**Journal of Marine Science**
https://ojs.bilpublishing.com/index.php/jms

ARTICLE

# UXO Assessment on the Romanian Black Sea Coast

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ARTICLE INFO

*Article history*
Received: 8 March 2022
Revised: 8 April 2022
Accepted: 24 April 2022
Published Online: 30 April 2022

*Keywords*:
Unexploded Ordnance
Black Sea
Side-scan sonar
UXO survey
Romanian Navy
Historical minefield
Second World War
Mine Warfare Data Center

ABSTRACT

This paper aims to provide the reader with the results of the Unexploded Ordnance (UXO) survey of the defensive historical naval minefields launched by the Romanian and German Navies on the Romanian Black Sea coast, during the Second World War. This UXO survey was carried out between 2015-2018 by the Romanian Navy's hydrographic ship "Commander Alexandru Cătuneanu" and Romanian Mine Warfare Data Center, using towed side-scan sonar technology and oceanographic observations. After explaining the materials and methodology, the results are presented and discussed: mosaics of the minefields, side-scan images of UXO contacts, side-scan images of the wrecks that were sunk in the minefields and some visible natural geological features of the seafloor. It was concluded that most of the objects discovered are sinkers, wreck debris or parts of chains, which does not represent a danger to navigation.

## 1. Introduction

Underwater explosive ordnance (EO) and abandoned explosive ordnance (AXO) are placed in territorial or international waters worldwide and subject to an arming sequence that has been failed to explode and constitutes a major environmental and safety issue. The disposal of the projectiles in the sea was a standard until the 1970s that occurred mainly immediately after World War II. For example, the ships or planes' wrecks contained substantial amounts of AXO that prevailed along the coasts. Historically, comprehensive efforts have been

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DOI: https://doi.org/10.30564/jms.v4i2.4497

made to develop data standards for Unexploded Ordnance (UXO) applications of geophysical surveys [1-4]. Qualitative descriptions of the workflows with the threshold values partly related to the reference object for marine geophysical surveys, and some extent for UXO campaigns, are well documented in relevant guidelines on UXO marine surveys or hydroacoustic mapping [4-7].

For offshore activities, UXO represents a threat and in response, Frey [8] developed the "Quality Guideline for Offshore Explosive Ordnance Disposal (EOD)" that addresses the four phases: (a) a desk-based preliminary survey of historical data, (b) a technical survey in the field, (c) an investigation of suspected UXO sites, and (d) UXO clearance and disposal [9].

Unfortunately, the ecological impact of the EO is not widely understood, and environmental assessments should be conducted to analyse the impact on the marine ecosystem. Tactically, assessments should be considered in the planning phase to determine whether the impact justifies the time, risk and effort required to survey and ordnance clearance.

Recent information was achieved from the European seas projects on chemical munitions dumpsites attained using hydrographic and geophysical mapping. New efficient methods and technology were applied like advanced AUV-based data acquisition, applying artificial intelligence, and developing data quality factors (e.g. [10]), or enabling near-real-time detection of dissolved explosive compounds in the water column (e.g. [11]). Furthermore, various methods are used to accurately establish the site of submerged UXO or artefacts, like magnetic sonars or optical technologies. From the technologies mentioned above used for seabed mapping, the most effective has proved to be the magnetic method for ferro-metallic objects masked by seafloor sediments or buried under the seabed [12]. Recently, various methods and adaptive technologies for shallow waters are used, such as an alternative approach as combined surveys using unmanned surface vehicles (USV) integrated with side-scan sonar (SSS) and magnetometers in a gradiometer set-up. The same configuration was recently used on UXO clearance for offshore drilling campaigns [13]. At the ecological level, a marine UXO risk assessment tool was identified that could aid managers working in marine industries in mitigating the risks presented by marine UXOs [14,15].

