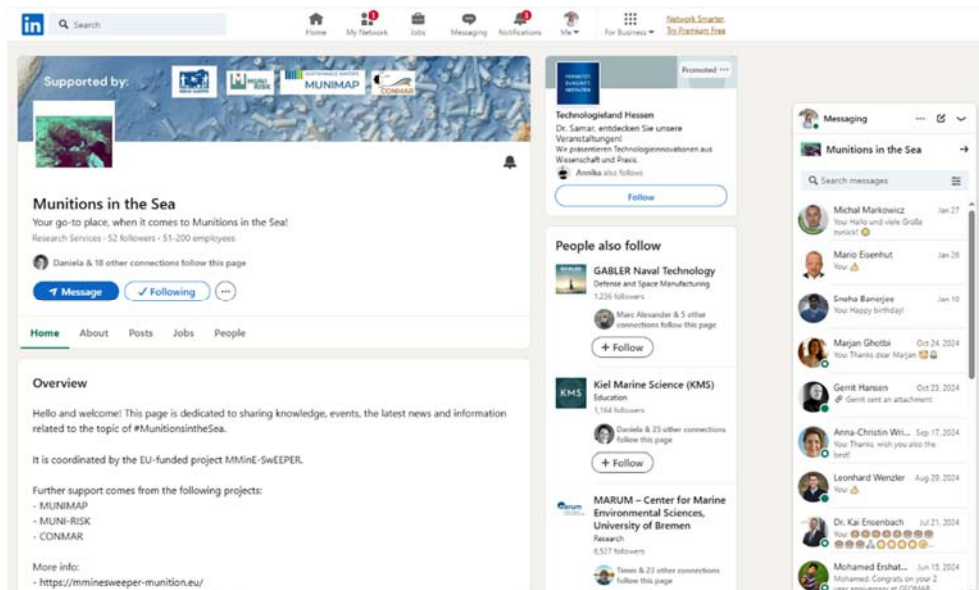


LinkedIn Account 'Munitions in the Sea'

In order to reach beyond the German interested public, MMinE-SwEEPER's communication team identified a LinkedIn account as the most suitable platform for disseminating information and updates related to the project's topic. The page, which will be coordinated by MMinE-SwEEPER, will also receive support and contributions from the EU-funded projects MUNI-RISK and MUNIMAP, as well as the German national project CONMAR.

The main LinkedIn page is called Munitions in the Sea and it dedicated to publishing the latest news, developments, events and information related to the topic of marine munitions.

The following screenshots of the LinkedIn page and the first post were taken from <https://www.linkedin.com/company/munitions-in-the-sea/?viewAsMember=true> on 28.01.2025 at 11:00.



Munitions in the Sea
52 followers
4d • Edited •

Welcome to the MunitionsintheSea LinkedIn page!
We invite everyone interested in this topic to stay informed about the latest developments, events and news surrounding the crucial topic of munitions in the sea. Use [#MunitionsintheSea](#) or link directly to this channel to help strengthen and support visibility for this important issue.

For those who want to network more closely with the community, exchange ideas, and dive deeper into discussions, we've created the Forum: Munitions in the Sea—a dedicated space to collaborate, share knowledge, and tackle challenges together.
Join us in creating awareness and driving meaningful progress!

