PROJECT TITLE

Professional intelligent munitions assessment using 3D reconstructions and Bayesian Neural Networks

PRIORITY AREA

PA3: Automation, sensors, monitoring and observations

SUBTOPIC

PA3: Technologies for detection and removal of munition

PROJECT DURATION	TOTAL REQUESTED FUNDING	TOTAL COSTS
36 Months	1197000 €	1641000 €

CONSORTIUM

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KEYWORDS

Supplementary keywords	Munition, Data Management, Photogrammetry, Bayesian Networks, Artificial Intelligence

ABSTRACT

The "Blue Growth" strategy of the European Union indicates great potential for an expansion of offshore economic development. The presence of large amounts of submerged munitions (1.6 million tons are expected in German waters alone) constitutes a major obstacle for the sustainable economic use of the European seas. Due to increasing offshore activities the frequency of munitions encounters is bound to increase. Accordingly, having reliable, efficient and objective tools for decision-making during munitions clearance operations available, will become more important. The tools that are developed during ProBaNNt address the most critical point in the value chain of munitions clearance: After the detection of munitions and before the clearance operation itself.

Figure 1: Torpedo head in the munitions dumpsite Kolberger Heide (GEOMAR).

The ProBaNNt project aims at improving these decision-making capabilities on various levels and generating a comprehensive tool to support offshore explosive ordnance disposal (EOD) campaigns. ProBaNNt integrates sustainable convergence, use and analysis of existing EOD data with new data acquisition techniques, such as 3D photogrammetry and ad-hoc assessment of sediment properties. All of this information will be integrated into an EOD decision-making software that uses Bayesian Neural Networks to propose the most viable clearance option for a given munitions item at a given location.

Data will be gathered both by reviewing past EOD campaigns of project partners and other data suppliers, by accompanying EOD campaigns that may potentially take place during ProBaNNt's runtime and by executing specific field campaigns that project partners will conduct in known munitions dumpsites. These data will be merged into an EOD database that serves as the major source of input for the EOD support tool. The viability of all developments will be validated though dialogue with EOD experts, to determine whether and how these tools improve decision-making capabilities and to adapt the project research according to industry needs.

PROJECT OBJECTIVES

Decision-making during offshore EOD is a highly complex task requiring extensive knowledge on (1) a multitude of types of munitions, (2) numerous available clearance technologies and (3) the surrounding marine environment. It is the **overall objective** of the project ProBaNNt to:

Transform the decision-making process during EOD, which is currently heavily experience driven, non-rigorous and non-transparent, into an objective, structured, reproducible and well-informed procedure.

This transition will make EOD safer, more reliable and objective for project owners to judge the undertaken action, for nature conservation authorities to understand the rationale behind the action and most importantly for the EOD experts themselves to select the best and safest action.

After ProBaNNt, the decision on how to deal with any given munitions item will no longer be based on a situational ad-hoc-analysis of a single expert, but on a holistic assessment of many past EOD operations supported by artificial intelligence (AI). For this purpose, an easy to use EOD support software tool will be developed. The tool will not replace EOD experts or undermine their decision-making, but instead strengthen their position by providing additional unprecedented analytical capacity. In order to achieve this, the entire process from data acquisition, munitions assessment, risk assessment and the ultimate selection of an EOD method needs to be revisited. During ProBaNNt the following challenges will be addressed:

A) Thousands of EOD datasets were recorded by expert companies, but remain largely unused. During ProBaNNt these data will be merged into an**EOD database**, a data management structure will be established and a standard operating procedure for the recording and subsequent handling of such data will be defined. The project consortium possesses a sufficiently large dataset to perform a large data evaluation. The partners will seek contact with relevant authorities and other EOD companies to extend the dataset and to increase representativeness across the industry and diverse environmental conditions. Data provided by external partners will be anonymized.

B) The project will feature **field campaigns for the acquisition of new data**. ROVs and AUVs will be equipped with high-resolution optical cameras and high-resolution sonar/acoustic cameras to perform visual and acoustic mapping of pre-determined munitions sites (see Figure 2). These recordings will be used to subsequently generate photogrammetric/acoustic 3D reconstructions of munitions items to improve decision-making during clearance campaigns. As EOD depends on a comprehensive situational assessment, (e.g. potential presence of other munitions, sediment properties, degree of object burial in the seafloor), a characterization of the surrounding environment of the munitions object has to be performed. Data will be acquired using sediment characterization, side scan sonar and magnetometer mapping.

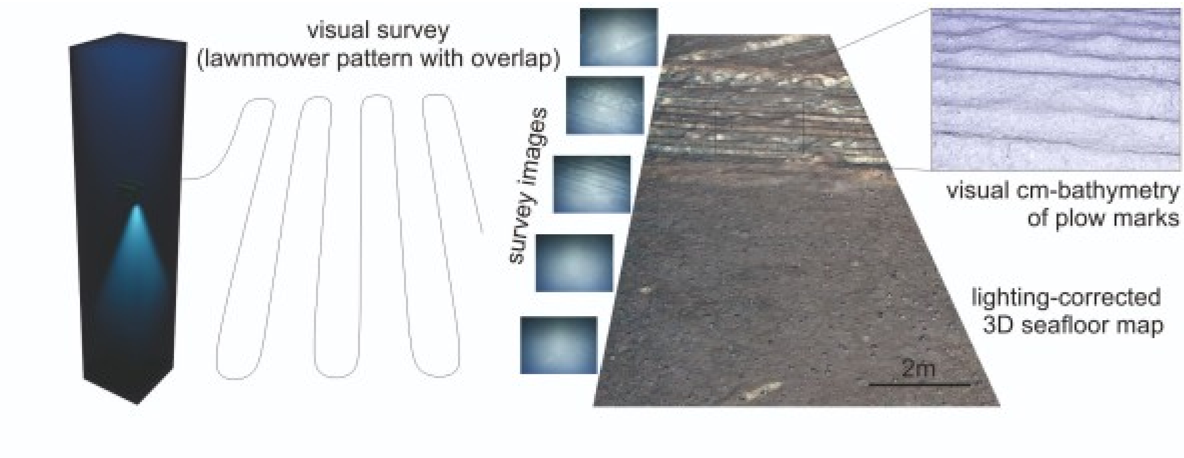


Figure 2: Example object area mapping design with an AUV that is equipped with optical camera and magnetometers (GEOMAR).

C) A **Bayesian Neural Network (BNN)** will be set-up and trained, based on the data gathered in A) and B), to serve as an analytic algorithm for an EOD support tool. For this purpose, critical parameters of munitions, clearance technologies and environmental conditions of past EOD operations will be identified. The BNN provides the ability to identify and analyse complex interrelationships. This way, previously unknown correlations between parameters will become obvious and suggestions for required adaptations of munitions clearance operations can be made. The network will be used to perform probabilistic assessment of risk paths towards unplanned detonation and leakage of hazardous substances into the sea. Ultimately, both a risk value for the given munitions item and a recommendation for EOD procedures will be generated.

ProBaNNt will improve the planning of EOD campaigns, data acquisition and the decision-making process. We will develop a BNN-based software tool, the output of which will be objective and reproducible as it is based on the existing data information. The BNN output can be compared to decisions of EOD experts. The project consortium will continuously assess and test how the newly developed methods and technologies can be integrated in the existing industry practice.

STATE OF THE ART IN RESEARCH AND TECHNOLOGY; OWN EXPERIENCES

Historical development

Due to the more immediate threat of munitions to the safety of the population, for a long time, EOD operations were conducted primarily on land. In many countries, specialized military units perform such EOD operations. Due to the hazardous nature of EOD, it is common practice to only have a one expert in the vicinity of the munitions object. This led to a concentration of knowledge and decision-making competence in a limited number of individual experts. The emergence of remote technologies for investigation, fast processing and visualisation as well as digitally sharing data together with the ability to analyse large amounts of historical and other data challenges this paradigm of single-handed decision making.

Research on munitions in the sea has long focused on chemical munitions (e.g. projects CHEMSEA, MODUM), as concerns regarding harmful environmental effects were higher for chemical warfare agents than for explosive compounds. However, with increasing offshore economic activities – with a focus on offshore construction – research has recently extended towards conventional munitions (i.e. those containing explosives). These are randomly distributed in European Seas and therefore constitute an underlying risk during all offshore activities.

State of the Art in Research and Technology in accordance with the work plan

WP1:Data compilation and management

Currently, no comprehensive and maintained offshore EOD database exists in Germany or Europe. The German Maritime Safety and Security Centre in Cuxhaven maintains a database of with munitions clearance information in accordance with the respective OSPAR Recommendation (OSPAR 2010). However, this database does not contain sufficient information to perform statistical analysis on the interplay between EOD parameters. Other authorities and private companies performing munitions clearance operations in the sea do not publish the acquired data. This is in part because the data are owned by the private companies' customers (e.g. a company operating an offshore wind park).

Due to the lack of a comprehensive database, there are no standards on data structure and formats. The Quality Guideline for Offshore Explosive Ordnance Disposal (Frey 2020) proposes a set of minimum required information that should be gathered and stored during EOD operations. It is however not mandatory to follow this guideline and therefore no uniform data structure and formatting can be expected. Even SeaTerra's data are heterogeneous, as technological and managerial developments over the past decades have led to changes in the data that were acquired during EOD.

In contrast to a database of EOD operations, several munitions databases containing information about the type, fuse mechanism, net explosive quantity, etc. exist (e.g. DAIMON ammunition catalogue (Miętkiewicz 2020), Dresdener Sprengschule (Fricke 2013) or Collaborative ORDnance data repository (CORD)). EOD experts consult these databases to understand the properties of the munitions that they are dealing with. These databases have shortcomings that will be overcome with ProBaNNt results. They do not consider the specificities of managing munitions underwater. Further, the databases do not cover the potential states of degradation and biofouling that munitions are subjected to when stored in saltwater for over 75 years.

WP2: Fieldwork, technology application and detailed mapping

Visual data acquisition during EOD is usually conducted with a high-resolution camera attached to an ROV or Airlift. Based on an evaluation of the resulting 2D images, EOD experts have to make the decision on how to deal with a given munitions object. Decisions may include salvaging the object and transporting it to a treatment facility on land, relocating the object to a different location underwater or performing in-situ detonation. The experts do not have the opportunity to comprehensively compare their own assessment to the decision other experts would make or have made in similar situations in the past. During the EOD process, the personnel usually has access to a digital munitions database to support the decision making.

In other cases, a diver is employed to perform EOD tasks, such as detailed observations, salvaging of munitions or placing of charges for in situ detonation. The diver may carry a camera, so that a support team aboard the vessel can supervise the diver's work. In this case cameras are only used for monitoring, not for data collection and further processing of the data.

In murky water, forward-looking sonar (FLS)/acoustic cameras based on the principle of scanning sonars, but with multiple transducer heads, are used to substitute optical cameras, given their capability of delivering high quality acoustic images at a near-video frame rate. FLS imagery has been employed in the inspection of underwater structures (Chen 2011) and the automated detection of targets on the sea-floor (Galceran 2012). It was successfully applied for munitions identification in MODUM and DAIMON (Grabowski 2018; Vanninen 2020).

For the purpose of object area mapping, magnetic measurements are carried out with a fluxgate magnetometer array mounted on an ROV. They can be arranged to discriminate between several magnetic field gradients. The gradient's direction and its change over time along with the change in its field value at different locations are the basis for determining whether a ferromagnetic object is nearby. After collection is finished, data have to be filtered and processed. This way, it is possible to determine the location of the object and estimate the distance between the sensor and the object.

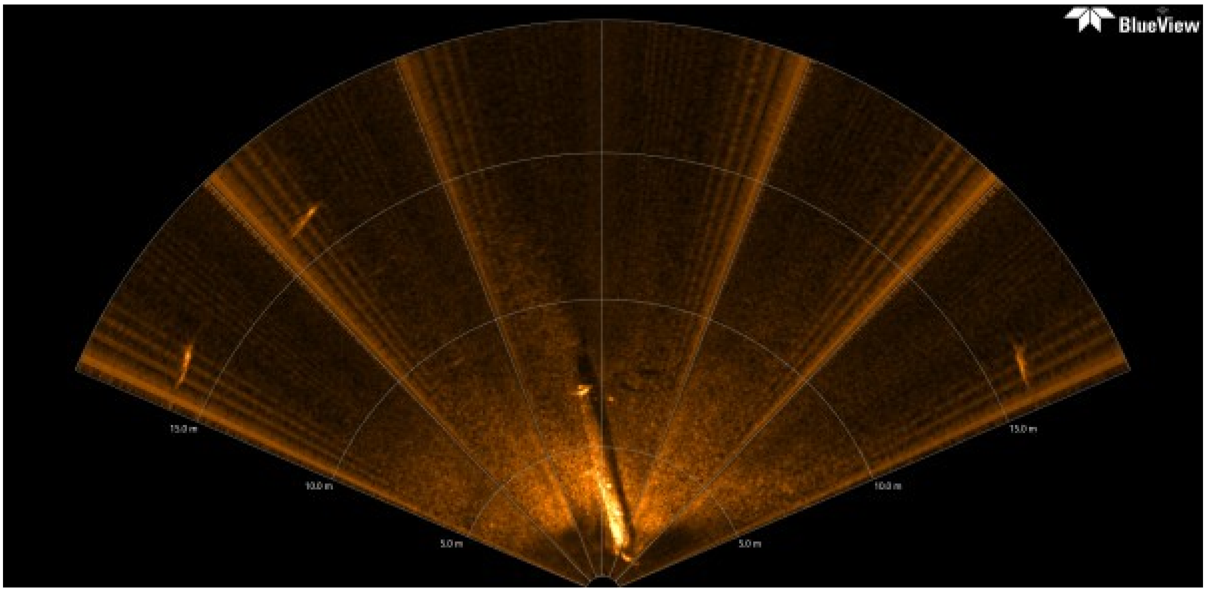


Figure 3: Image of a torpedo recorded with a forward-looking acoustic camera of a torpedo (IO PAN).