Small objects detection is one of the key components in underwater operations for the North-Western Black Sea as similar to other regions, during the two World Wars (WWI and WWII). Significant quantities of explosive ordnance were dropped from the air or placed on and around the beaches of the Romanian Black Sea coast, including bombs and mines. Laid by surface vessels, the moored naval mines were intended for primary use against submarines: the UMA mine was deployed first in 1928, UMB mine in 1941 and appeared in four forms, EMC I and II often actuated in heavy seas, FMB completed in 1928 was a chemical-horn mine using a cylindrical preset-type anchor [16].

This assessment is based on the archival research done by the Romanian Mine Warfare Data Center (MWDC) at the Historical Service of the Army - Bucharest. One hundred twelve files from the Romanian Royal Navy Command archive, the Sea Division and the Modern Romanian Navy Command were studied, related to the mining/demining activities, naval combat actions, and anti-submarine combat in the Western Black Sea during the Second World War.

Moreover, the Notices for Navigators from 1952 to 2011 were examined, extracting data referring to submarine obstacles, wrecks, pipelines, and other contacts.

More than twenty minefields were installed during the Second World War on the current Romanian coast, totalling approximately 3000 sea mines of various types (UMA, UMB, VICKERS, EMC I, EMC II, FMB, UC, etc.) and more than 3000 protection mines and anti-sweep devices, generally known as Unexploded Ordnance, as seen in Figure 1.

The Romanian and German forces launched the historical minefields on the Romanian Black Sea coast with specialised ships (minesweepers: Dacia, A.Murgescu, Durostor cargo, German submarines, Aurora tug-arranged as minesweepers), according to Ioan Damaschin [18]. During the same period, an unknown number of magnetic minefields were launched on the Romanian coast by Soviet forces. Soviet forces between 1946-1948 carried out the first dredging operations. As a result, the minefields located on the Romanian coast were dredged, and a considerable number of mines were neutralised by dredging or shooting.

Between 1948-1978, the Romanian Naval Forces constantly carried out dredging activities on the mined areas. During this period, although the Romanian dredging forces made great efforts to clean up the coast, there were still dangerous districts in the Mangalia area, south and north of Constanţa, south of Sf. Gheorghe and Sulina areas, as shown in Figure 2. Furthermore, freedom of navigation on all means of communication on the Romanian coast was restored only in 1979, as stated by the Navigators' Notice no. 11 from 1979.

Between 1946 and 1960, the documents studied so far showed that approximately 600 mines and 300 protection buoys were destroyed by dredging, shooting, or blasting.