Link to the Forum: <https://lnkd.in/dwRx5GC5>

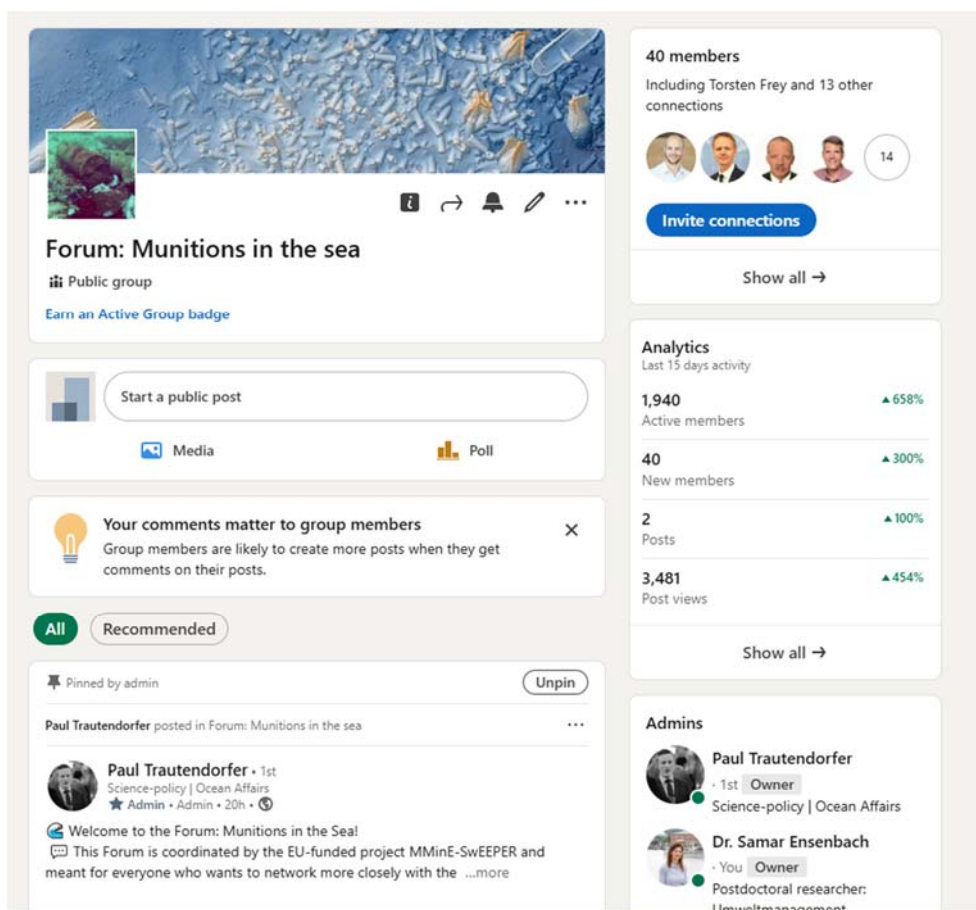
[#mminesweeper](#) [#munitionsinthesea](#) [#emfaf](#) [#munirisk](#) [#munimap](#)
[#sustainableoceans](#)