WP3: Demonstrator development for in-situ sediment property analysis

Sediments in the vicinity of munitions are frequently contaminated, both by degradation products of explosives and heavy-metals from munitions fuses (Hg, Pb) (Bełdowski 2019, Vanninen 2020). Therefore, the risk of sediment resuspension during EOD has to be quantified. Models predicting sediment erosion use the critical shear stress value to calculate the current velocity required to erode single particles or layers of sediments (Jakacki 2020). Those values are either based on laboratory experiments with sediment resuspension for specific sites (Emeis 2002) or on field measurements with current meters and sediment concentration in the water column (Salehi 2012). The laboratory procedure is complicated and prone to errors, as it requires the collection of perfect, undisturbed sediment cores. The field method, on the other hand, is largely based on theoretical calculations, as current meters usually have a poor resolution in the near-bottom water layer. Measurements of critical shear stress are scarce, which means that models use the same values for similar types of sediment, often collected hundreds of kilometres or decades apart. This leads to uncertainties in predicting the mass of resuspended sediment and hence spread of contamination during EOD operations. This can be overcome with actual in-situ measurement of $\sigma 0$ using defined, artificial bottom currents and optical measurements of total suspended solids in a benthic chamber.

WP4: Optic and acoustic 3D munitions object reconstruction

The last two decades have seen significant progress in visual underwater mapping, (Vincent 2003, Pizarro 2004, Nicoserici 2009, Johnson 2010, Jordt 2016). Because of refraction and light absorption, backscatter of particles and challenging illumination, underwater 3D reconstruction from images is still more challenging than on land or in space (Köser 2020). It has been successfully used for munitions detection(Shiavuddin 2014) and reconstruction (Song 2019), environmental monitoring, archaeology and infrastructure inspection. During previous projects, GEOMAR has generated large scale seafloor images of 400 m by 500 m (Kwasnitschka 2016; Simon-Lledo 2019) and reconstructed munitions objects from images acquired by AUV and divers in 3D as displayed in Figure 4 (unpublished data from UDEMM and BASTA projects). The seafloor area around the torpedo was systematically photographed. Each of those photos individually only covers a small part of the area and offers a limited view. However, by assembling the overlapping photos and removing the water and lighting effects, digital 3D models can be obtained, that allow to inspect the object in virtual 3D.

Figure 4: 3D reconstruction from several hundred photos of a torpedo (GEOMAR). Left: top view. Right: side view.

WP5: Data analysis through Bayesian Neural Network application

There is no decision support tool for the EOD operation, that enables an objective assessment of the different possibilities to clear a specific munitions object and give an objective recommendation. A more general decision support tool for evaluating the threats of munitions objects and munitions areas in the sea was developed in the project DAIMON. The tool uses different environmental factors to assess the risk that originates from munitions for different stakeholders, including the environment. It performs risk assessment on a macro scale, allowing decision-makers to prioritize dumpsites or individual munitions objects and to propose a treatment strategy. It does not support EOD experts during project planning or the clearance process. Nonetheless, DAIMON results will be reviewed for their usability in ProBaNNt.

It is common practice during EOD operations to perform assessment based on historical data. This does not follow a standard procedure and may include ALARP risk assessment. Such assessments are used for project planning and are not based on statistical evaluation of EOD data. Once a munitions item is found, an operating procedure that differs between companies is executed. Most decisions are taken ad-hoc on the clearance vessel. The decision-making process is rarely fully documented: It is driven by the level of experience, thoroughness of the EOD expert in charge and the tools available at the time of the operation.

Bayesian Networks have been used to assess munitions burial and mobility in SERDP Project MR-2227 (Rennie & Brandt, 2015). A number of the parameters used in that project will be relevant for the EOD support tool developed in ProBaNNt. However, Bayesian Networks are determined based on one-time data input. Bayesian Neural Networks, on the other hand, are able to learn the probabilities in the network using artificial neural network intelligence. In a BNN, each node represents an event and edges infer probabilities, which is not true for other neural networks (NNs). NNs have not been applied for risk assessment for munitions.

ProBaNNt partners' focus of previous research and technology development

GEOMAR

GEOMAR is engaged in investigating and understanding the environmental impacts of munitions in the sea. GEOMAR was an associated partner in the German **RoBEMM** project funded through BMWi. The project targeted the development of an automated underwater munitions salvage method and subsequent thermal treatment. One GEOMAR employee was previously engaged in the RoBEMM sub-project OffVali, where a validation procedure for EOD was developed (Frey 2019)). This way, expertise on available clearance methods has been gathered, which is necessary for the generation of the BNN.

As a parallel project to RoBEMM, GEOMAR coordinated the BMBF funded joint project **UDEMM** to investigate strategies for monitoring the environmental impact of underwater munitions. Study regions included the Kolberger Heide, Bay of Kiel and the southwest Baltic Sea. Data recorded during UDEMM cruises will be made available for 3D photogrammetric reconstruction in ProBaNNt and assessment for experts to propose clearance operations.

In December 2019, two other EU-funded (EASME) munitions-related projects started and are coordinated at GEOMAR. **BASTA** aims at improving munitions detection approach both on local- and larger-scale. Conducting data analysis of big data utilizing artificial intelligence will lead to new approaches in the detection and identification of munitions. BASTA field data will be made available for use in ProBaNNt. The second project **ExPloTect** aims at developing quasi in-situ analyses methodologies, based on mass spectroscopy (MIMS). This technology will enable quick and on-site analysis of a large number of munitions compounds.

SeaTerra

SeaTerra is a registered munitions survey and clearance company (§ 7 of German Explosives law). Over the past 20 years, SeaTerra performed several thousand of individual munitions clearances and numerous munitions survey projects in different countries all over the world but mainly in Europe (Germany, Netherlands, France, Belgium, Denmark, Norway, Poland, Austria, Serbia and Finland). As a result, SeaTerra possesses a huge field dataset of interpretations, target lists and protocols of munitions found, investigated, cleared or detonated. The complete chain of information, from data collection to data interpretation and target identification and cleared, is part of SeaTerra's project documentation, kept in our archives. Formats such as x/y/z-data of magnetic surveys, geo-tiffs, or spreadsheets of interpretations are available in large numbers.

SeaTerra developed several software packages for survey planning, survey execution, data collection and data interpretation. This provides SeaTerra with the ability to convert or integrate datasets of all types for further use.

OBR CTM

CTM focuses on underwater detection of different objects. The company was engaged in the **BURMIN** project, dedicated to search and disposal of sea mines, especially those buried in sediments. The objective of the project was to eliminate technological gaps in the field of mine detection and neutralization and to establish common standards for future European Unmanned Maritime Systems. During the project, CTM tested gradiometers, fluxgate magnetometers, synthetic aperture sonar, electromagnetic and electrochemical sensors and integrated them into one platform (Figure 5). The platform will be available for the field campaigns (WP4). Data fusion algorithms were developed to reduce the number of false positives, that appear during surveys. CTM also executed seabed mapping work in Gdansk Bay, using the integrated platform, to collect data. For the same project CTM also performed data analysis.

Figure 5: The integrated sensor platform will be available for the field campaigns (CTM).

Institute of Oceanology of the Polish Academy of Sciences (IO PAN)

During the EU FP5 Project **BASYS**, resuspension of suspended matter and transport of sediments to other areas was investigated, and a basic model was created. Critical shear stress of bottom currents was assessed, and mechanisms of the release of contaminants from the seabed were described.

The BSR project **CHEMSEA** established methods to identify munitions and assess the spread of munitions constituents. The NATO SPS project **MODUM** established methods to monitor munitions dumpsites, including target recognition, sonar data and acoustic data image processing. This knowledge will be used for the scene recognition and 3D reconstruction of objects during ProBaNNt. Also, a high-resolution hydrodynamic model was constructed to predict contaminant spreading from munitions dumpsites.

The Interreg project **DAIMON** was coordinated by IO PAN. In this project risk estimation methods were developed and bundled in a strategic Decision Support System. DAIMON outputs such as recorded munitions datasets and environmental data will be utilized in the EOD support tool. The spread of munitions constituents in a former EOD site was also studied during DAIMON, which confirmed sediment contamination. This experience will be utilized in sediment mobility analysis (WP2).

WORKPLAN

The research project consists of six different work packages (WPs). WP1 through WP5 cover the scientific and technical project work, while WP6 is an administrative WP. These five WPs have been visualized in Figure 6.

In WP1 an EOD database structure will be developed, in which available EOD data will be converged and harmonized into a prototypical database setup. Data that are available to the consortium at project start, will be the starting point for data entry. Additional data from external stakeholders will be added throughout ProBaNNt's runtime. WP2 is dedicated to fieldwork, during which both existing and new methods will be used to gather information on munitions objects and their surroundings. Existing methods are side-scan sonar, multibeam imaging and magnetometer surveys, all of which will be used for detailed object area mapping. Newly applied methods are a demonstrator for critical shear stress analysis of sediments and 3D reconstructions of munitions objects. Development of the critical shear stress device (CSSD) is organized in WP3. The generation of 3D photogrammetric/hydroacoustic reconstructions will take place in WP4. To understand how these reconstructions can aid EOD decision-making, repeated feedback from EOD experts will be sought. Data for WP3 and WP4 will be recorded during WP2. Object area mapping data (WP2), sediment data (from WP3) and imaging data (from WP4) will all be added to the EOD database (WP1). In WP5, data will be analysed through the application of a Bayesian Neural Network (BNN), which is a model of parameters relevant to EOD and the interconnections between these parameters. For this purpose, WP5 will extract data from the constantly growing database (WP1). WP5 furthermore includes the development of software for EOD experts to support their decision-making. Feedback from EOD experts will be collected, to increase the software's benefit to their daily work. The software user interface will allow easy access to the EOD database (WP1). Data collected from within the consortium (WP1), from external stakeholders and throughout the project (WP2, WP3 and WP4) are all relevant for EOD decision-making (WP5). WP1, therefore, serves as the central hub of the project, connecting collected data and fieldwork data into the decision-making process.

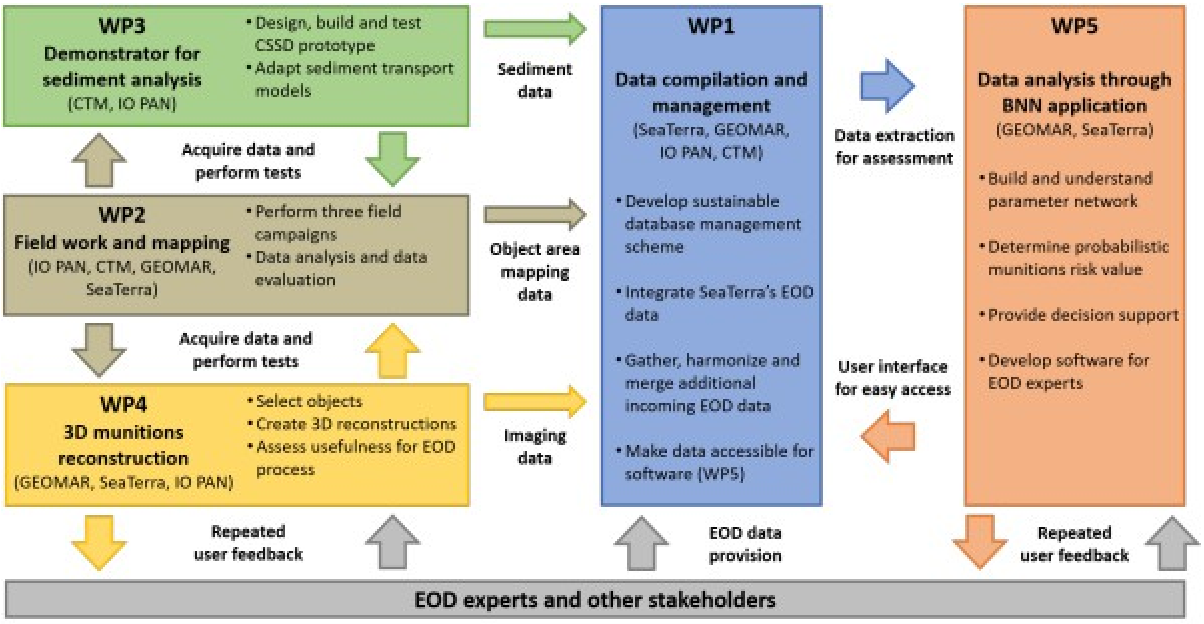


Figure 6: Concept of the ProBaNNt project visualizing the interconnections between WPs. EOD experts and stakeholders are critical for the industrial application of project results.

