SHORT TERM MOBILITY 2016
FINAL REPORT
"MUSE, Munitions in the Sea"

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1. OBJECTIVES

Unexploded ordnance (UXO) group both conventional explosives and chemical weapons dumped at sea, during or after conflicts. With respect to their effects in the oceans, overall MUSE objectives aimed at:

-to establish firmer contacts in order of exchanging practices, knowledge and procedures between EU/USA;
-to begin assessing benefits/needs of hydrodynamical models employed in support;
-to briefly outline state-of-the-art technological aspects adopted in recent US projects;
-to work towards favoring the exchange of datasets to validate theories and models and stimulating joint research projects, envisaging also the definition of common conceptual approaches to Risk Assessment.

2. BACKGROUND

Until the 70s it was a commonly accepted solution to dispose of unexploded ordnance (UXO) or munitions remnant of conflicts by dumping them in the oceans. Although UXO may contain chemical warfare agents (CWA) or

conventional explosive, the risks associated to this practice have been underrated for several decades. In the last years, however, the problem has been gaining considerable importance, in view of the more intensive use of ocean resources, of the need to carefully planning several maritime concurrent activities (fishing, sea-farming, tourism, energy distribution, oil and gas extraction, etc.) and of the fact that, after many decades at sea, most of these munitions are now facing a high-corrosion stage and could possibly leak toxic and even mutagenic products, representing a point or distributed source contaminant to the marine ecosystem.

Still, standing the uncertainties in the specific nature of most UXO, in the exact position of their disposing sites and in the unknown degree of corrosion and decomposition of explosive/chemical warfare agents, predicting the risk of detonation or the magnitude of possible releases of contaminants in the marine environment is an extremely difficult task. In addition to this, the known presence on the seafloor of large amounts of military ordnance and warfare agents has produced a series of specific procedures and national binding regulations that may highly differ from country to country. As a result, when it comes to clearing operations, almost each nation and each Navy adopts different strategies and procedures.

Nevertheless, some recent international projects have paved the way setting a series of good-practices when facing the problem of munitions at sea, making it very clear that the problem needs to be accounted for using an holistic approach involving several different disciplines, an effort well beyond the specific reductionist one that generally characterized this subject in the past. As an example, during the CHEMSEA (*Chemical munitions search and assessment*, 2011-14; www.chemsea.eu) project a large series of interdisciplinary studies in the Baltic Sea area were conducted, including oceanography (current measurements, salinity and temperature distribution), bottom survey (side scan sonar images), chemical analyses, biota communities structure and biomarker response of organisms to environmental stress (see www.chemsea.eu and there available CHEMSEA Findings report; see also Beldowski et al., 2016a). Again in the Baltic region, the MODUM initiative (*Monitoring of dumped munitions*, 2013-16; Beldowski et al., 2016b), supported by NATO's Science for Peace and Security (SPS) Programme, established a cost-effective monitoring network to observe munitions dumpsites using research vessels, Autonomous Underwater Vehicles (AUVs) and Remotely Operated Underwater Vehicles (ROVs). Funded by the EU, the recently launched project DAIMON (*Decision aid for marine munitions*) will be capitalizing on the past experiences, proposing a

risk management tool so that decision-makers could evaluate risks and benefits of various options in selected case sites.

Looking at the US side, the HUMMA project (*Hawai'i Underwater Military Munitions Assessment*, www.hummaproject.com) recently provided an extremely large integrated dataset, combining sonar, photographic, time-lapse acquisitions and environmental data with the results of chemical analyses of physical specimens to investigate the basic questions such as munitions casing integrity, distribution of CWA in the sediments, level of toxic chemicals in animals, focusing on a large dumping area south of the island of Oahu, Hawai'I (Edwards and Beldowski, 2016).

Overall, results outlined by these few examples confirm that UXO presence in the oceans represents a problem that goes far beyond what a single country (or even a decently funded Project) can attempt to solve, and that indeed requires a more "global" approach. Among the existing challenges, we recall here that: international activities have to be established since UXO are very often distributed on marine areas that are pertinent to more than a single nation, or threaten international infrastructures; funding has to be secured for multi-year monitoring programs, allowing the collection of long time series; sampling strategy and instrument specifics (sonars, ROVs, AUVs, magnetometers, etc.) should be concerted; protocols to detect warfare agents and degradation products in the physical and biological environments should be agreed at international level; large shared efforts should be devoted to high resolution *ad hoc* numerical modelling activities, capable of producing scenarios of interventions and supporting Risk Assessment procedures; more has to be understood on the chemical speciation of the conventional and chemical warfare agents at sea, and their modelling.