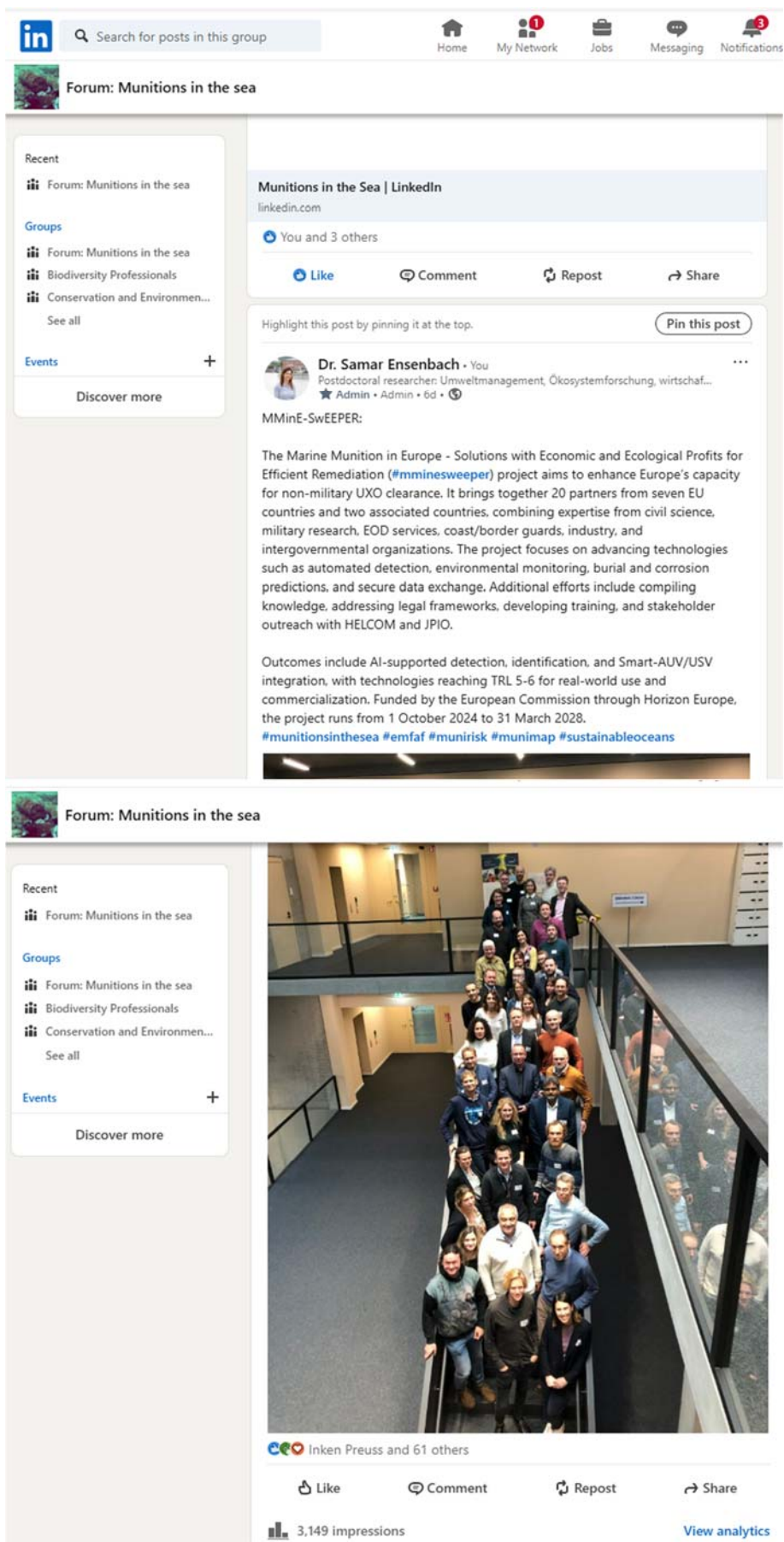


LinkedIn group 'Forum: Munitions in the Sea'

To complement the LinkedIn page 'Munitions in the Sea', a new LinkedIn group called 'Forum: Munitions in the Sea' has been launched. This group serves as a platform for stakeholders, experts, decision-makers, and the interested public to communicate, discuss, participate in polls, and interact with one another. Within hours of its creation, the forum gained significant traction, with over 3,100 views. The social media accounts are managed by GEOMAR (led by Samar Ensenbach) in collaboration with JPI Oceans (co-administered by Paul Trautendorfer). The first news post introduced the MMinE-SwEEPER project, setting the stage for future updates and discussions.

The following screenshots of the LinkedIn group were taken from <https://www.linkedin.com/groups/10047351/> on 28.01.2025 at 10:45.





Forum: Munitions in the sea

Search for posts in this group

Home My Network Jobs Messaging Notifications

Munitions in the Sea | LinkedIn
linkedin.com

You and 3 others

Like Comment Repost Share

Highlight this post by pinning it at the top. [Pin this post](#)

Dr. Samar Ensenbach • You
Postdoctoral researcher: Umweltmanagement, Ökosystemforschung, wirtschaf...
★ Admin • Admin • 6d •

MMinE-SwEEPER:

The Marine Munition in Europe - Solutions with Economic and Ecological Profits for Efficient Remediation ([#mminesweeper](#)) project aims to enhance Europe's capacity for non-military UXO clearance. It brings together 20 partners from seven EU countries and two associated countries, combining expertise from civil science, military research, EOD services, coast/border guards, industry, and intergovernmental organizations. The project focuses on advancing technologies such as automated detection, environmental monitoring, burial and corrosion predictions, and secure data exchange. Additional efforts include compiling knowledge, addressing legal frameworks, developing training, and stakeholder outreach with HELCOM and JPIO.