WP1: Data compilation and management

The basis for objective, structured, well-informed decision making is a well-managed database, in which all available EOD data are converged and organized. These data need to include the information on the munitions item but also information on the particular local environment and a clear reasoning of the decision that leads to a particular EOD method. Over the years, during which offshore EOD has taken place in Europe, thousands of these datasets have accumulated at SeaTerra, as a by-product of daily business. The same is true for other EOD companies and military bodies. While SeaTerra data will be made available to the project, data of other actors must first be acquired.

Task 1.1: Set up of database hosting infrastructure

Task 1.2: Collection and integration of EOD datasets

Task 1.3: Development of a data management strategy

WP2: Fieldwork, technology application and detailed mapping

Field campaigns of the project will take place twice in Kolberger Heide (site A) in German waters and once in Gdansk Basin (site B) in Polish waters (Figure 7). These sites are known from previous surveys by IO PAN and GEOMAR. Therefore, data acquisition can immediately focus on individual objects without the need for large scale reconnaissance surveys beforehand.

Task 2.1: Execution of three field campaigns

Task 2.2: Evaluation of all data acquired in field campaigns for scene recognition

Task 2.3: Integration of all data acquired in field campaigns into EOD support tool

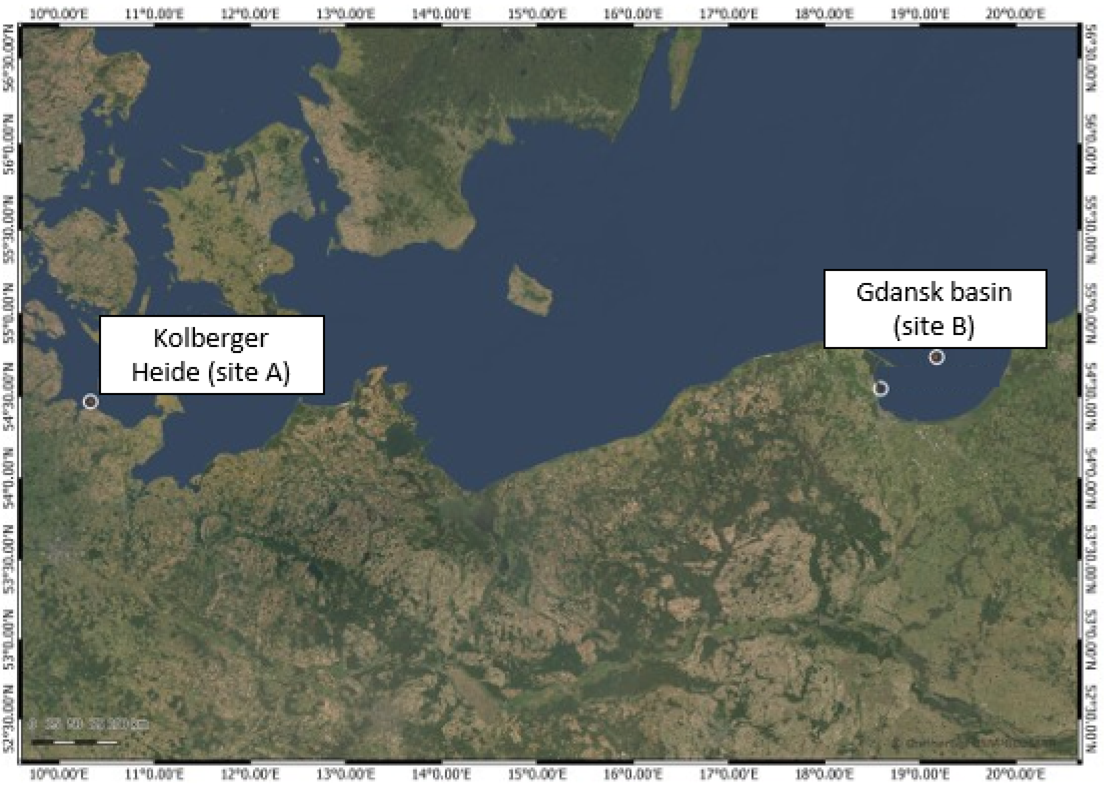


Figure 7: Map of the German and Polish Baltic Sea coast. Field campaign sites are located at Kolberger Heide (site A) and Gdansk Basin (site B).

WP3: Demonstrator development for in-situ sediment property analysis

Polluted sediments and its distribution pose an environmental hazard. Thus, spreading of such sediments during EOD should be avoided. To assess sediment mobility, an in-situ demonstrator will be developed. This critical shear stress device (CSSD) will generate progressive water currents while monitoring turbidity, to assess critical shear stress of sediments. This way the probability of sediment resuspension and mass of material that might be transported can be calculated. These results might exclude some EOD methods, eliminating those which could spread contaminated sediments to other areas.

Task 3.1: CSSD conceptualization and product requirement documentation

Task 3.2: CSSD construction

Task 3.3: CSSD testing and calibration

Task 3.4: Sediment transport model adaptation

WP4: Optic and acoustic 3D munitions object reconstruction

The aim of WP4 is to support the EOD decision-making with computer-generated and correctly scaled 3D reconstructions of munitions objects which can be rotated and jointly observed with other EOD specialists in the field or remotely on a computer. The visual or acoustic information of cameras, will be acquired during the field campaigns. We want to verify, whether such 3D reconstructions are a useful addition to the EOD expert toolbox and remotely supported decision-making processes, which currently do not exist. If this is the case, the acquisition of relevant data and required processing will be integrated into the existing EOD workflow.

Task 4.1: Selection of exemplary munitions objects

Task 4.2: Collection of data in the field

Task 4.3: 3D reconstruction

Task 4.4: Verification of applicability

Figure 8: Photogrammetric reconstruction of a British ground mine and its surroundings in the Kolberger Heide (GEOMAR).

WP5: Data analysis through Bayesian Neural Network application

WP5 deals with the generation of a holistic parameter network and its development into a Bayesian Network at first and a Bayesian Neural Network in the time of the project. Input data will include the munitions items, EOD methods and the location-specific environmental conditions. This allows for an objective evaluation of the interrelationships between these parameters.

The main input source for this network will be the assessment of the information that is contained in the EOD database (WP1). Once the network is designed, case studies will be selected to test its ability to predict even probabilities, contributing factors and derive recommendations for EOD methods. A feedback process with industry experts (from SeaTerra and associated partners) will make sure that the network's results are useful for the EOD process in practice.

Task 5.1: Parameter identification and generation of network

Task 5.2: Development and testing of the BNN

Task 5.3: BNN application to EOD case studies

Task 5.4: Integration of EOD support tool into the EOD process

Task 5.5: Development of user-friendly EOD support software

WP6: Coordination & administration (GEOMAR)

This WP covers administrative and coordinative tasks. A project bureau will be established to perform activities such as the organization of the kick-off, yearly project meetings, and the final event. It will support cruise logistics, organize outreach material and facilitate the cooperation with stakeholders and data suppliers.

Task 6.1: Administration of the project and preparation of reports

Task 6.2: Coordination of joined activities and control of timely execution

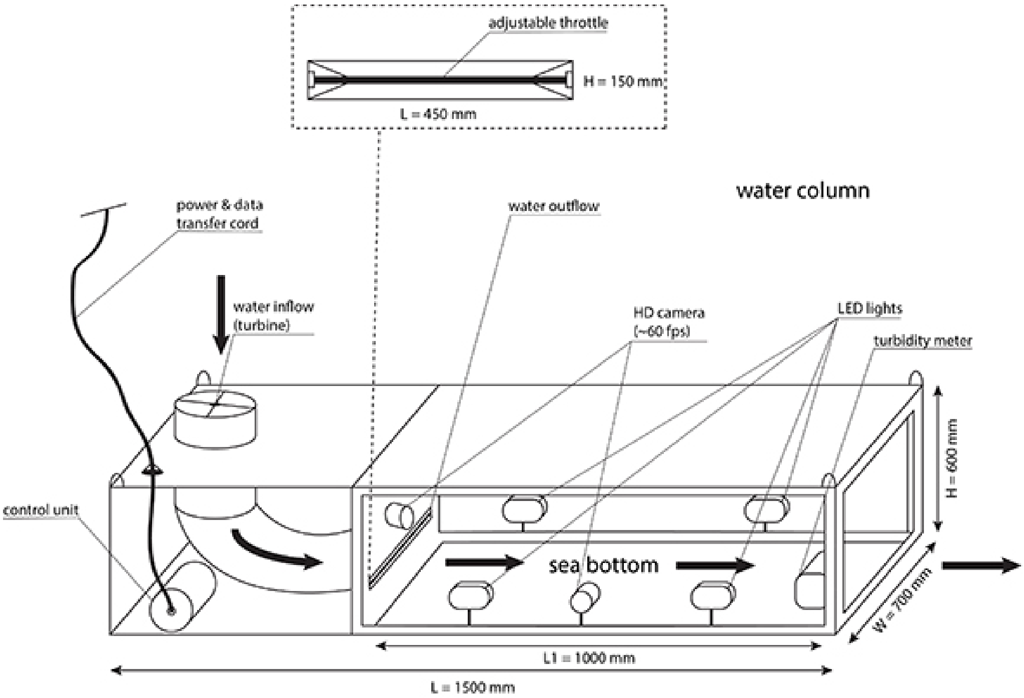
WORK PACKAGES

Table of Work Packages + Tasks

WP	Task	Start Month	End Month	WP / Task Title
1		1	36	Data compilation and management
	1.1	1	18	Data management strategy
	1.2	1	30	Set up of database infrastructure
	1.3	1	36	Data collection (internal and external)
2		9	35	Fieldwork and detailed mapping
	2.1	9	30	Field campaigns
	2.2	10	35	Field data processing and evaluation
	2.3	16	35	Integration of field data into software
3		1	24	Demonstrator for sediment analysis
	3.1	1	6	CSSD conceptualization
	3.2	7	12	CSSD construction
	3.3	13	21	CSSD testing and calibration
	3.4	18	24	Sediment transport model adaptation
4		1	33	3D munitions object reconstruction
	4.1	1	3	Selection of exemplary munitions objects
	4.2	9	30	Collection of data in the field
	4.3	4	33	3D reconstruction
	4.4	13	33	Verification of applicability
5		1	36	Data analysis through BNN application
	5.1	1	12	Parameter identification
	5.2	10	27	Development and testing of the BNN
	5.3	19	33	BNN application to EOD case studies
	5.4	25	36	EOD support tool and EOD process
	5.5	1	36	EOD support software development
6		1	36	Coordination & administration
	6.1	1	36	Administration of the project
	6.2	1	36	Coordination of the project

WP/Task No.	WP Objectives + Description / Task Description	Partner (**strong** = Teamleader)	Person Month(s) (**strong** = Teamleader)
WP1	**Objectives:** Title: Data compilation and management • Develop a technical solution for the database, that can be maintained at low cost after the finalization of ProBaNNt and that can be readily adapted and amended in the future • Gather, structure, harmonize and merge as many EOD data as possible, if they meet the quality requirements for the use by the BNN **Description:** Partners: SeaTerra, GEOMAR, IO PAN, CTM WP1 will be dedicated to converging available data on EOD operations in a structured manner. For this purpose infrastructure for database hosting will be established. In ProBaNNt, an open-source database suite will be utilized. Several thousand individual EOD datasets are already available at SeaTerra, which can be entered into the database. Project partners will collect additional data from relevant authorities and other EOD companies, project owners and military. Data types will include (but are not limited to) images, videos, UXO clearance certificates, signatures of magnetometers, sonar images, written documentation of EOD experts, reports on in-situ detonations. Information precisely characterizing the munitions object, the marine environment and the clearance method will either be available or must be extracted from the available documentation. Throughout the runtime of ProBaNNt, the processes of adding data and data formats to the database and of maintaining the database will be gradually improved upon. Based on this experience, the database structure and database management strategy will be formalized and documented.	P1, P2, P3, P4	43, 18, 1, 2
T1.1	**Description:** Title: Data management strategy A data management strategy will be developed. Data need to be made available for easy access and utilization by the BNN (WP5). Data management also includes the definition of the database structure and the determination of data formats that will be entered into the database. Existing knowledge from the BASTA project will be integrated here. Furthermore, a workflow for adding data during and after the project will be developed and access rights for different actors will be determined. This workflow may also affect the method of data acquisition and subsequent data handling. Data quality requirements (Task 1.3) will be formalized. This will result in the development of a standard operating procedure for clearance data handling. As offshore EOD is an ongoing task – that will continue throughout the 21st century – the database itself and the data management strategy must be forward compatible.	**P1**, P2	**10**, 7
T1.2	**Description:** Title: Set up of database infrastructure An infrastructure for the database will be set up. This may take place at existing infrastructure (e.g. GEOMAR or other means provided by the Helmholtz Association, DAM or NFDI). The options will be assessed and evaluated as an initial step, before one is selected. High performance of the infrastructure will be a critical parameter. In addition, high accessibility for the EOD support software is required. Based on a small set of example data provided by SeaTerra and on requirements of the EOD support software a database format will be selected (WP5). Due to the sensitive nature of the data, high data security standards must be employed.	**P1**, P2	**9**, 1
T1.3	**Description:** Title: Data collection (internal and external) All available data of the project partners will be collected. SeaTerra holds thousands of EOD datasets that will serve as a starting point. In addition, partners will contact other actors to ask for the provision of additional data. For this task, project partners will rely on their networks. Additional contacts will be established during industry events. Finally, 3D reconstructions of munitions objects (WP3) and field campaign data (WP4) will be integrated into the database. As far as possible, the incoming data formats will be harmonized. Quality gates for the incoming data will be defined after the first datasets have been reviewed. Data which do not meet quality requirements will not be included or flagged accordingly. This way data requests towards external partners can be specified to only obtain relevant data. The goal of ProBaNNt is to improve decision-making processes for EOD experts, which means that incomplete or inconsistent data cannot be included for safety reasons.	P1, **P2**, P3, P4	24, **10**, 1, 2