3. THE JPI-OCEAN PERSPECTIVE AND THE U.S. CONTEXT

The prime purpose of Dr. Carniel visit under the Short Term Mobility grant to University of Hawaii was to establish firmer contacts between the European and USA communities investigating the problems of munitions at sea.

Indeed, in an effort to set the UXO issue in a truly international framework, in November 2015 the European *Joint Programming Initiative – Healthy and Productive Seas and Oceans* (JPI Oceans, a high-level coordinating and integrating strategic platform, open to all EU Member States and Associated Countries) launched a joint action named "*Munitions in the Sea*" (http://www.jpi-oceans.eu/munitions-sea), that will provide knowledge-

based support to operators and policy makers. The aim of the action (coordinated by Italy and at the moment involving BE, DE, ES, GR, IE, NL, NO, PL, PT, SE, UK) is to assess risks and describe case studies, define priorities and suggest common intervention options (Campana et al., 2016).
The idea of such a coordinated trans-national effort aims at increasing the efficiency and effectiveness of interventions to emergencies, often adopted at national or local levels, by sharing experience and skills across Europe. Outcomes will be used to support decision makers in the identification, monitoring and elimination of threats through more systematic and shared approaches across Europe.
At the same time, already during the spin-up phase, the JPI Ocean action *Munitions in the Sea* has been involving in its activities Navies of different countries, is actively discussing within the NATO Science and Technology community (a recent Workshop in Varna has been held) and has established contact with the USA experts in Univ. of Hawai'i Manoa.

JPI-O action *Munitions in the Sea* comprises three lines of activities represented by:
(i) Science support, to increase safety and efficiency of interventions
(ii) Technology transfer, analysis and update of technologies and procedures for detection, monitoring, removal, remediation
(iii) Exchange practices and knowledge, establishing panels of experts and providing updated support to authorities.

When dealing with the UXO problem it is very difficult to come up with a series of effective shared protocols and recommendations. This is due both to the scientific nature of the problem, that is *per se* incorporating several disciplines ranging from hydrodynamics, biology, chemistry, marine technology, etc., and to the fact that the topic is often treated as a national problem by each country and Navy as well.
On the contrary, there are several outcomes that the umbrella of the concerted action *Munitions in the sea*, favoring joint efforts between different countries and Navies, is expected to bring along, as listed below.

Innovation. Agreed protocols of interventions for munitions at sea (starting from an interactive map of a working area and the type of dumped munitions, addressing main risks associated in case of intervention); shared protocols to determine toxicity (especially chronic) on marine organisms (e.g. the development of specific biomarkers), including the development of portable methods; the definition of maps of risks integrating the *in situ*

available information information with numerical models in selected areas; the definition of a knowledge-based support for interventions in terms of options, guidelines, scenarios and state of the art methodology that can be adopted by the different Navies.

Science-Policy. The science support to issues related to *Munitions in the sea* has the potential to contribute towards a safer planning and removal of munitions from the sea floor. Moreover, it will contribute to establish working scenarios and provide risk-assessment estimates. As a direct consequence, it will establish accepted and standardized procedures relevant to the military and commercial end-users, e.g.in a context of Maritime Spatial Planning.

***Marine Research Infrastructures and data*.** The action will be promoting and stimulating initiatives to optimize interventions on UXO sharing existing infrastructures, such as supercomputing centers, shiptime, AUVs, ROVs, etc., and establishing an open access to existing data.

Human capacities. The JPI Ocean action will promote a higher interaction among different level of governance, sectors and disciplines. Specifically, a number of specific actions will be oriented towards off-shore operators and public authorities training, fishermen training, public awareness of sea-dumped UXO, disseminating the message within the education system; establishing a permanent scientific task-force.
The first phase of *Munitions in the Sea* has been mostly devoted to identify the main research challenges that can be tackled, and to build a flexible structure for the interaction of the main actors which can allow adequate feasibility and impact. National experts from the participating countries have been appointed and relevant stakeholders have been asked for collaboration. A collection of end-users' priorities at national level is now been conducted and will be outlining the priorities that will be guiding the next steps of the action towards the definition of an implementation plan, in particularly focusing on main areas of interventions with joint and dedicated sea-trials (expected to be in the Baltic sea and the Adriatic sea regions).