Outcomes include AI-supported detection, identification, and Smart-AUV/USV integration, with technologies reaching TRL 5-6 for real-world use and commercialization. Funded by the European Commission through Horizon Europe, the project runs from 1 October 2024 to 31 March 2028.

[#munitionsinthesea](#) [#emfaf](#) [#munirisk](#) [#munimap](#) [#sustainableoceans](#)

Forum: Munitions in the sea

Recent

Groups

Forum: Munitions in the sea
Biodiversity Professionals
Conservation and Environmen...
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Events +

Discover more

Inken Preuss and 61 others

Like Comment Repost Share

3,149 impressions [View analytics](#)

Common hashtags

To optimize communication and outreach efforts, the three EU-funded projects MMinE-SwEEPER, MUNI-RISK, and MUNIMAP have jointly established a communication group. This collaborative initiative aims to not only facilitate internal coordination but also to bundle and amplify the projects' external communication. A first outcome of this effort is the adoption of a common hashtag, **#munitionsinthesea**, which will be used in conjunction with project-specific hashtags (#mmminesweeper, #munirisk, #munimap, #emfaf). By harmonizing their social media presence and messaging, the three projects seek to increase their visibility and impact among stakeholders, policymakers, and the broader scientific community.

Appendix: First Newsletter

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Newsletter #1 | January 2025

Welcome to the MMinE-SWEEPER Newsletter!

We are excited to launch our bi-monthly newsletter, designed to keep you informed about the latest news, updates, and achievements from the MMinE-SWEEPER project. As a stakeholder, you will receive regular insights into our progress, milestones, and upcoming events, helping you stay up-to-date and connected with our community.

With MMinE-SWEEPER, we want to come closer to a European solution for the removal of unexploded ordnance from the sea. With a budget of almost six million euros from a EU Horizon Europe Grant, MMinE-SWEEPER will work over the next three and a half years, bringing together 20 international partners to develop innovative and safe solutions to this urgent environmental problem in European waters.

[Link to Project Webpage](#)

MMinE-SwEEPER



The MMinE-SwEEPER consortium.

On 13-14 November 2024 the EU-funded project MMinE-SwEEPER kicked off with a meeting at the GEOMAR Helmholtz Centre for Ocean Research Kiel. The project aims to develop safe strategies for removing unexploded ordnance from European waters. The meeting was attended by 43 participants from 20 partner organisations coming from nine European countries and focused on collaboration, sharing insights into key work packages and setting the stage for future efforts.

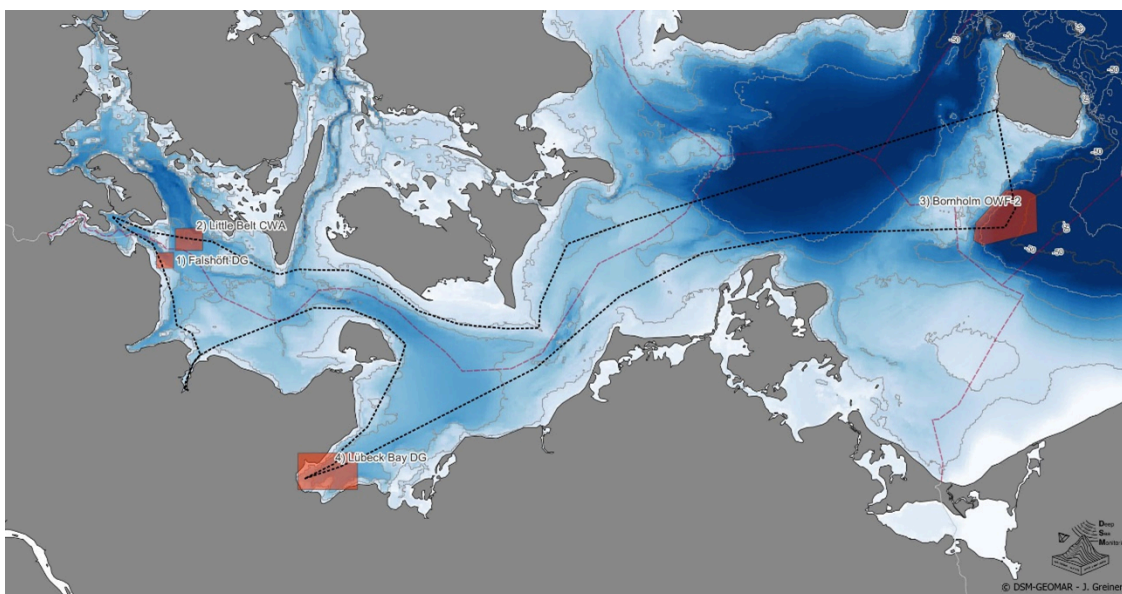
[Read more](#)