WP/Task No.	WP Objectives + Description / Task Description	Partner (strong = Teamleader)	Person Month(s) (strong = Teamleader)
WP2	**Objectives:** Title: Fieldwork and detailed mapping • Perform fieldwork for detailed area mapping of munitions object surroundings (side-scan sonar, magnetic, bathymetry) and subsequent data processing to generate complete, high-quality datasets around selected munitions objects that can be added to the EOD database (WP1) • Collect sediment property data for and with the CSSD (WP3) and perform optical and acoustic mapping of munitions objects for 3D reconstructions (WP4) **Description:** Partners: IO PAN, GEOMAR, SeaTerra, CTM Field campaigns of the project will take place in Kolberger Heide (site A) in German waters for field campaigns 1 and 3 and in Gdansk Basin (site B) in Polish waters for field campaign 2. During fieldwork the following methods for detailed object area mapping will be applied: 1. A magnetometer array will be equipped with magnetometers. It enables detection of buried metal objects in the vicinity of the target munitions object, which is highly relevant for EOD decision making. 2. Side-scan sonar will be used to generate a detailed acoustic map of the seafloor of and around the munitions object. 3. Ship-based multibeam mapping will be used to generate additional acoustic data of the seafloor and the munitions object in a fully georeferenced mode. This is important to georeference the magnetic and side-scan data correctly With the combination of the three datasets, we collect the same information typically available during regular EOD campaigns. For some objects data from other projects (BASTA, UDEMM, DAIMON) may exist and not all of the above methods must be applied to generate complete, high-quality datasets, that can be added to the EOD database (WP1). 4. The CSSD developed in WP3 will be used during field campaigns. 5. ROVs and AUVs with high-resolution optical cameras and acoustic cameras will be used to acquire data for WP4.	P1, P2, P3, P4	8, 2, 8, 7
T2.1	**Description:** Title: Field campaigns Three field campaigns will be executed. These are currently planned for project months 9, 21 and 30. The precise months may shift, due to the limited availability of research vessels. Equipment for field campaigns includes CTMs multi-sensor platform (Figure 5), ROVs from IO PAN and AUVs from GEOMAR. All field campaigns are planned to take place in the Baltic Sea. In terms of munitions in general and the dumpsites targeted in this proposal (sites A and B) in particular, the Baltic Sea is better studied than other European seas, which allows for the selection of munitions objects for detailed investigation, based on existing data. Sites A and B are easily accessible from GEOMAR and IO PAN. This saves time and is therefore cost-efficient.	P1, P2, **P3**, P4	3, 1, **3**, 2
T2.2	**Description:** Title: Field data processing and evaluation All data that are acquired during the field campaigns will be processed and evaluated. Magnetometer data will be evaluated, to determine whether other munitions objects are present in the target object vicinity. Side-scan sonograms will be superimposed to produce high-resolution images of the munitions object area. Optical and acoustic camera data will be reviewed by EOD experts to identify munitions types.	P1, P2, **P3**, P4	3, 1, **4**, 4
T2.3	**Description:** Title: Integration of field data into software For all munitions objects that are surveyed during the fieldwork, the database entries including collected magnetic, acoustic, visual and sediment property data will be created. The acquired and processed data will be evaluated for their value to better inform EOD decisions. We will assess how to best integrate them into the EOD support tool (WP4) and the data management strategy (WP1).	**P1**, P3, P4	**2**, 1, 1
WP3	**Objectives:** Title: Demonstrator for sediment analysis • Conceptualize, construct and test the CSSD, thereby enabling the collection of information on the probability of resuspension of contaminated sediments in EOD dumpsites • Provide this information to the EOD database (WP1), so it can be accessed by the EOD support software (WP5) to support EOD decision-making • Adapt existing sediment transport models to include the new findings on critical shear stress **Description:** Partners: CTM, IO PAN To assess sediment mobility, a critical shear stress device (CSSD) demonstrator will be developed (Figure 4). This CSSD will be lowered from the ship and generate progressive water currents while monitoring turbidity. These data are used to assess the critical shear stress of the sediment. Based on the obtained results, the probability of sediment resuspension and the mass of suspended material will be calculated. The CSSD will be deployed during field campaigns (WP2). For the placement of the CSSD on the seafloor (during WP2) a spot that is confirmed to be free of munitions must be found. Detailed object area mapping that takes place during WP2, will provide the required information.	P3, P4	5, 29

WP/Task No.	WP Objectives + Description / Task Description	Partner (strong = Teamleader)	Person Month(s) (strong = Teamleader)
T3.1	**Description:** Title: CSSD conceptualization Critical shear stress estimations available in literature will be compiled, and sources of possible errors and uncertainties analysed. Available turbidity sensors will be assessed based on their sensitivity and parameters. Based on that, the functionality of the demonstrator will be conceptualized. Types and sensitivity of sensors will be specified and typical flows regimes encountered in the marine environment will be considered. The versatility of equipment, ruggedness and ease of deployment/retrieval will be considered. Dimensions, sensor geometry, deployment mode as well as communication and control protocols will be specified. Power supply and communications will be designed to fit coaxial cables. The CSSD will allow in-situ measurements of critical shear stress, which is not offered by available commercial technology. Nonetheless, during the CSSD conceptualization, partners will review and consider the design of existing commercial technologies for the analysis of other physical sediment properties such as erosion velocity and erosional behaviour (e.g. Aquatec Group's Voyager II sea flume). For the purpose of documenting all of the above, a product requirement document will be prepared.  *Figure 9: Conceptual sketch of the CSSD (IO PAN).*	P3, **P4**	2, **10**
T3.2	**Description:** Title: CSSD construction A CSSD demonstrator that can generate water currents and that can monitor turbidity will be built. The device will be optimized for easy deployment with a wide range of vessels using minimum onboard equipment. Data collection will be automated to simplify handling. The control software will be developed to combine recorded data into an integrated critical shear stress value, that can be directly used as a parameter in sediment distribution models. The mechanical design will include a lightweight box, with turbine and sensors, that could be placed on sediments with limited disturbance of the surface. A landing system will be developed to ensure slow positioning of the device. Slow descent will be ensured by designing buoyancy control. Sensors will include a turbidity meter, that is able to integrate the signal from multiple positions inside the test-chamber. Turbine speed control will be based on speed profiles tested in the laboratory.	**P4**	**13**
T3.3	**Description:** Title: CSSD testing and calibration The demonstrator will be tested and calibrated in the laboratory and during field campaign 2. Difficulties will be eliminated by redesigning problematic parts or re-calibrating sensors. Tests will be performed with different types of sediment, to determine the landing speed and avoid sinking of the instrument in soft sediments. Different roughnesses of the sediment surface will be included to test the device in turbulent flow condition. Raw sensor data will be recorded to evaluate the turbidity in different locations of the flow chamber. Algorithms producing a value for the total suspended solids (TSS) will be used to calibrate the sensor to the in-situ situation of natural shear stress. Mechanical design, power control and turbines will be tested for stability and performance. Communication possibilities will be assessed with different cable set-ups. Positioning and landing procedures of the CSSD will be evaluated by means of ROV inspection during and after the deployment.	P3, **P4**	2, **6**
T3.4	**Description:** Title: Sediment transport model adaptation Existing sediment transport models will be evaluated based on literature, and possibilities of including critical shear stress values, will be assessed. The sediment spreading model developed for munitions dumpsites within MODUM and DAIMON will be updated to handle the data obtained from the CSSD demonstrator. This is to quantify the mass of sediments and the potential environmental pollution during EOD operations. Simulations of sediment transport using original models or shear stress data from the literature will be compared and evaluated to new results.	**P3**	**1**

WP/Task No.	WP Objectives + Description / Task Description	Partner (strong = Teamleader)	Person Month(s) (strong = Teamleader)
WP4	**Objectives:** <u>Title: 3D munitions object reconstruction</u> • Perform 3D object reconstruction for numerous munitions objects, to demonstrate the benefits of such 3D models and their advantages over conventional images or videos • Provide the 3D reconstructions to the EOD database (WP1), so it can be accessed by the EOD support software (WP5) to support EOD decision-making • Assess how 3D reconstructions can support the work of EOD experts (independently from the EOD support software) **Description:** <u>Partners: GEOMAR, IO PAN, SeaTerra</u> The aim of WP4 is to support the EOD decision with computer-generated and correctly scaled 3D munitions objects as computer reconstruction. The aim is to allow EOD experts in the field and simultaneously at other places to evaluate the munitions object on a computer by virtually rotating, zooming and exploring it in great detail. To facilitate these 3D visualizations, digital 3D models of the surrounding environment are required. Such 3D models will be obtained by registering and analysing the sensor data captured in WP2 using machine vision and photogrammetry techniques. Since both optical and acoustic images will be collected, it will also be possible to assess how both datasets can be merged. Which type of data will be more useful for 3D reconstruction will always depend on the visibility conditions during data collection. We want to verify, whether such 3D reconstructions are a useful addition to the current EOD expert toolbox and if and how a remotely supported decision-making process is feasible and advantageous. If this is the case, the acquisition of relevant data and required processing will be integrated into the existing EOD workflow.	P1, P2, P3	28, 3, 8
T4.1	**Description:** <u>Title: Selection of exemplary munitions objects</u> Using the knowledge of exact munitions locations gained during the UDEMM, DAIMON and MODUM projects a variety of munitions types and corrosion states will be selected for 3D reconstruction. For this, existing high-resolution multibeam and side-scan sonar data will be reviewed to select munitions items. Objects must be clearly distinguishable from the surrounding sediment and ideally not completely overgrown by benthic flora and fauna. Furthermore, single objects are preferred over piles of munitions, both of which are well known in the envisioned working areas.	**P1**, P2	**1**, 1
T4.2	**Description:** <u>Title: Collection of data in the field</u> ROV- or AUV-based high resolution optical and acoustic camera systems will be used to record data during the field campaigns (Task 2.1). Calibrated optical and acoustic cameras will take pictures of each selected object from different directions to maximize coverage. Optical and acoustic datasets will be compared and merged for the best possible representation of the object and the surrounding seafloor. Placing markerboards of known size next to the objects (Figure 8) and potentially using stereographic imaging will ensure a correct scale. In preparation of and during the first field campaign, an ideal survey path for the AUV and ROV will be developed and tested. This includes assessing the survey pattern (e.g. lawn mowing pattern as in Figure 2 or rotating around the object with the cameras facing the centre) and determining the ideal distance to the sea floor and the munitions object, to balance the trade-off between survey efficiency and image quality.	P1, **P3**	3, **3**
T4.3	**Description:** <u>Title: 3D reconstruction</u> Collected images will be imported to specialized software to create 3D photogrammetric and acoustic reconstructions. Additionally, 2D mosaics of side scan sonar data will support absolute georeferencing of the photogrammetric reconstruction on the side-scan and bathymetric data (see WP2).	**P1**, P3	**22**, 5
T4.4	**Description:** <u>Title: Verification of applicability</u> EOD experts will review the 2D and 3D reconstructions in an interactive, maybe virtual reality, computer environment in a fictional clearance scenario. This way, we will evaluate, which data and presentation methods are most useful for decision-making during EOD, and, whether decisions change with the availability of the new visualisation capabilities and the possibility to jointly and remotely contribute to the decision. Feedback may be gathered via questionnaires or during expert workshops, that could be coupled to the annual project meetings. If SeaTerra (or associated partners) work on ongoing offshore EOD campaigns during ProBaNNt, 3D reconstructions of objects found during those campaigns could be generated. Thereby assessment of 3D models can be integrated into real-world EOD. Experts will be asked to provide feedback on the general usefulness of the reconstructions, but also to identify scenarios in which the reconstructions are most useful. In the scenarios, they may differentiate between different environmental conditions, types of munitions and the condition of the munitions. Furthermore, experts will be asked to compare the benefits of reconstructions of optical camera images, acoustic camera images and combinations thereof. Based on the evaluation, it will be possible to define minimum quality requirements for data acquisition during field campaigns 2 and 3.	P1, **P2**	2, **2**