During the STM period a series of literature has been and reviewed, including many outcomes of the CHEMSEA, MODUM and HUMMA projects:

Bełdowski J., Szubska, M., Emelyanov, E., Garnaga, G., Drzewińska, A., Bełdowska, M., Vanninen, P., Östin, A., Fabisiak, J., 2016. Arsenic concentrations in Baltic Sea sediments close to chemical munitions dumpsites. *Deep-Sea Res. Part II: Top. Stud. Oceanogr*. 128, 114–122.

Bełdowski J., Klusek, Z., Szubska, M., Turja, R., Bulczak, A.I., Rak, D., Brenner, M., Lang, T., Kotwicki, L., Grzelak, K., Jakacki, J., Fricke, N., Östin, A., Olsson, U., Fabisiak, J., Garnaga, G., Nyholm, J.R., Majewski, P., Broeg, K., Söderström, M., Vanninen, P., et al., 2016. Chemical munitions search & assessment – an evaluation of the dumped munitions problem in the Baltic Sea. *Deep-Sea Res. Part II: Top. Stud. Oceanogr*. 128, 85–95.

Briggs C., Sonia M. Shjegstad, Jeff A.K. Silva, Margo H. Edwards, 2016. Distribution of chemical warfare agent, energetics, and metals in sediments at a deep-water discarded military munitions site. *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, June 2016, Pages 63-69*

Edwards M., and Jacek Bełdowski, 2016. Chemical munitions dumped at sea. *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 1-3*

Edwards M., Sonia M. Shjegstad, Roy Wilkens, James C. King, Geoff Carton, Deserie Bala, Brian Bingham, Martine C. Bissonnette, Christian Briggs, Natalie S. Bruso, Rich Camilli, Max Cremer, Roger B. Davis, Eric H. DeCarlo, Carter DuVal, Daniel J. Fornari, Iolana Kaneakua-Pia, Christopher D. Kelley, Shelby Koide, Christopher L. Mah, Terry Kerby, *et al., 2016.* The Hawaii Undersea Military Munitions Assessment. *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 4-13*

Edwards M., Daniel J. Fornari, Mark R. Rognstad, Christopher D. Kelley, Christopher L. Mah, Logan K. Davis, Kyle R.M. Flores, Erin L. Main, Natalie L. Bruso, 2016. Time-lapse camera studies of sea-disposed chemical munitions in Hawaii. *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 25-33*

Mah C. L., 2016. A new species of *Brisingenes* from the Hawaii undersea military munitions assessment area with an overview of Hawaiian brisingid *in situ* video observations and functional morphology of subambulacral spines (Forcipulatacea; Asteroidea). *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 43-52*

Kelley C., Geoffrey Carton, Michael Tomlinson, Arthur Gleason, 2016. Analysis of towed camera images to determine the effects of disposed mustard-filled bombs on the deep water benthic community off south Oahu**.** *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 34-42*

Koide S., Jeff A.K. Silva, Vilma Dupra, Margo Edwards, 2016. Bioaccumulation of chemical warfare agents, energetic materials, and metals in deep-sea shrimp from

discarded military munitions sites off Pearl Harbor. *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 53-62*

Silva Jeff A.K., Taylor Chock, 2016. Munitions integrity and corrosion features observed during the HUMMA deep-sea munitions disposal site investigations
Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 14-24
Michael S. Tomlinson, Eric Heinen De Carlo, 2016. Occurrence and possible sources of arsenic in seafloor sediments surrounding sea-disposed munitions and chemical agents near Oʻahu, Hawaiʻi. *Deep Sea Research Part II: Topical Studies in Oceanography, Volume 128, Pages 70-84*

HELCOM, Helsinki Commission, 1994. Report on Chemical Munitions Dumped in the Baltic Sea. Report to the 15th Meeting of Helsinki Commission from the Ad Hoc Working Group on Dumped Chemical Munition. Danish Environmental Protection Agency, January 1994.

MEDEA, 1997. Ocean Dumping of Chemical Munitions: Environmental Effects in Arctic Seas. MEDEA, McLean VA, p. 235.

Specific discussions have been conducted with scientists working at the UH, specifically: Dr. James Potemra (assessing the potential role that an Integrated Ocean Observing System may offer to the UXO problems), Dr. Brian Powell (potentialities of hydrodynamical modeling tools as support in the UXO direction), Dr. Bruce Howe (efforts of UH in the direction of developing a ROV capable of assisting operators during interventions) and Dr. Margo Edwards (the HUMMA context, new projects undertaken by UH in the field of UXO, and new ways of identifying objects at sea via cameras installed on cell phones).