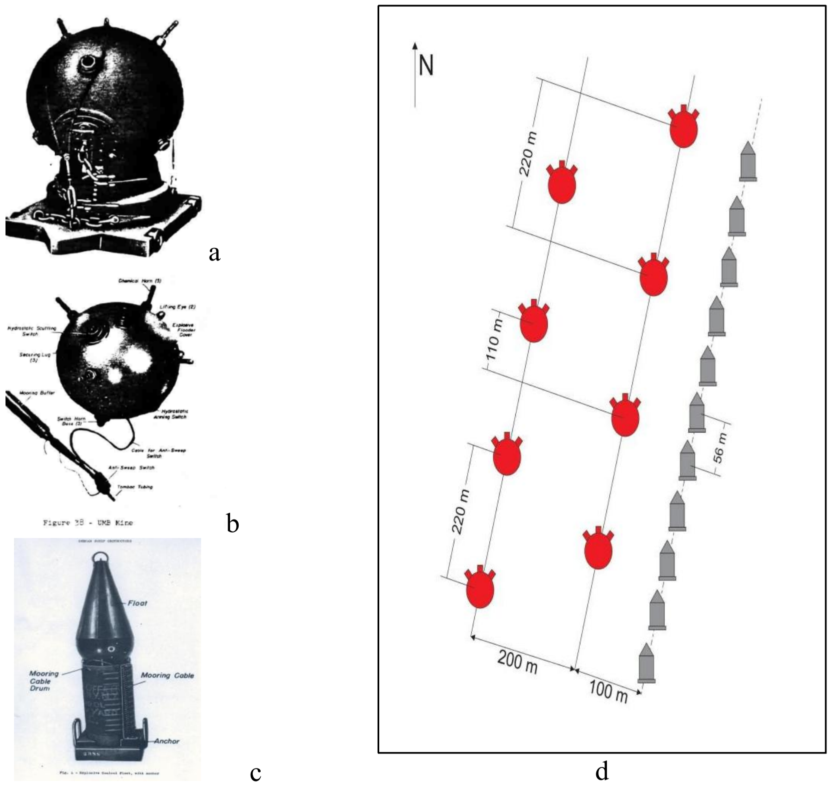



**Figure 1.** Types of mines launched during WW2 in the Western Black Sea [17]: a.UMA mine - anchored contact mine used against submarines, b. UMB mine - anchored contact mine used against submarines and surface ships, c. Explosive conical float-anti-sweep device, d. historical minefield layout

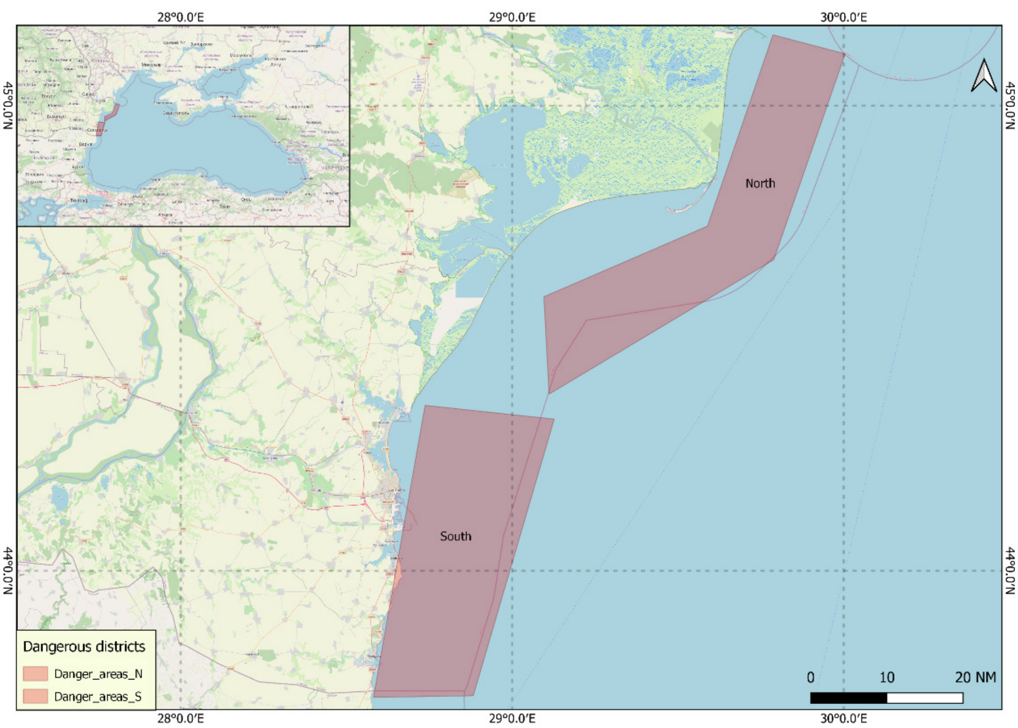



**Figure 2.** Dangerous areas after the dredging campaign

So, a significant number of contacts and debris from the historical minefields are still lying on the Romanian Black Sea seafloor, posing a potential environmental threat and a real danger for the fishery sector, as seen in Figure 3. Moreover, the UXO threat must be taken away for the safe construction of offshore windfarms in the renewable market sector, which is constantly growing [19].