<table>
<tr><th>WP/Task No.</th><th>WP Objectives + Description / Task Description</th><th>Partner (strong = Teamleader)</th><th>Person Month(s) (strong = Teamleader)</th></tr>
<tr><td>WP5</td><td>

Objectives:

Title: Data analysis through BNN application
• Use gathered and generated data from WP1 to WP4, to understand the interrelationships between munitions, marine environment and EOD methods
• Based on these relationships, apply a Bayesian network to determine a probabilistic risk value for munitions items and EOD methods
• Provide decision support for selected scenarios
• Implement the complete workflow from data acquisition, data analysis and data use for decision making in the software user interface that will be developed
• Improve project planning capabilities before the initiation of EOD campaigns and improve the objectivity and representativeness of EOD decision-making

Description:

Partners: GEOMAR, SeaTerra
The data in the database (WP1), can be used to perform linear and multiple regression analysis to estimate the relationship between parameters with the aim of assessing how the type and state of the munitions objects and environmental parameters have affected EOD decision-making in the past. Furthermore, the risk that originates from the presence of a given munitions item in a given environment can be evaluated. Finally, the way this risk changes during EOD can be assessed.
Next, a Bayesian network can be used, to extend the analysis beyond the scope of understanding the relationship between selected variables, i.e. to enable assessment of the interrelationship of parameters in a multivariate network. This network is a probabilistic graphical model, representing the conditional dependencies between variables. This way it is possible to predict the probability of an event, such as the unwanted explosion of a UXO and to determine main contributing factors to this event. It will also be possible to assess which combinations of input values into the variables are most likely to lead to such an event.

</td><td>P1, P2</td><td>31, 6</td></tr>
<tr><td>T5.1</td><td>

Description:

Title: Parameter identification
Relevant environmental and munitions parameters need to be identified and organized in a network, displaying interdependencies. Parameters include among others net explosive quantity, fuse type and state of corrosion for the munitions item; salinity, temperature, currents and depth for environmental conditions; sediment spread and distance to munitions object for EOD methods. Parameters will be tested for correlation and causality, which will allow predicting e.g. the state of a given munitions item based on its location.

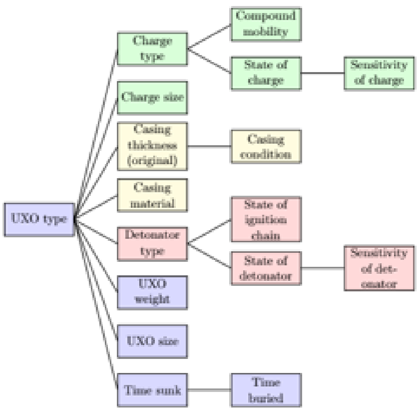


Figure 10: A preliminary parameter network of munitions parameters (not including environmental or EOD parameters).

</td><td>P1, P2</td><td>4, 1</td></tr>
<tr><td>T5.2</td><td>

Description:

Title: Development and testing of the BNN
From the parameter network, a Bayesian network will be developed. The network is used to generate a risk measure for each munitions object, based on the object input data and its surrounding environmental conditions. Next, EOD methods and their parameters (which can be extracted from product data sheets of the deployed equipment) are added to the Bayesian network, giving the network the ability to provide a recommendation of the most favourable EOD process.
As a second step, based on the Bayesian Network, a BNN will be trained by accessing the EOD database (WP1). In contrast to the Bayesian Network without artificial intelligence, the BNN will retrain when new data are entered into the EOD database, to adapt the conditional dependencies. The BNN will be able to give two types of decision support:
1. An overall risk value for any given munitions object in any given environment and proposed clearance method.
2. Case-by-case evaluation of munitions items that will act as ad-hoc EOD decision support during the execution of clearance.
In ProBaNNt open source software will be used for the design of the Bayesian network, which provides an API to allow for the connection of the network to the database.

</td><td>P1</td><td>8</td></tr>
<tr><td>T5.3</td><td>

Description:

Title: BNN application to EOD case studies
The recommendations of the BNN will be compared to real-world decisions that are made by EOD experts. If the BNN confirms the decision of the expert, this can be seen as data supported confirmation that several past EOD operations occurred in the same way. If BNN and EOD export decisions do not align, an evaluation of the differences will be conducted, to determine, whether the expert decision or the tool’s recommendation needs to be revisited.

</td><td>P1, P2</td><td>5, 2</td></tr>
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WP/Task No.	WP Objectives + Description / Task Description	Partner (strong = Teamleader)	Person Month(s) (strong = Teamleader)
T5.4	**Description:** Title: EOD support tool and EOD process The use of the decision support tool will be integrated into existing EOD workflows, to be beneficial during commercial EOD. This concerns the early stage planning of EOD campaigns and the decision-making process on munitions clearance. If SeaTerra (or associated partners) work on ongoing offshore EOD campaigns during ProBaNNt, the integration can be tested with munitions objects from those campaigns. This way, the software can be tested during real-world EOD. Otherwise, a fictional campaign will be played through, to simulate the implementation. Furthermore, EOD support software alpha and beta versions will be presented to industry experts. This way adaptations to user interface and functionality can be made. This feedback process will ensure that the software is an impactful support for users. It will furthermore increase acceptance among potential users. Feedback may be gathered via questionnaires or during expert workshops, that could be coupled to the annual project meetings.	**P1**, P2	**2**, 2
T5.5	**Description:** Title: EOD support software development A user-friendly EOD support tool utilizing a pre-trained BNN will be developed. A user interface will allow EOD experts to enter details of clearance scenarios and generate case-specific decision support. Using the software will not require a detailed understanding of probabilistic prediction or artificial intelligence. Furthermore, end-users will be able to import new clearance datasets and retrain the BNN with the new input.	**P1**, P2	**12**, 1
WP6	**Objectives:** Title: Coordination & administration • Ensure timely achievement of all milestones and production of deliverables; monitor project progress **Description:** Partners: GEOMAR, IO PAN Coordination between the partners is necessary for the alignment in all work packages, especially in those that include both German and Polish partners (WP1, WP2 and WP4). The project bureau will coordinate data integration into the EOD database, field campaigns, report writing and communication to associated partners and other external organizations. In addition, the bureau will organize the interface with other relevant national and international running projects in the domain of munitions in the sea (e.g. BASTA, ExPloTect, North Sea Wrecks) as well as munitions projects that may be funded through MARTERA (e.g. AMMOTRACe). Communication furthermore includes the setup of a project website, the distribution of newsletters and the identification of suitable events for the presentation of project results.	P1, P3	9, 1
T6.1	**Description:** Title: Administration of the project Project administration will be organised via a central project bureau, reports will be compiled and meetings arranged. Overall project administration and administrative duties on the German side, will be executed at GEOMAR. Administrative requirements on the Polish side, will be coordinated by IOPAN.	**P1**, P3	**4**, 1
T6.2	**Description:** Title: Coordination of the project Coordination of joined activities and control of timely execution of deliverables and milestones.	**P1**	**5**

Table of Milestones

Milestone No.	Month	Milestone Title + Description
M1.1	3	**Title:** Preliminary data management strategy **Description:** The data management strategy will be developed continuously throughout Task 1.2. Nonetheless, a preliminary data management strategy is required. Third-party data can be requested according to this strategy and own field data can be acquired accordingly as well.
M1.2	6	**Title:** Database infrastructure **Description:** The database infrastructure will be established and made available to all project partners and all potential third-party data providers for data upload.

Milestone No.	Month	Milestone Title + Description
M1.3	18	**Title:** Internal data collection finished **Description:** At this point, all EOD data and otherwise relevant munitions data that were available within the consortium at project start will be homogenized in terms of format and content, based on the preliminary database structure. All this data will be available in the database. Moving forward, third party data, data that SeaTerra potentially acquires during commercial field campaigns and data that are gathered during project fieldwork will be added to the database.
M1.4	24	**Title:** Final database structure **Description:** Based on the EOD data and the field campaign data, that are gathered and merged during the project (WP1, WP2), and on the requirements of the EOD support tool, a final database structure will be defined.
M1.5	24	**Title:** Final data management strategy **Description:** Based on the experiences that are made during the first half of ProBaNNt, the final data management strategy will be defined. The data acquisition, data entry and database management will henceforth all be executed according to this strategy which is described in Deliverable 1.1.
M2.1	9	**Title:** Field campaign 1 executed **Description:** The first field campaign will take place in Kolberger Heide (site A). Equipment, as laid out in the WP description, will be deployed. The CSSD will not be available at this point, as it will still be under development. During the first field campaign, all other equipment will be tested and standards of operations will be established to collect the highest possible quality data. Data collected during the campaign will be secured with at least two copies and provided to all project partners.
M2.2	21	**Title:** Field campaign 2 executed **Description:** The second field campaign will take place in Gdansk Basin (site B). Equipment, as laid out in the WP description, will be deployed. The CSSD demonstrator will be used for the first time during this cruise. Data collected during the campaign will be secured with at least two copies and provided to all project partners.
M2.3	30	**Title:** Field campaign 3 executed **Description:** The third field campaign will take place in Kolberger Heide (site B). Equipment, as laid out in the WP description, will be deployed. Data collected during the campaign will be secured with at least two copies and provided to all project partners.

Milestone No.	Month	Milestone Title + Description
M3.1	6	**Title:** CSSD requirements document **Description:** A document describing the mechanical design and landing system of the CSSD will be prepared. A list of sensor specifications and a description of the water current generation system design and control will be compiled. Transmission protocols and power supply requirements will be specified. Sensor placement inside the current chamber as well as the integration of sensors with the mechanical design will be described.
M3.2	12	**Title:** CSSD preliminary version **Description:** A preliminary version of the CSSD will be built. The device will include a benthic chamber with a landing system, bottom current generator with precise current speed control, turbidity sensors and power system. A communication interface will be produced, including an underwater module on the bottom chamber and deck unit for onboard control. Software for control, data recording and data integration will be developed.
M3.3	21	**Title:** CSSD demonstrator finalized **Description:** At this point, the CSSD will be finalized. All systems will be adjusted to solve the problems identified in field tests and maximize performance. The design will be simplified for future production.
M4.1	9	**Title:** Data collected during field campaign 1 **Description:** The execution of the field campaign 1 marks the milestone for the acquisition for the first set of optical and acoustic camera images. During this campaign, data are acquired for munitions objects that are identified during Task 4.1.
M4.2	15	**Title:** Expert survey on 3D reconstructions **Description:** Based on the first set of 3D reconstructions (and 3D reconstructions, that were already prepared during the UDEMM and BASTA projects) a questionnaire to gather expert feedback will be developed. Experts will be asked to provide information on the usefulness of 3D reconstructions from optical and acoustic images, to indicate in which use cases the 3D reconstructions would be most beneficial for their work and to provide ideas for improvement.
M4.3	21	**Title:** Data collected during field campaign 1 **Description:** The execution of field campaign 2 marks the milestone for the acquisition for the second set of optical and acoustic camera images. During this campaign, data are acquired for munitions objects that are selected in accordance with the expert feedback that is provided by the work in Task 4.4.
M4.4	30	**Title:** Data collected during field campaign 3 **Description:** The execution of field campaign 3 marks the milestone for the acquisition for the third set of optical and acoustic camera images. During this campaign, data are acquired for munitions objects that are selected in accordance with the expert feedback that is provided by the work in Task 4.4.

Milestone No.	Month	Milestone Title + Description
M5.1	18	**Title:** EOD support software alpha **Description:** The EOD support software can access the database and use the preliminary BNN to provide an overall risk value for a given munitions item at a given location.
M5.2	27	**Title:** EOD support software beta **Description:** The EOD support software can access the database and use the BNN to provide a risk value for a given munitions item at a given location and propose a clearance method for ad-hoc decision making. With the beta version, it will be possible to compare real decisions of EOD experts during previous EOD campaigns with the suggestions that are made by the BNN.
M5.3	36	**Title:** EOD support software final version **Description:** In addition to the achievements of the beta version, this version incorporates the feedback of EOD experts on how to best utilize the software. It has a fully functioning UI, that allows users to enter new EOD data and immediately obtain a recommendation for a clearance method for ad-hoc decision making and a risk value for a given munitions item at a given location.
M6.1	2	**Title:** Project Kick-Off Meeting **Description:** During the project kick-off meeting, project partners will make detailed plans for the project and align on the joint activities that will take place over the course of ProBaNNt. Furthermore, ProBaNNt's project background, methods and project aims will be presented to interested stakeholders.
M6.2	11	**Title:** 1st Annual Meeting **Description:** During the annual meeting, project partners will meet and stakeholders will be invited to inform about and discuss project progress.
M6.3	23	**Title:** 2nd Annual Meeting **Description:** During the annual meeting, project partners will meet and stakeholders will be invited to inform about and discuss project progress.
M6.4	35	**Title:** Final event **Description:** During the final event, project results will be showcased to national funding organizations and interested stakeholders.