4. PRELIMINARY RESULTS AND GAPS

After the preliminary assessment carried out during the STM grant, we can already draw some conclusions and better address some needs and gaps. The following aspects will need to be analyzed in the next future, benefiting from a continuation of the activity performed during the visit, and will hopefully have to involve other institutions and possibly Navies.

Identification of UXO at sea

With this respects, large efforts are being conducted by US colleagues in two main directions. One is related to the development of a Remote Operating Vehicle (ROV) capable of operating remotely underwater and identifying objects in the bottom. This is of course a very highly desirable feature when

dealing with unexploded ordnance, in order to limit the risks for human operators. However, the high cost of these tools and their scarce availability are not suggesting that underwater interventions will be mostly based on this specific approaches, that will most likely remain limited to particularly dangerous situations.
The other main stream where efforts are directed relates to the cheap identification and 3D imagery of objects sitting in the bottom, via dedicated software capable of assembling a series of pictures acquired using the current technology adopted in cell phone cameras. Although difficult and in need of further testing, this seems to be an interesting path to pursue, since it may be allowing a great number of "observations" and final results relatively high in terms of quality and rendering. However, this approach has to be carefully evaluated in turbid waters, of course.

Importance of join sea-trial campaigns

The necessity of conducting sea trial campaigns has been stressed during the colloquia.
An oceanographic campaign aiming at better locating UXOs needs to be structured, ideally, in a interdisciplinary way. There is need to have a geological setting of the area, but also to have an oceanographic and hydrological knowledge of the basin where end users are going to operate. These represent the background drivers where biological, chemical and ecological considerations will have then, when required, to be carried out.

Numerical Models

As far as it can be judged, both in Europe and in the USA the adoption of numerical models capable of providing the sea-state conditions in general, and during specific interventions, is a tool that has not been completely exploited. This is true also in areas such as the Hawai'i region, where still there exist several operational circulation model efforts (although at regional scale). However, we believe that the availability of a hydrodynamical model (capable of forecasting currents, temperature and salinity, wind wave, etc.) may represent a very interesting tool in the pre-intervention, intervention and monitoring phase at sea-disposed munitions sites. As an example of j0oit used, these tools could also be coupled with sediment transport models (in order to provide some useful information about the visibility and the saltation of potentially contaminated sediment) and with lagrangian models providing the likely distribution of plume of chemicals that may be leaking from the UXOs.

The same could be said about the possibility of modeling chemical speciation at sea, and that of modeling the underwater blast wave related to possible explosions (Kaloyanchev et al., 2016).

Needs of internationally accepted procedures and practices

Results outlined by recent projects confirm that UXO presence in the oceans represents a problem that requires a more "global" approach. UXO are very often are distributed on marine areas that are pertinent to several nations or threaten international infrastructures; the collection of long time series supported by international project is necessary; there is need for common sampling strategy and instrument specifics (sonars, ROVs, AUVs, magnetometers, etc.); an international agreement on protocols to detect warfare agents and degradation products in the physical and biological environments is needed; etc.

Also in terms of security, it should be recalled that problem of UXO go beyond the specific problems of homeland security (e.g. possible risks of mass detonation), but qualify to an international level, representing often a relatively easy source of explosives that may become available and used for terroristic attacks (Brooking et al., 2016).

5. ON-GOING AND FUTURE COLLABORATIONS

We underline that the STM activity deals with a subject that plays a potentially paramount role in continental margin dynamics and large-scale transport patterns, which at present is just partially accounted for in existing studies.

The subject appears to be particularly promising in the context of the JPI Ocean initiatives (action *Munitions in the Sea*) and USA-Italy bilateral collaboration. Collaboration with the Inst. of Geophysics (Hawaii, USA) have been established so that further visits and exchanges have been already planned, in order to allow post-doc and tenured scientists to foster the collaboration.

Future possible field-test dealing with UXO reconnaissance in US water may see the participation of European and Italian scientists, bringing their expertise and dedicated tools and instruments.

Bilateral projects endorsed by CNR and the Institute of Oceanology, Polish Academy of Science PAN (Italy-Poland) is going to be submitted under the coordination of Dr. Carniel and Dr. Beldowski.

Due acknowledgement of support received by CNR will be be made in any publication divulgating results deriving from such research activity. All data and technical – administrative or scientific information which the Contractor will gain possession of during the carrying out of the above-mentioned undertaking, will be and will remain confidential.

6. REFERENCES

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