**Figure 3.** UXO caught in fishnet on the Romanian Black Sea coast

Romanian Mine Warfare Data Centre (MWDC) based in the Maritime Hydrographic Directorate (MHD) conducted a project between 2015 and 2018, using different hydrographic and oceanographic survey equipment onboard the Romanian's Navy hydrographic ship "Commander Alexandru Cătuneanu", to assess the remaining UXO on the Romanian Black Sea shelf.

Naval Mine Warfare doctrine describes four stages of naval mine hunting procedures, from discovering a submerged contact during data collection using different methods to neutralisation. This UXO survey's main goal was to achieve the first two stages of the Naval Mine Warfare hunting procedure. MHD conducted this project in cooperation with the Romanian Navy Diver Centre to perform the last two stages of the Naval mine hunting procedure.

## 2. Material and Methods

The side-scan sonar is known to be a valuable tool in the Naval Maritime Mine Countermeasures (MCM) survey due to its capabilities to provide an accurate acoustic image of the seafloor and contacts above it.

A side-scan sonar emits sound beams in a fan shape perpendicular to its axis, as seen in Figure 4. In addition, it records the acoustic response (backscatter) to form a georeferenced seafloor image [20]. For this project, an Edgetech 4200 Multi Pulse (MP) side-scan sonar system was used, combined with a Vector VS 330 Hemisphere Global Navigation Satellite System (GNSS) Compass with SBAS and Atlas live corrections. The MP configuration accepts two pulses in the water during each ping cycle. Thereby, at typical survey speeds, this system can achieve twice the data density compared with a Single Pulse configuration [21]. These benefits of MP technology offer better contact detection and classification capabilities.

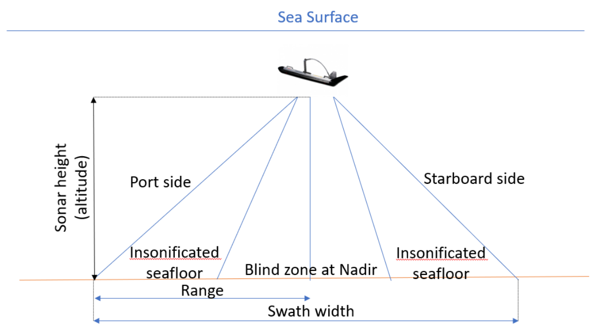



**Figure 4.** Side-scan sonar operations

For achieving a higher swath width, the sonar's lower frequency (300 kHz), in MP configuration, was chosen for this UXO survey. The higher 900 kHz frequency provides more pixel resolution, thus, greater detail of the acoustic picture, and was used for wreck investigation.

The positioning information (latitude, longitude, heading, speed) from the GNSS sensor is combined with the attitude sensor of the tow fish (pitch, roll) for an accurate location of the sonar echoes on the seabed.

The sonar's acoustic signals were calibrated at least twice a day using a Valeport Sound Velocity Profiler (SVP) that provided in-situ sound velocity profiles observations. In the Northern part of the surveyed area, more oceanographic stations were needed due to the rapid change of the halocline, based on the Danube River outflow.

In the survey planning, the following factors were considered: the depth of the water, characteristics of the historical minefields, the seafloor's topography, and the overlapping percentage of the planned survey lines (to cover the blind area of the sonar's Nadir region). After the assessment of the initial planning, three main survey areas resulted: North, Center and South, as shown in Figure 5.

Additionally, the ship's single-beam or multi-beam hydrographic sonars were used to complement the survey and determine underwater obstacles that could damage the towed sonar.

The mission's success was also attributed to the vessel's new autopilot system that processed data from the GNSS system, compass, and other instruments to accurately maintain the ship on the survey track. The speed vessel for the side-scan survey ranged between 4 knots to 6 knots, and the sonar was towed at a distance of 150 meters to 200 meters backward ship. However, several challenges made the survey difficult, like high sea states, inaccuracy in the positions of the historical minefields and the rapid change of the vertical structure of the water column that influenced the sonar operations.