Table of Deliverables

Deliverable No.	Month	Deliverable Title + Description
D1.1	24	**Title:** Database established **Description:** The EOD database will be established and available to all project partners and associated partners, interested in providing data or testing the use of the database. Furthermore, the data management strategy will be described in a guideline. It will include definitions of data formats, required information for EOD datasets, data quality requirements, data entry workflow (both for automated data import and for manual data entry) and hints for data acquisition that help to ensure obtaining high-quality data.
D1.2	34	**Title:** Description of database content **Description:** After the great majority of data have been gathered throughout the runtime of ProBaNNt, a description of the database content will be provided. This is to prove that the database content is representative for EOD operations and to communicate to users, what the suggestions of the EOD support tool are based upon. Furthermore, the description will discuss how representative the database content is for different regional seas and munitions types.
D2.1	12	**Title:** Cruise report 1 **Description:** After the first field campaign is completed, a technical cruise report will be prepared. The report will include detailed information about areas and objects that were surveyed, used equipment, its parameters and possibly occurred issues. Cruise reports will be prepared in accordance with reporting requirements mandated by the Quality Guideline for Offshore EOD.
D2.2	24	**Title:** Cruise report 2 **Description:** After the second field campaign is completed, a technical cruise report will be prepared. The report will include detailed information about areas and objects that were surveyed, used equipment, its parameters and possibly occurred issues. Cruise reports will be prepared in accordance with reporting requirements mandated by the Quality Guideline for Offshore EOD.
D2.3	33	**Title:** Cruise report 3 **Description:** After the third field campaign is completed, a technical cruise report will be prepared. The report will include detailed information about areas and objects that were surveyed, used equipment, its parameters and possibly occurred issues. Cruise reports will be prepared in accordance with reporting requirements mandated by the Quality Guideline for Offshore EOD.
D3.1	21	**Title:** CSSD available and described **Description:** The CSSD will be available and will be demonstrated to all project partners, associated partners and funding organizations. It will be capable of generating currents at precisely determined speeds. It will be able to measure turbidity and communicate measurement results to the vessel at the surface. A technical report of the CSSD demonstrator will be prepared. This document will include information on the process of conceptualizing, constructing and testing the device. It will describe the capabilities and limitations of the CSSD and describe used cases for future application in an EOD context and beyond.

Deliverable No.	Month	Deliverable Title + Description
D3.2	24	**Title:** Report on critical shear stress **Description:** In this report an updated sediment transport model, including measurements of critical shear stress will be presented. The model will be able to predict sediment erosion and transport in cases of EOD activities. In the report we will furhtermore analyse whether and how the critical shear stress values that are measured in-situ deviate from the laboratory measurements and the calculated shear stress values that are currently used. Consequently, the impact of these deviations on the sediment transport model will be assessed. In essence, this will be a report on the importance of the critical shear stress value for sediment transport values.
D4.1	12	**Title:** Objects from dataset 1 reconstructed **Description:** Numerous 2D and 3D reconstructions of optical and acoustic camera images from field dataset 1 are ready for expert evaluation and can be added to the EOD database.
D4.2	24	**Title:** Objects from dataset 2 reconstructed **Description:** Numerous 2D and 3D reconstructions of optical and acoustic camera images from field dataset 2 are ready for expert evaluation and can be added to the EOD database.
D4.3	33	**Title:** Objects from dataset 3 reconstructed **Description:** Numerous 2D and 3D reconstructions of optical and acoustic camera images from field dataset 3 are ready for expert evaluation and can be added to the EOD database.
D4.4	33	**Title:** Expert evaluation report **Description:** The outcome of the ongoing expert evaluation is summarized in a report. It describes the evaluation workflow and most relevant use cases and scenarios for 3D munitions scanning and reconstruction.
D5.1	36	**Title:** EOD support software and documentation **Description:** The EOD support software will be released and made available to EOD experts. The software will provide decision support that is based on the results generated by the BNN. The software will access the EOD database. With the software, EOD experts will be able to understand how EOD parameters impact one another, to assess the risks of a given munitions item in its environment and to receive a recommendation on the safest EOD method. The software will have an intuitive user interface both for the entry of new EOD data into the EOD database and for the decision-making support. The software code can be made available upon request. A technical description of the functionality of the software, the underlying workflows and a manual on how to utilize it. This description will also feature a detailed explanation and a depiction of the underlying BNN.
D6.1	3	**Title:** Project website **Description:** The project website will inform about the content, the progress and the results of ProBaNNt.

Deliverable No.	Month	Deliverable Title + Description
D6.2	12	**Title:** 1st annual progress report **Description:** This is a report informing the funding organization and interested stakeholders on the progress of ProBaNNt in accordance with the reporting requirements of the national funding organizations and MARTERA.
D6.3	24	**Title:** 2nd annual progress report **Description:** This is a report informing the funding organization and interested stakeholders on the progress of ProBaNNt in accordance with the reporting requirements of the national funding organizations and MARTERA.
D6.4	36	**Title:** Final report **Description:** This is a report informing the funding organization and interested stakeholders on the results of ProBaNNt in accordance with the reporting requirements of the national funding organizations and MARTERA.

GANTT CHART

Name	Months	Duration
Work package 1	Months 01 - 36	36 Months
Task 1.1	Months 01 - 18	18 Months
Task 1.2	Months 01 - 30	30 Months
Task 1.3	Months 01 - 36	36 Months
Milestone 1.1	Month 03	1 Month
Milestone 1.2	Month 06	1 Month
Milestone 1.3	Month 18	1 Month
Milestone 1.4	Month 24	1 Month
Milestone 1.5	Month 24	1 Month
Deliverable 1.1	Month 24	1 Month
Deliverable 1.2	Month 34	1 Month
Work package 2	Months 9 - 35	27 Months
Task 2.1	Months 9 - 30	22 Months
Task 2.2	Months 10 - 35	26 Months
Task 2.3	Months 16 - 35	20 Months
Milestone 2.1	Month 9	1 Month
Milestone 2.2	Month 21	1 Month
Milestone 2.3	Month 30	1 Month
Deliverable 2.1	Month 12	1 Month
Deliverable 2.2	Month 24	1 Month
Deliverable 2.3	Month 33	1 Month
Work package 3	Months 01 - 24	24 Months
Task 3.1	Months 01 - 06	6 Months
Task 3.2	Months 07 - 12	6 Months
Task 3.3	Months 13 - 21	9 Months
Task 3.4	Months 18 - 24	7 Months
Milestone 3.1	Month 06	1 Month
Milestone 3.2	Month 12	1 Month
Milestone 3.3	Month 21	1 Month
Deliverable 3.1	Month 21	1 Month
Deliverable 3.2	Month 24	1 Month
Work package 4	Months 01 - 33	33 Months
Task 4.1	Months 01 - 03	3 Months
Task 4.2	Months 9 - 30	22 Months

Name	Months	Duration	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Task 4.3	Months 04 - 33	30 Months																																				
Task 4.4	Months 13 - 33	21 Months																																				
Milestone 4.1	Month 9	1 Month																																				
Milestone 4.2	Month 15	1 Month																																				
Milestone 4.3	Month 21	1 Month																																				
Milestone 4.4	Month 30	1 Month																																				
Deliverable 4.1	Month 12	1 Month																																				
Deliverable 4.2	Month 24	1 Month																																				
Deliverable 4.3	Month 33	1 Month																																				
Deliverable 4.4	Month 33	1 Month																																				
Work package 5	Months 01 - 36	36 Months																																				
Task 5.1	Months 01 - 12	12 Months																																				
Task 5.2	Months 10 - 27	18 Months																																				
Task 5.3	Months 19 - 33	15 Months																																				
Task 5.4	Months 25 - 36	12 Months																																				
Task 5.5	Months 01 - 36	36 Months																																				
Milestone 5.1	Month 18	1 Month																																				
Milestone 5.2	Month 27	1 Month																																				
Milestone 5.3	Month 36	1 Month																																				
Deliverable 5.1	Month 36	1 Month																																				
Work package 6	Months 01 - 36	36 Months																																				
Task 6.1	Months 01 - 36	36 Months																																				
Task 6.2	Months 01 - 36	36 Months																																				
Milestone 6.1	Month 02	1 Month																																				
Milestone 6.2	Month 11	1 Month																																				
Milestone 6.3	Month 23	1 Month																																				
Milestone 6.4	Month 35	1 Month																																				
Deliverable 6.1	Month 03	1 Month																																				
Deliverable 6.2	Month 12	1 Month																																				
Deliverable 6.3	Month 24	1 Month																																				
Deliverable 6.4	Month 36	1 Month																																				

research aspects and disciplines, including physical oceanography, marine meteorology, geology and geophysics, benthic and pelagic biogeochemistry, trace element chemistry as well as biology and microbiology. Research topics include ‘Marine Resources’, ‘The Role of the Ocean in Climate Change’, ‘Marine Hazards’ and ‘Human Impact on Marine Ecosystems’. GEOMAR has long-lasting experiences in coordinating FP7, H2020 and other international and national large-scale projects including SFBs and the Future Ocean Excellence Cluster.

Next to its scientific tasks, GEOMAR operates large equipment, that is relevant to the ProBaNNt project. This includes two research vessels that will be utilized for the project. Further GEOMAR operates three AUVs, two ROVs, mobile multibeam systems and seafloor deployable camera systems among equipment for water and sediment sampling. GEOMAR also has extensive analytical capabilities, among them a specialised laboratory for analysing trace-concentrations of munitions compounds. All these facilities will be available for the project.

Concerning munitions in the seas, GEOMAR gained substantial knowledge since 2013, cooperated with RoBEMM project and coordinated the UDEMM project. Particular knowledge exists for munitions mapping and chemical analyses of water samples. GEOMAR has also some knowledge with regards to the oceanography of the Baltic Sea and toxicological analyses of biota. The main proponent of GEOMAR (Prof. Greinert) is head of the DeepSea Monitoring group and coordinated the BMBF funded Project UDEMM (https://udemm.geomar.de/). Currently, he is coordinating the BASTA project and is closely cooperating with Prof. Achterberg from GEOMAR who is coordinating the ExPloTect project. As such GEOMAR is very well suited to join the ProBaNNt project and to take over the assigned task in the various WP.

SeaTerra

Founded in 1999, German company SeaTerra GmbH has over twenty years of extensive experience in the field of UXO surveys and clearance campaigns on land, nearshore and offshore. From military training grounds to developing inner-city areas, from surveys on tidal flats to offshore wind parks, or searching for pipelines in the desert sand, SeaTerra can look back on hundreds of successfully completed projects. The wide range of sensor systems available to SeaTerra, the experience of our employees, and the ability to react flexibly to new challenges are the hallmarks of our work.

SeaTerra employs various methods to locate, excavate and identify munitions objects. Our skilled employees have extensive experience in handling underwater munitions, recovering, relocating and also professionally demolishing large munitions in the sea. During numerous offshore projects, SeaTerra assists in the construction of wind turbines and the safe installation of submarine cables within budget and on schedule by clearing the UXOs in a professional manner.

SeaTerra employs a wide range of EOD specialists, geophysicists and technical personnel. For over 20 years, SeaTerra has been one of the driving forces behind technical innovations in the field of geophysics and UXO survey and clearance operations.

CTM

Established in 1982, the Polish Ośrodek Badawczo-Rozwojowy Centrum Techniki Morskiej JSC has extensive competences and experiences in designing, constructing, supplying and maintaining integrated systems in the area of naval and civilian maritime technologies. This particularly concerns command, data analysis and processing, communication, naval vessels and underwater systems. With its modern research, technical and production facilities, CTM delivers and develops its solutions thanks to continuous research, development and implementation work. Participation in national and foreign R&D programmes is the key activity of the centre, including for EDA and NATO.

CTM offers services of design, testing, implementation and development of prototype and demonstrator solutions and technologies, while ensuring their integration with IT systems, creating their environment. In the area of detection and classification of sea mines CTM is a producer of SHLtriple frequency band high-resolution hull mounted MCM sonar. Last implementation of this system took place on MCM class Polish Navy vessel ORP Kormoran.

IO PAN

Polish research institute IO PAN performs all kinds of marine research, ranging from oceanography to marine chemistry and marine biology, employing ca. 200 Scientists. IO PAN is equipped with the 49 m Research Vessel “Oceania”, Autonomous Underwater Vehicle IVER2 and remotely operated underwater vehicle (ROV, Saab SeaEyeFalcon). IO PAN has developed a high-resolution model for contamination spread from munitions objects and has the capability to apply it to EODs scenarios. IO PAN’s operational oceanography department is capable of performing a wide range of oceanographic measurements and our chemistry department is experienced in analyzing metals that could be used as tracers for explosive compounds. IO PAN has fully equipped mechanical and electronic workshops for prototyping underwater devices.