Safeguarding Sensitive Information: SAB and Project Security Officer start work

The MMinE-SwEEPER project, which focuses on locating and detecting marine munitions, has established a Security Advisory Board (SAB) to address security concerns related to sensitive information. The Board, chaired by a Project Security Officer, has begun meeting with partners to ensure the safe handling

[Read more](#)

Baltic Bound: MMinE-SwEEPER's first cruise of 2025, departing March (AL628)



Planned track of research cruise AL628 (black line) with dedicated working areas in German and Danish waters.

Hands-on field research is a critical component of our project, enabling us to advance technology and conduct in-depth ecological investigations, as outlined in work packages 3, 4, 6, 8, and 10. On 13 March 2025, we will embark on research vessel ALKOR to conduct crucial fieldwork in German and Danish waters. Over the course of the cruise, we will be testing cutting-edge mapping techniques, deploying intelligent autonomous underwater vehicles (AUVs), and measuring concentrations of explosives in the Baltic Sea, with a focus on the area around and west of Bornholm, Denmark. This collaborative effort will also support the objectives of the CONMAR and MUNI-RISK projects, with a dedicated week of research in Lübeck Bay, Germany.

News from other #MunitionsintheSea projects

Dumped Munition Risk Project Surfaced



Representatives of the MUNI-RISK project partners: Aarhus University (lead), Bornholm Regional Municipality, CBSS, GEOMAR, HELCOM, and IOPAN.

The MUNI-RISK project, an EU-funded initiative addressing the environmental and safety risks posed by submerged munitions in the Baltic Sea, has officially launched and had its kick-off meeting in Roskilde, Denmark on 14-16 January 2025. The project is led by Aarhus University.

Running from 2024 to 2027, the MUNI-RISK project brings together leading scientists, practitioners and policymakers to develop solutions for managing munitions in the sea.

CONMAR: Goodbye 1st phase - Welcome 2nd phase

On 2-3 December 2024, the CONMAR-1 final meeting and the kick-off meeting for the second phase took place at GEOMAR Helmholtz Centre for Ocean Research in Kiel with the participation of 25 CONMAR colleagues. The findings of the last three years - including the research gaps identified - were discussed in depth. Planning for the second phase was also on the agenda: What will happen in CONMAR-2? Read more on their website.

[Read more](#)

[Stay up to date](#)



Stay up to date and get the latest news on the broader topic of munitions in the sea by following our new LinkedIn page.

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ideas and dive deeper into discussions, join the [Forum: Munitions in the Sea](#).

Follow us



Knowledge Portal Munitions in the Sea

For further information around marine munitions in Europe check out the JPI Oceans Knowledge Portal Munitions in the Sea.