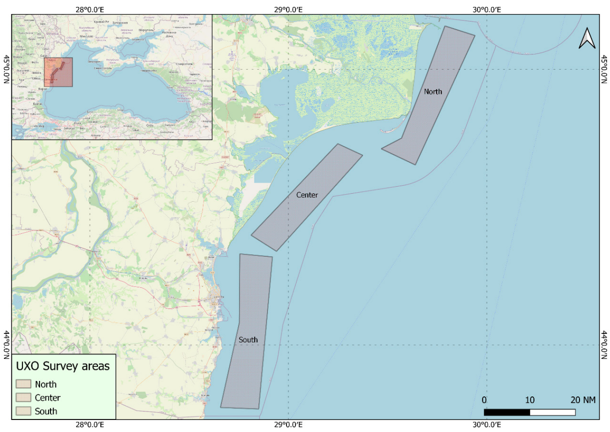



**Figure 5.** UXO survey area areas based on the location of the historical minefields

The side-scan data were calibrated with altitude, attitude, layback and GNSS data, saved as sonar native format and more generally used eXtended Triton Format (.xtf). Recorded acoustic data was processed using the HYPACK software suite. Bottom track, gain and slant corrections (picking up the first return from the seafloor, thus separating the nadir blind area on the sonograms and removing it) were applied, and the resulting sonograms were compiled to form a mosaic.

A comprehensive contact analysis was performed, for every survey line, to determine and classify the minelike echoes from the sonar into a minelike contact. Minelike contacts are selected by assessing their sonar echo intensity, shape, size and shadow.

## 3. UXO and the Black Sea Physical Marine Environment

The Black Sea is a semi-enclosed basin [22,23] and communicates with the Mediterranean Sea through a complex straits system: the Kerch Strait connects the Black Sea with the Azov Sea; the Bosphorus Strait with the Marmara Sea, which through the Dardanelles Strait connects with the Mediterranean Sea.

The physical conditions that prevail within the marine environment and their behaviour over time can significantly impact objects' position and state, like UXO. In particular, the following physical aspects are described below, alongside an overview of how these physical conditions and changes can interact with UXO.

Regarding the geology and sediments, much of the marine environment comprises underlying rock overlain by less consolidated sediments, such as silts, clays, sands and gravels [24,25]. The extent of overlying sediment cover can vary significantly between areas of little or no sediment cover, such as areas of exposed rock, as seen in Figure 7(a), and areas of the seabed with a sediment thickness greater than tens of meters (Danube outflow areas). As an effect, the composition of the present sediment cover and the underlying geology will determine the depth to which deployed UXO initially penetrates the seabed or shore and to what extent such objects may subsequently become buried by natural processes. The shallow waters characteristic for the North-Western Black Sea coastal area (littoral), represents a significant issue in the underwater acoustics, used by mine warfare communities. Moreover, there is a high rate of false alarms within shallow waters from irregularities of the seabed or magnetic anomalies [26].

Bedforms may form depressions, such as channels and extrusions across large areas of the seabed and typically include mobile sediments, such as mega ripples and sand waves. Subsequently, many areas of the seabed are not uniformly flat. More notable features, such as sand ridges, sand ribbons and sand or gravel banks, may also be present in some cases. Bedform features often indicate the relationship between the physical processes and sediments, and the bedforms asymmetry can demonstrate active sediment erosion, transport, and deposition processes. As seen in Figure 6, these areas can significantly impact the acoustic signal received by the side-scan sonar, but they provide essential information regarding the potential burial of UXO.