IO PAN has long-lasting experience in munitions related projects. It coordinated the CHEMSEA project, focusing on munitions surveys and environmental impact of dumped munitions. This work was continued in NATO SPS project MODUM, where IO PAN, again as coordinator, focused on multidisciplinary approaches of dumpsites monitoring. This experience was then extended into a neural-network-based Decision Support System (DSS) and into aggregating both environmental and munitions data in projects DAIMON and DAIMON2, coordinated by IO PAN. Within those projects, scene recognition was conducted to provide input to the DSS.

IO PAN will be responsible for the development of EOD scene characterization by means of a compilation of multiple AUV and towed side scan sonar runs into pseudo-3D-image and construction of in-situ shear stress measurements, development of 3D object reconstruction based on video and front looking sonar imagery and field tests of developed technologies in the Baltic Dumpsites.

Necessity of cooperation within the consortium

All data that support munitions identification and EOD decision-making are relevant inputs for the EOD support tool. Accordingly, such data, which are available to members of the consortium will be forwarded to GEOMAR, where data processing and integration into databases and the training of the BNN will be executed. The same is true for data that are acquired during the field campaigns and data that SeaTerra collects during EOD campaigns while the project is running. This process is not limited to the transfer of the data, but also includes support with data interpretation and joint definition of a standard operating procedure for data handling. GEOMAR will provide or organize the provision of data infrastructure for all other partners to access. This can be seen as a starting point (one additional pillar) for a coming European EOD database.

SeaTerra will support IO PAN and GEOMAR with the selection of appropriate objects for the 3D photogrammetric and acoustic reconstruction. Objects that have posed as challenges during previous EOD campaigns will be favoured as 3D reconstructions are expected to yield higher benefits for such objects. Once reconstructions are available, SeaTerra will consult IO PAN and GEOMAR on necessary improvements to the reconstructions to be able to routinely integrate them into daily EOD work. EOD experts of SeaTerra will also verify results generated by the EOD support tool. Once primary results of scene recognition, 3D reconstruction and the EOD support tool are available, personnel of IO PAN and GEOMAR will be available to support SeaTerra with the integration of these tools in the EOD value chain, when such an opportunity arises.

For budget reasons, vessel time will be requested both in Germany and Poland by GEOMAR and IO PAN, respectively. This way, the project result representativeness for the Baltic Sea region will be improved. CTM representatives will join field campaigns to supervise the use of the CSSD to generate progressive water currents and will supervise the magnetometer and side scan surveys. Furthermore, CTM will support IO PAN with the processing and evaluation of data acquired during the field operations.

The data generated during field campaigns and integrated into the EOD support tool are complimentary to the DSS system developed during DAIMON and DAIMON 2. Interoperability of databases will increase the performance of both tools. We anticipate that at a later stage the EOD support tool will be linked to the decision aid process provided by DAIMON DSS, for cases in which remediation is the conclusion for a given area.

IO PAN will support GEOMAR with regard to environmental aspects of EOD method selection and scene recognition. ProBaNNt is the first project that will use results originating from both UDEMM and DAIMON.

Necessity of cooperation outside the consortium

Collection of EOD data from all over Europe will be partially done from within the consortium and in cooperation with running projects at GEOMAR (e.g. BASTA). Data from additional actors will help to increase the quality of the database and the BNN and might be the first step towards a European EOD database. This will require the consortium to clearly communicate the benefits of such a joined database. The GEOMAR coordinated project BASTA contains a stakeholder engagement process. A BASTA stakeholder workshop could therefore be extended to also address the objectives and data requirements of ProBaNNt. GEOMAR will try to align this plan with BASTA project requirements and partners.

If both projects are funded by MARTERA, ProBaNNt partners will strongly interface with the AMMOTRACe consortium. The aim of AMMOTRACe is to perform real-time detection of munitions compounds in the water column. Data generated in the project can be added to the EOD database, as information on the type of explosive compound detected next to a munitions object can provide information on the type and state of that object (or objects that may be present in the vicinity). AMMOTRACe technology should therefore be applied during ProBaNNt cruises and EOD experts from SeaTerra should, in turn, review the objects investigated during AMMOTRACe cruises. Furthermore, since there will be considerable overlap among interested stakeholders in the scientific and industrial community, workshops and events will be aligned. This will safe costs and provide increased visibility for both projects.

As an important and iterative step, we see that EOD experts will be requested to verify results generated by the EOD support tool as well as its applicability and usability.

Offering the EOD support tool as an easy to use the solution in the future relies on a professional distribution of the software to expert companies. Software development and Software as a service (Saas) provider EGEOS GmbH has signalled willingness to become an associated partner to the project in case of funding (see attached LOI). After successful completion of ProBaNNt, EGEOS can host the software on webservers and distribute licenses to end-users. The Decision Support System (DSS) created within DAIMON project operates on the same platform. Availability of both systems on one platform may serve further growth of its user base. Similarities in the interface may simplify training for those users, who are already familiar with the DSS.
As munitions identification plays a central role in ProBaNNt, the project consortium will facilitate a dialogue with providers of munitions

databases. During DAIMON, an ammunition catalogue was generated (Miętkiewicz 2020), to which ProBaNNt-partners will have access. The most comprehensive database in Germany is owned by Dresdner Sprengschule GmbH and first talks on implementing this munitions database with ProBaNNt's EOD database were successful (see attached LOI). These databases are already consulted by EOD experts to identify munitions objects and to look up their specific properties. High-resolution images and reconstructions generated during ProBaNNt can be added to these databases as representative examples of an object that has been in the marine environment for decades. Having direct access to these databases would benefit the BNN training and the usability of the EOD support tool.

Figure 11 provides an overview of numerous ongoing and proposed projects dealing with munitions in the sea. Each of the projects covers different aspects of the offshore EOD value chain, thereby demonstrating that no redundant funding is requested through all these projects. EASME funded projects BASTA (orange) and ExPloTect (yellow) and Interreg Baltic Sea Region project DAIMON (turquoise) are already running. ProBaNNt (blue) aims at the investigation and assessment of munitions objects and areas of concern. AMMOTRACe aims at performing real-time detection of munitions compounds in the water column, to support area surveys. UnLowDet (red) proposes a new way of opening munitions underwater with lasers. The CLEAR (grey) proposal will address the salvaging of munitions with a crawler, focusing on dumpsites. Finally, a successor to RoBEMM (purple), which will deal with the thermal treatment of munitions, is currently in preparation. The project consortium will ensure close cooperation with the consortiums of those projects, to avoid overlaps and ensure the exploitation of synergies.

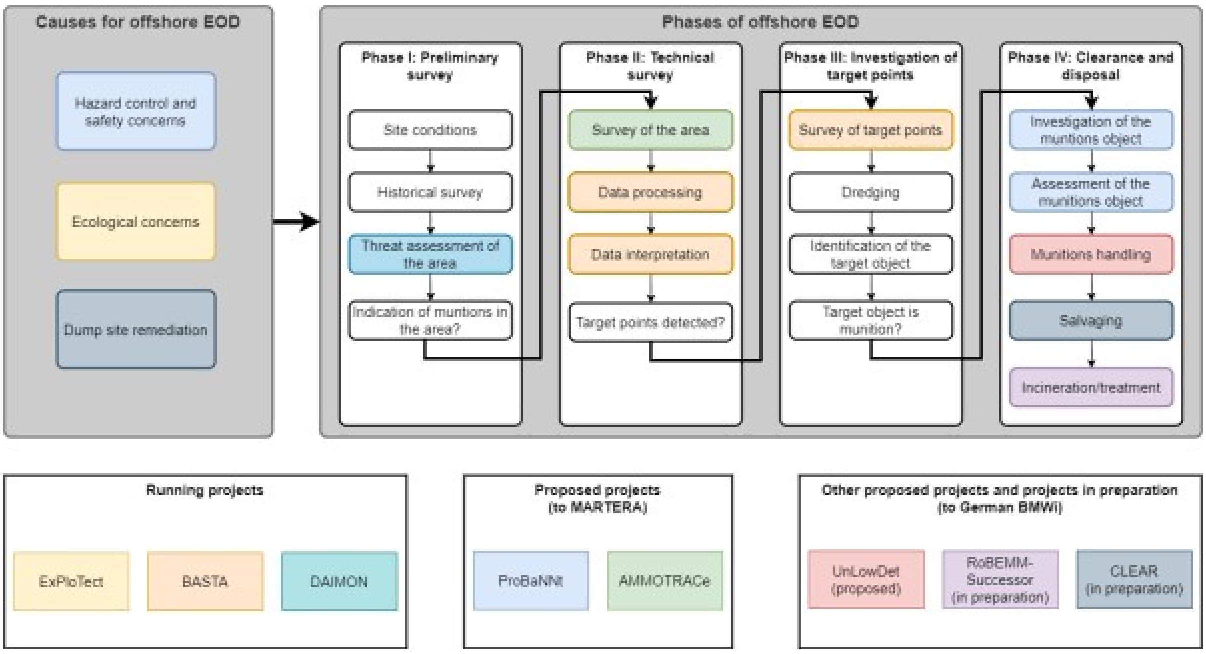

Figure 11: Overview of ongoing and proposed projects related to munitions in the sea (GEOMAR).

EXPLOITATION PLAN

Economic advantages, commercialisation and impact for the companies

Through ProBaNNt, SeaTerra will be the first company in the world that is equipped with the new EOD database, 3D reconstructions of munitions and the EOD support software. Currently, EOD operations' primary execution takes place during offshore construction projects (e.g. offshore wind and pipelines) and cleaning of shipping routes. While the project results will also apply to these efforts, the improvement lies in the newly gained ability to apply all of the above to the clearance of munitions dumpsites on a large scale. When funds for the clearance of these sites are made available, the results of ProBaNNt will give SeaTerra a significant competitive edge.

With the capacity to generate a risk estimate for any given munitions item at any location in European waters and exclusive economic zone, SeaTerra will be able to offer novel consultancy services to offshore contractors, EOD companies and military. The EOD value chain would benefit greatly from being able to assess the risks of munitions during the project planning stage. After the project has been finished, SeaTerra will be able to offer training to EOD experts on operating the EOD support tool.

CTM will bring the CSSD demonstrator to market readiness. CTM and IO PAN will jointly file a patent for the device. Assessing local sediment mobility is important for all industry sectors dealing with polluted sediments (e.g. offshore oil and gas drill-cuttings). Furthermore, it can be used to predict the time period that it takes until divers can access a site with sufficient visibility after sediment interference. An integrated and comprehensive methodology for area mapping will allow CTM to offer a complete sensor suite, that allows to efficiently acquire high-resolution data for small areas of great interest. The area of application in ProBaNNt are EOD sites, but transfer to other uses, such as pipeline leak detection is possible. We expect that utilizing the CSSD during the clearance of single munitions objects will be too time-consuming and therefore inefficient. However, it can serve as a valuable addition to the assessment of the properties of munitions dumpsites. Before thousands of individual objects in dumpsites are cleared, measurements of critical shear stress are relevant to determine the overall EOD strategy for such sites.

ProBaNNt results will generally improve SeaTerra's and CTM's capacity to perform munitions object identification and classification. The developed technologies can be used for EOD campaigns that take place in preparation of offshore construction (e.g. the expansion of offshore wind parks) and dredging projects (e.g. the navigation channels leading towards the ports of Wilhelmshaven and Gdansk (see attached LOI), both of which will be expanded in the next years).

Scientific and technical expectations

Scientifically and technically we have four expectations:

a) We will set up the ProBaNNt database, which is initially planned as a project database but will later be integrated into of a federated European database concept. A federated database should act as a central source for data related to munitions in European seas. It would increase both the capacities of companies such as SeaTerra to perform EOD services and of scientific institutions for future big data analysis projects on the topic. While DAIMON and UDEMM data should also be added to the federated database, these mainly contribute information on environmental impacts of munitions. ProBaNNt, on the other hand, with its focus on EOD data, will add a completely new source of information.

b) We will develop a standardised workflow for the 3D reconstruction of munitions objects and their surroundings, using optical and hydroacoustic imaging cameras. While we assess the use of 3D reconstruction in connection to EOD, the methods developed in ProBaNNt can be combined with the automated munitions target picking developed in BASTA, to further support munitions detection campaigns. 3D reconstructions can not only support EOD, but improve the capacity to discriminate between munitions and other anthropogenic objects on the sea floor. This applies specifically to the 3D object reconstruction from hydroacoustic images, which has not been done before. Finally, the standardized workflow will serve as a basis for integrating an automated 3D reconstruction module into the EOD software in the future.

c) We want to better understand the resuspension and distribution of sediment through in-situ measurements and the application of the gained knowledge within oceanographic sediment transport models. Based on the results obtained with the CSSD demonstrator, the accuracy of sediment resuspension models will be increased. This provides relevant input into the discussion of transboundary environmental impact, where this parameter is frequently questioned, due to differences in modelling software used by offshore experts and scientists.

d) We want to improve decision-making capacities during EOD project planning and during EOD execution, through AI-based decision support. This aims at integrating the benefits of EOD expert knowledge, that was gathered over years of clearing munitions, with the advantages of objective, reproducible and data driven AI-generated results. The understanding on how this integration works, can be extrapolated to other high-risk offshore activities.