[Click here](#)

Get involved

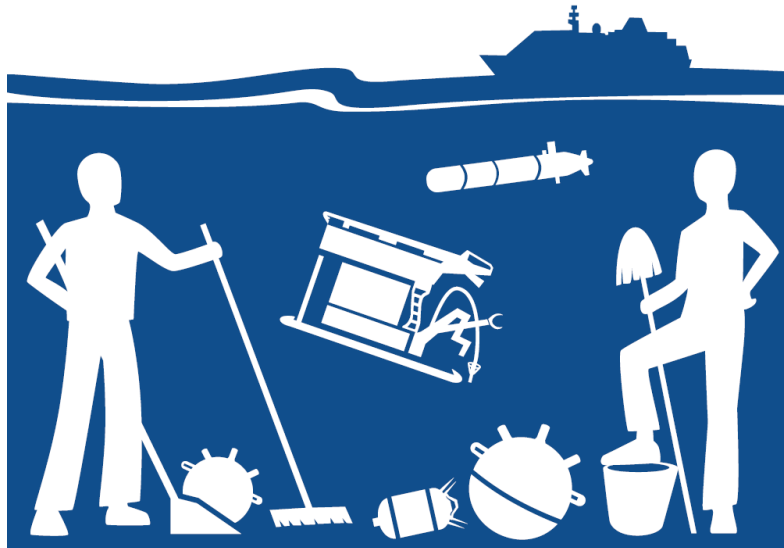
Contact:
mmine-sweeper@geomar.de

Share what's new

Contact:
knowledge-munition@jpi-oceans.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101167839.

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MMinE-SwEEPER

Milestone Report

Milestone No. 23: Project Flyer



Funded by
the European Union

Authors | Inken Preuss

Contributing organisations:



DOCUMENT TRACKING DETAILS

Project Information

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Project title	Marine Munition in Europe - Solutions with Economic and Ecological Profits for Efficient Remediation
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Grant Agreement	No. 101167839
Starting date	1 October 2024
Duration	31 March 2028
Project Coordinator	GEOMAR Helmholtz Centre for Ocean Research Kiel

Milestone Information

Milestone Name	Project Flyer
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Related Task (s)	Task 12.2
Milestone Beneficiary	GEOMAR
Author(s)	Inken Preuss
Due date	31.05.2025
Submission date	26.05.2025
Type of milestone	
Dissemination level	PU

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Disclaimer

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Project Flyer	6
Dissemination	6
Conclusion	6
Appendix	6

Objective

The development of the project flyer contributes to Task 12.2 on promoting the project and its topic. As planned, a flyer has been produced for active dissemination and will be updated regularly to reflect project progress.

This activity supports the overall dissemination goals by raising awareness at different levels, communicating key aspects of marine munition and project results, and facilitating knowledge transfer to relevant stakeholders across Europe.

Project Flyer

The first project flyer has been created in May 2025 using the design platform Canva, ensuring a clear layout and visually consistent presentation aligned with the project's communication materials. It contains basic project information alongside a dedicated section highlighting the importance of addressing marine munitions in Europe. The flyer also includes key objectives, methodological approach, and expected outcomes. Partner logos and the required EU funding acknowledgment are featured in compliance with the project's visual identity guidelines. The full version of the flyer is provided in the Appendix.

Dissemination

The flyer was first used in a few printed copies and digitally via a QR code linking to the project website, where it can be downloaded. This approach was initially applied during the UNOC Side Event in Nice 2025 and the Kiel Munition Clearance Week 2025 and has since been employed at other dissemination activities, reaching a broad range of stakeholders.

Conclusion

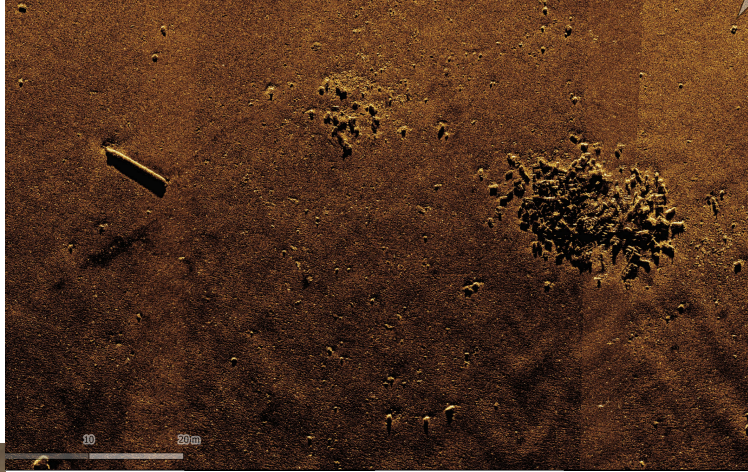
This milestone has been successfully achieved with the development and availability of the first version of the project flyer. It will be updated annually (M24 and M25). The flyer constitutes an important dissemination tool and will continue to support the visibility of the project and consistent communication of its objectives and results.