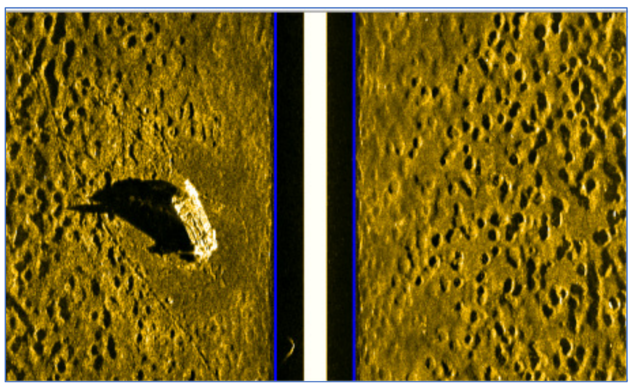


**Figure 6.** Seabed sand features

Coastal processes [27-29] can significantly impact the objects lying on the seafloor, especially in shallow waters. These mechanisms are accelerated from the energy generated from physical processes, such as winds, water, and tides, which have the most significant effects on a water body's surface. These forces may be affected by the modification of both wave and tidal processes in nearshore areas, which can cause larger forces to be exerted on objects or sediments on the seabed. The relationship between water depth and wavelength affects the strength of these coastal processes [30-34]. Therefore, information about these factors can be used to determine the depth of a wave's influence and whether the wave will have significant interaction with objects like UXO present on the seabed.

Sediment transport can take the form of a gradual, progressive trend or can occur rapidly as a result of storm or surge events. Significant sediment movement is therefore difficult to determine, and any resulting morphological change can affect the exposure and movement of the present UXO.

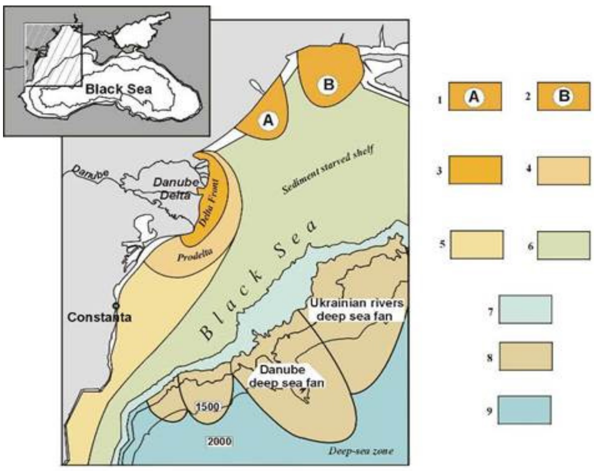



**Figure 7.** Main sedimentary environments in the northwestern Black Sea (after [35,36])

These physical marine conditions can interact with UXO present in the marine environment in the following three main approaches: a) the exposure or penetration into the seabed or shore; b) the subsequent burial or uncovering, and c) migration of UXO. Surface waves and underwater currents significantly impact the seafloor [22,37-39] and drifting objects inside the Black Sea basin. Underwater buried objects migration decreases with water depth, with munitions in a minimal burial state being particularly susceptible to movement when influenced by a large wave or strong current [40,41].

Historical documents revealed that not all the naval mines were deployed correctly. Thus, some UXOs were drifting with the underwater and surface currents, following the thermohaline circulation process of the Black Sea generated by density gradients [42]. Mathematical models of the waves and currents in the Black Sea may bring an operational value to the Romanian Navy by providing circulation predictions that have a considerable impact on the Romanian Navy operations [43].

Further research is needed on the estimation of bathymetric variation and to predict with parameterised models driven by wave observations [33,34,37,38]. Another tool to be included in the detection and migration of UXO or artefacts expert system is represented by the bedform migration modelling as a new mechanism for buried and exposed objects [44-47].

## 4. Results

The survey results and analysis allowed the detection and identification and afterwards to classify more than 2000 contacts using the side-scan sonar processed images. Most of the contacts are mine sinkers (anchors of naval moored mines) as seen in Figure 8, debris from the naval mines or parts from the wrecks placed near these locations.