Scientific and economic continuation

ProBaNNt will focus on conventional, explosive munitions, which make up the majority of submerged munitions both in Europe and worldwide. During the project, the consortium will first concentrate on data from the project partner SeaTerra. Hoping that a number of other EOD companies will supply data as well, we will extend the database as needed during the project runtime. We foresee that after the project successfully ends more EOD companies will want to provide their data in exchange for getting access to all the data already contained in the database. At this stage, we see a European wide initiative of a federated data management scheme developing, which will be an economically valuable extension of the project aims.

Additionally, with growing economic use of the European seas, clearing chemical munitions will become an increasingly important task to perform. Accordingly, an expansion of the BNN to include chemical munitions and warfare agents as well as specific EOD practices that are required for this type of challenge is planned by GEOMAR after the finalization of the project. Generally, the BNN approach can be transferred to decision-making processes taking place e.g. in the offshore oil and gas industries as well as the emerging deep-sea mining sectors (GEOMAR runs the MiningImpact-II project as part of a JPIO activity, dealing with deep sea mining and its environmental impact; https://miningimpact.geomar.de/).

The 3D reconstruction workflow developed within ProBaNNt will enable more reliant risk assessment for munitions objects, which will, in turn, lead a new approach for evaluating the state of corrosion of munitions and thus predict the severity of pollution.

Compatibility with Norms, Standards and Regulations

In 2020, the German *Quality Guideline for Offshore Explosive Ordnance Disposal* was released, the closest document to a standard in offshore EOD to date. When ProBaNNt is completed, an update of that document would be appropriate to introduce the newly developed technologies and decision-making practices into the guideline framework. The barriers for changing the document are low, as the main author of the quality guideline is part of the ProBaNNt consortium.

The CIRIA guidance document C754 *Assessment and management of unexploded ordnance (UXO) risk in the marine environment* covers the assessment of risks originating from munitions for the offshore construction industry. It does, however, view EOD as part of risk management and not as a risky activity itself and does not include scenario-specific clearance methods. The proposed risk value that is generated in WP5 is an opportunity to amend the document so that it also includes EOD risk and proposes clearance methods.

German Explosives Law requires a certificate of competence for the person who is responsible for the handling of explosive material §§ 20, 21 SprengG. All project objectives of ProBaNNt aim at strengthening this person's position as an objective decision-maker, in dealing with munitions in the sea. The same is true for the equivalently competent personnel according to the regulations of other European states.

Sustainability including social and environmental impact (employment, quality of life, regional aspects, working conditions)

ProBaNNt contributes to the sustainable use of the seas. The main aspects of Integrated Coastal Zone Management – multi-sectoral economic growth, environmental protection and sustainable resource use – are all negatively affected by the presence of submerged munitions on a global scale. The ability to assess the risk of munitions objects and to make more informed decisions on EOD processes will increase occupational safety in the offshore EOD industry itself and will positively affect the offshore construction sector.

EUROPEAN ADDED VALUE IN CARRYING THE WORK AT EUROPEAN LEVEL

Added value in carrying out the work at a transnational level

Submerged munitions are present in European territorial waters, EEZs and inland waters. Over the past decades, thousands of munitions objects have been detected, identified and cleared all over the continent. However, environmental conditions that affect EOD vary in the different European Seas. On top of that, different types of munitions are submerged in different countries. Therefore, information from EOD campaigns from all over the continent should be included, to enable truly representative data analysis and to provide decision support for all European seas. The result will be an EOD support tool that is ready for application in the Baltic Sea and can be transferred to the North Sea, Mediterranean Sea, Black Sea and North-East Atlantic.

ProBaNNt is a contribution to expanding European market leadership in offshore munitions clearance and disposal. Given the trend towards a globally growing offshore industry, it is inevitable that munitions dumpsites, as well as scattered munitions originating from combat, will to an increasing level become a challenge for countries outside Europe. Establishing critical technologies in the European market now, will therefore lead to the ability to export both technologies and services outside Europe in the future.

Societal solutions

The presence of millions of tons of explosive material in the seas constitutes a constant underlying risk during all offshore activities. This includes industries such as aquaculture, coastal tourism, ocean energy and seabed mining, all of which were identified as sectors with high potential for sustainable jobs and growth in the European Union's Blue Growth strategy (European Commission 2017). Being able to safely and reliable remove munitions will gradually reduce this underlying risk over the next decades. ProBaNNt, therefore, contributes to Blue Growth. Offshore EOD has most prominently been practised as a step during ground reconnaissance during offshore wind park construction. ProBaNNt therefore also contributes to Europe's transition to a low carbon society.

The 21st century presents European defence with a variety of new geopolitical challenges. ProBaNNt, therefore, proposes to relieve European military forces of the burden of having to deal with the legacies of wars of the past. Instead, this task is shifted to specialized private EOD companies, such as SeaTerra. ProBaNNt equips these companies with additional tools for decision making during munitions clearance. Provided the requirements of acting in a competitive market, the project consortium is convinced that private companies can execute large scale EOD campaigns in the seas at a significantly lower cost than naval forces could.

CTM previously executed projects for European Defence Agency. After the project is finished, ProBaNNt results on object identification and EOD decision-making can be transferred to active mine hunting. Accordingly, the project results indirectly benefit European defence.

Environmental solutions

ProBaNNt directly contributes to the MSFD which intends to achieve the Good Environmental Status (GES) of European marine waters. The GES is described in article 9 of this directive based on 11 descriptors. Descriptor 8 is specifically relevant for the topic of offshore munitions dumpsites as it addresses “Contaminants and pollution effects”. It furthermore supports HELCOM, OSPAR and the Barcelona conventions for the protection of the marine environment in Baltic, North and Mediterranean Seas.

Underwater detonations of larger munitions objects (such as ground mines and torpedoes) are the largest point sources of underwater noise (Koschinski 2009). The resulting sound and pressure waves have various harmful effects for all kinds of marine biota, but most prominently on marine mammals by strongly affecting their hearing and orientation capabilities. The EOD support tool will provide propositions for clearance methods, that is informed by the comprehensive EOD database and the BNN. The harmful in-situ-detonations will only be proposed as a clearance method, when they are necessary and no other available technology can be utilized. In addition, 3D reconstructions of sonar camera images will provide EOD experts with new information on the properties of munitions objects despite limited underwater visibility. Objects that can be identified this way might be salvaged instead of being detonated on site. Furthermore, additional EOD experts can contribute to the decision process if 3D information can be shared quickly.

Since BNN will also assess the risk of leakage of hazardous substances, they will furthermore propose clearance methods that are most suitable for avoiding such leakage.

The CSSD demonstrator will be used to determine the potential spread and distribution of contaminated sediments in the vicinity of munitions objects. Based on the results of this assessment, EOD methods can be adapted to avoid stirring up polluted sediments.

NECESSITY FOR FUNDING AND RISK

Scientific risks

Relevant authorities and specialist companies that are not part of the project consortium may be reluctant to provide information on previously performed EOD actions. This may especially be true for the military and competitors of SeaTerra. In this case, it is possible to generate EOD scenarios for areas in which no data are available. This can be achieved by using GIS to distribute fictional EOD scenarios at random locations in European waters. These scenarios will be randomly generated and based on past clearance actions. EOD experts will then be asked to propose a clearance strategy under the light of the given local environmental conditions.

Obtained EOD data may be collected with different methods. In addition, data quality may vary and recordings of environmental parameters may be insufficient. To supply all relevant information to the BNN, recorded data will be supplemented with georeferenced data from field studies, public databases and through extrapolation using existing ocean models for the North and Baltic Sea.

The heavy reliance on expert knowledge and situational assessment has been the standard procedure in EOD decision-making. Moving towards a data-driven EOD support tool marks a paradigm shift for industry actors, responsible authorities and military bodies. In order to, later on, be able to offer consultancy services and training to EOD experts, it is necessary to engage in a stakeholder dialogue during the project. This way, we will create trust in the newly developed tools.

Calculation of critical shear stress may be difficult in sediments with low fine grain content (i.e. sandy bottom and non-cohesive sediments). This will be addressed by adding extra channels in sensors and measuring total suspended solids at different heights above the seafloor. This will enable the use of differential equations instead of simple gradients in the calculation and hence ensure the precision of calculation even in case of minimum resuspension. In the case of coarse-grained sediments, the equation for sand transport will be used instead of cohesive sediment erosion formulae.

Technological risks

Bad weather may negatively influence the consortiums capacity to acquire meaningful data in sufficient quality during field campaigns. Measurement results acquired with magnetometers and side-scan sonar may be unfit for scene recognition. In addition, visibility may be reduced, so that optical camera records may not be of suitable quality to generate 3D reconstructions. In order to partially overcome the issue of low visibility, the acoustic camera with high-resolution settings was added to this project. Field demonstrations of ProBaNNt are planned to take place in summer, thereby reducing the probability of bad weather but decreasing visibility. Dates (and alternative dates) for field campaigns will be determined immediately if ProBaNNt is funded. Finally, in Gdansk Basin, there are two separate sites with munitions present. An ad-hoc assessment prior to field campaigns will be performed to determine the site with most favourable conditions at the time of the cruise.

Like any operation that involves investigating underwater munitions, there is a risk that any given piece of munitions may detonate. This residual risk cannot be eliminated. It will be reduced to a minimum by thorough risk and hazard assessments prior to the initiation of the field demonstrations.

There is a risk of equipment malfunction and loss. Malfunctioning might occur during the first tests of the CSSD demonstrator. The work at all sites will be limited to day cruises, meaning that technical problems can be worked on during the following days. Before testing of the equipment before the cruise will be done. All the other equipment is proven technology and will work reliably as all partners are well trained for their operations. Loss of equipment is minimal and includes the normal danger of operating equipment at sea. Highest risks are given during deployment and recovery of equipment when the sea state is not ideal. However, the shallow water depth enables a fast recovery well before the sea state is getting problematic. In the case of AUVs and ROVs used in the project, recovery systems that are able to operate in heavy weather will be used (latch-lock and recovery net).

Economical risks

Due to the limitations that still exist in employing certain technologies in the underwater environment, it is possible that part of the development of the CSSD is not successful. This risk cannot be financially carried by IO PAN and CTM.

Administrative risks

Due to the high hazard connected to placing the CSSD in a munitions dumpsite, it is possible, that authorities deny or delay approval to use the device. To avoid this, a hazard assessment for using the demonstrator in this environment will be developed and discussed with responsible authorities immediately after ProBaNNt started. Tests with the CSSD can furthermore, be performed outside of munitions dumpsites, which drastically reduces the risk of encountering munitions and of denied approval by authorities.

Environmental risks

Impact on marine life might come from the operation of acoustic equipment. All the used equipment is high frequency and low energy. The degree of interference will be in the range of normal low-level geophysical operations and the ambient noise of the marine environment.

Necessity for funding

At this point, several thousand munitions items in European waters have been identified and EOD has consecutively been performed. These data remain largely unvalued, as high-intensity day-to-day operations in EOD do not allow for a thorough assessment of projects that lie years in the past. Accordingly, the work proposed in ProBaNNt can only be performed as part of a publicly-funded research project.

The great majority of offshore munitions related projects funded in Europe have focused on the detection of munitions objects. In order to clear European waters of this legacy, it is necessary to advance technologies aiding processes that benefit the clearance of the objects. Object identification, scene recognition and EOD decision support are the final steps before clearance actions can take place in a largely objective way (see Figure 5).

Offshore EOD technological and methodological development was driven by European Blue Growth, in particular by offshore wind park construction. This industry's expansion, in turn, depends on national decision making on energy policy. Thus, the speed with which EU member states choose to construct offshore wind parks strongly determines whether offshore EOD will be a profitable business model. Offshore EOD (with all its environmental benefits) is therefore currently a by-product of Blue Growth and not an integrated part. Investments such as the ones proposed in ProBaNNt are therefore risky and require funding.

Momentarily there is no large-scale order for clearance operations of a munitions dumpsite. A contract volume of such magnitude can only be carried by state actors. These are currently reluctant to commission a contractor. ProBaNNt has the aim of demonstrating to public authorities, how objective, data-driven and transparent decision making during offshore EOD works. However, as it remains unclear whether public funding for dumpsite clearance on a strategic level will be made available in the near future, every investment in this direction is high risks for private corporations, as it is impossible to make a return on investment prediction. If governments decide to move towards large-scale clearance of munitions dumpsites, offshore EOD will become a billion-euro industry-leading a very high return on the investments proposed in ProBaNNt.

Performing technological development and research in times of a pandemic challenges profit-oriented companies to an even greater degree, than it would under normal circumstances. While both SeaTerra and CTM are fully committed to the goals of the project, conducting it presents an additional burden, which makes funding specifically necessary.

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