Appendix

Full Version of the Flyer

CONSORTIUM PARTNERS

21 partners from 7 EU and 2 associated countries bring experience and capabilities from the civil science community, EOD services and coast/border guards, military research, industry, and intergovernmental organizations into the project.



MORE INFORMATION

Duration October 2024 – March 2028

Funding €5.9 million

Website mminesweeper-munition.eu

LinkedIn #MunitionsintheSea
<https://www.linkedin.com/company/106285095/>

E-mail mmine-sweeper@geomar.eu



MMinE-SwEEPER

Marine Munition in Europe –
Solutions with Economic and
Ecological Profits for
Efficient Remediation

COORDINATED BY  **GEOMAR**



AARHUS UNIVERSITY

FFI

Norwegian Defence
Research Establishment



VLIZ
pioneer in marine science



Consiglio Nazionale
delle Ricerche



MMinE-SwEEPER is funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.



MMinE-SwEEPER is a Horizon Europe project that has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101167839.

WHY WE SHOULD ADDRESS MARINE MUNITIONS IN EUROPE

1. **Marine Safety** of offshore infrastructure and maritime traffic (Blue Economy, Green Energy)
2. **Security Risks** through misuse of munitions
3. **Environmental Concerns** from pollution, especially from conventional munitions
4. **Citizen Safety** due to direct effects of toxic chemicals, accidental detonation, or physical burns)

Munitions are the only environmental pressure that can be entirely solved by physical removal. Unlike climate change, marine munition clearance does not require a global collective effort.

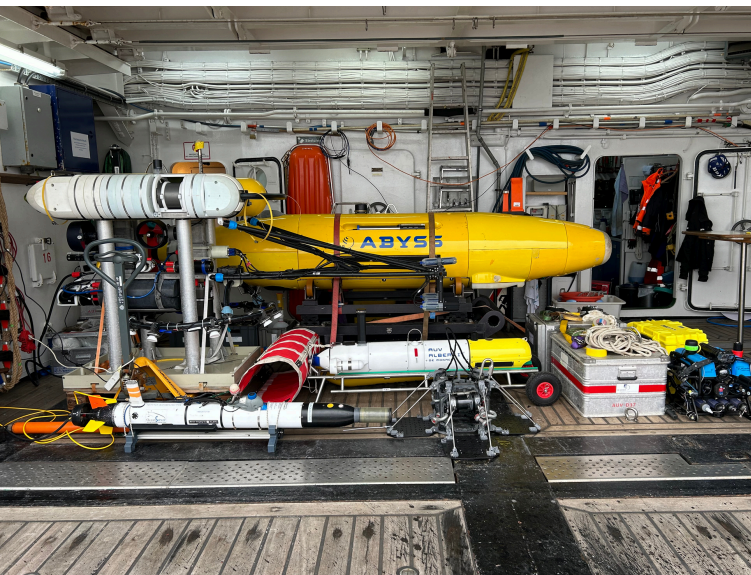


ENHANCING EUROPE'S CAPACITY FOR CLEARANCE

MMinE-SwEEPER puts a strong focus on specific technological developments, and on stakeholder dialog, transferring and sharing knowledge across Europe.

MMinE-SwEEPER works on

- Automated UXO detection, AI-supported identification
- Environmental monitoring, corrosion/burial prediction
- Smart integration of AUVs/USVs
- Perform trials and use-case surveys around Europe
- Secure data exchange
- Legal framework analysis
- Knowledge compilation
- Stakeholder dialog and knowledge transfer



EXPECTED OUTCOME

Technologies developed will reach Technology Readiness Level (TRL) 5-6, making them ready for field testing and paving the way for commercialization.