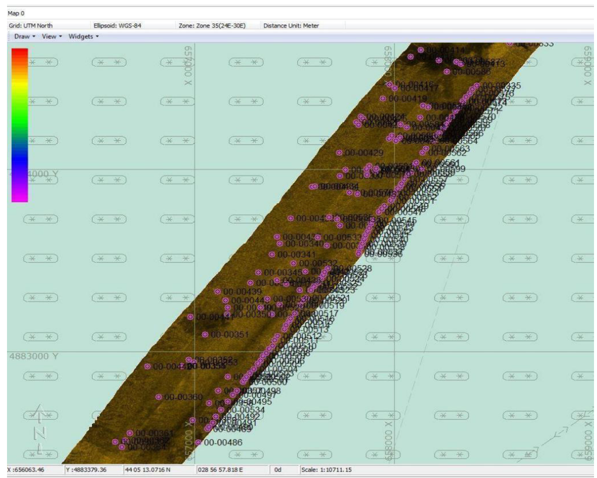


**Figure 8.** Contacts discovered on a historical minefield (Side-scan mosaic created with Hypack software)

However, a few contacts were observed and classified as naval mines, as it can be observed from Figure 9. Once a submerged object is identified as a sea mine, the district is prohibited for navigation by the Maritime Hydrographic Directorate issuing a navigator's notice, and Romanian Navy's Explosives Ordnance Disposal (EOD) divers begin neutralisation operations.

The images delivered by the side-scan sonar proved to help roughly identify the type of seabed on the surveyed areas, as seen in Figure 10(a). Figure 10(b) shows a bottom sample that was taken during the oceanographic stations, to ground truth the side-scan image of the seafloor.

Seabed composition data is of strategic importance to calculate the burial percentage of objects on impact according to their size and weight and a subsequent estimate of the burial rate per year.

As seen in Figure 11, during this survey mission, the positions of some known wrecks were reconfirmed, but also new wrecks or wreck debris were also discovered.

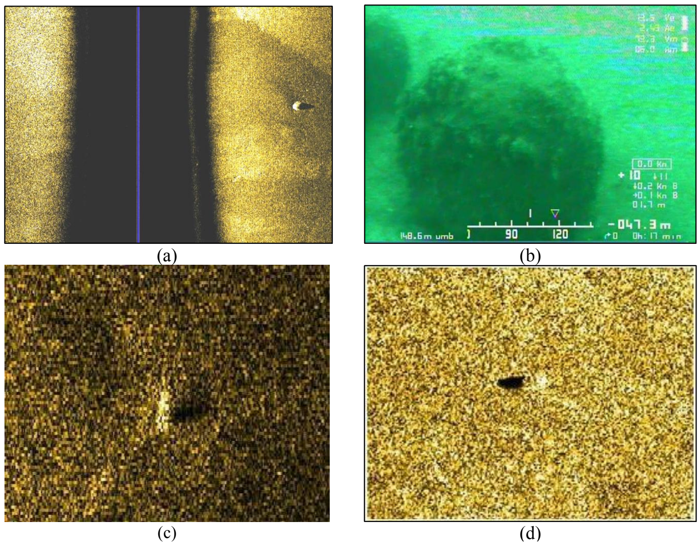
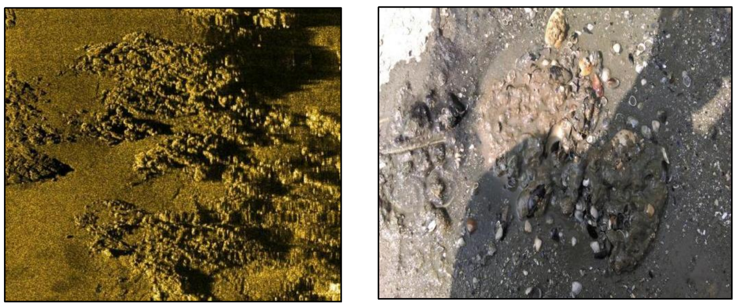