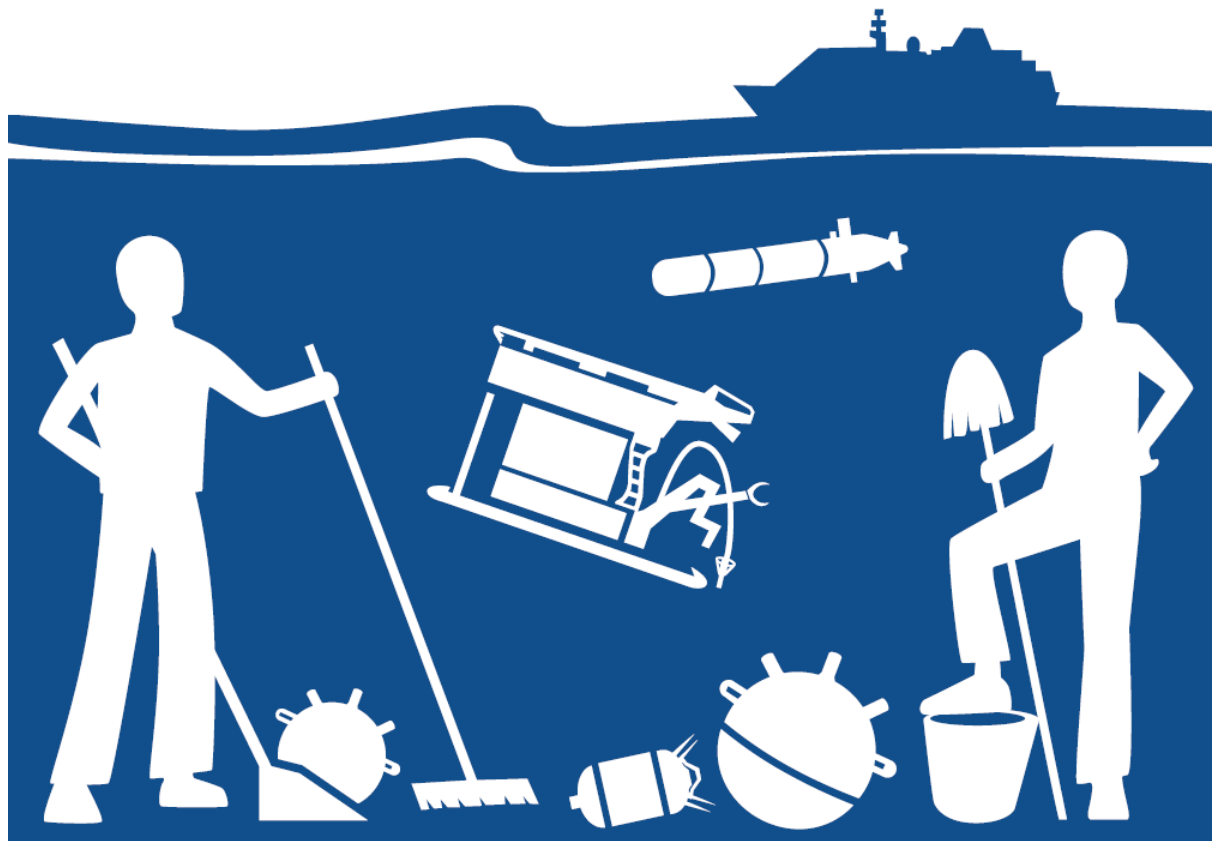
The outcomes are explicitly targeted for EU-wide dissemination, in order to increase cooperation at and between all levels of the target groups. MMinE-SwEEPER updates the leading source of information on marine munitions in Europe:

[The JPI Oceans Knowledge Portal Munitions in the Sea.](#)

PROJECT EVENTS IN 2025

- Jun** UNOC2025 Nice Side Event
- Jun** Booth and Stakeholder Workshop at Kiel Munition Clearance Week
- Jul** Test Cruise Baltic Sea
- Oct** Research Cruise Baltic Sea
- Nov** Stakeholder Workshop





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