**Figure 9.** (a) UMA mine SSS image, (b) Remoted Operated Vehicle naval mine image, (c) explosive buoy SSS image and (d) EMF mine SSS image



a b

**Figure 10.** (a) Rocky seabed SSS image, (b)-bottom sample-muddy-sand with parts of shells

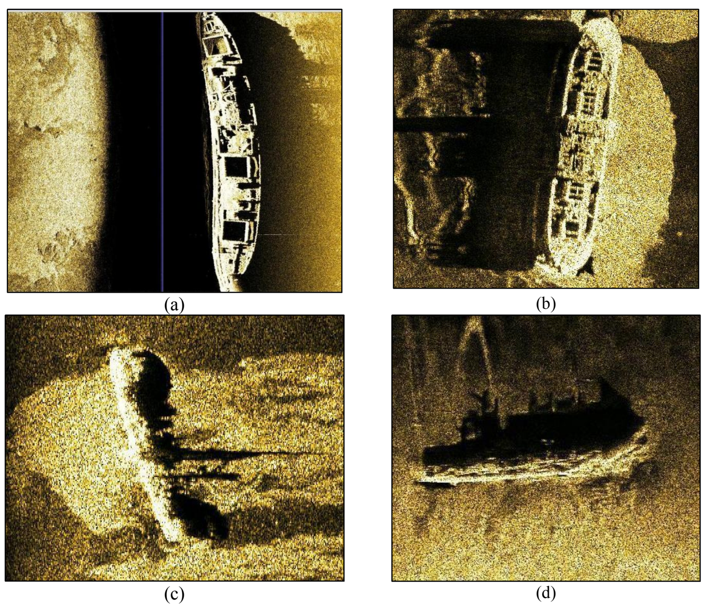



**Figure 11.** Wrecks discovered during the side-scan survey: (a) unknown wreck, (b) Arcadia wreck, (c) Sciuka class soviet submarine wreck, (d) Russian destroyer Moskva wreck

## 5. Discussion

The side-scan sonar is a valuable tool in Naval Mine Warfare to discover and classify mine-like contacts, wrecks, and underwater debris. It offers a high-quality image of the contacts lying on the seabed with good knowledge about their position and dimensions.

The North-Western part of the Black Sea has many particularities that impact any survey activities using sound energy: different types of seabed features, distinctive water column structure, and rapidly changing surface water parameters.

The unique water column characteristics of the North-Western Black Sea area (the low salinity and the low presence of Oxygen (anoxic layer) [23,48,49] preserved the metallic contacts in an excellent shape. The contacts have been found to be in good state, considering the marine environmental conditions in the area, considering the time elapsed since their launch in the water, due to the specific oceanographic conditions of the Black Sea [49].

The topography and nature of the seabed create false echoes/contacts, considerably increasing the detection and classification time of objects; a seabed with rock formations can easily hide metallic objects in their shadow. Moreover, the type of seabed act differently from the acoustic impulse sent by the side-scan sonar: higher-frequency sound and rocky seabed reflect more efficiently, while lower-frequency and fine silt and clay absorb more sound. However, it was observed that some muddy with embedded shells areas reflected more sound energy than sandy regions. The type of seabed significantly influences the process of marking targets and classifying them by the operator, especially in the case of small and partially buried contacts.

Comparison of the images using two different frequencies of the sonar showed advantages and disadvantages of each frequency: the low frequency can provide a broader range, in deeper waters and faster surveys, while the higher frequency provides more resolution on shallower areas with less area coverage.

As a recommendation, the initial survey can be conducted using the low frequency of the side-scan sonar, and after that, a high detail survey can be performed on contacts of interest (wrecks, mine-like contacts, etc.)

## 6. Conclusions

This research paper presents the outputs of the first UXO survey project performed on the Romanian Black Sea coast, after World War II. The raw and processed data is stored in the Maritime Hydrographic Directorate database. The database is constantly updated with the information and knowledge from the Romanian EOD Divers or other Institutes or civilian companies that are conducting similar surveys in this area.

The in-situ survey period of the project was conducted between 2015-2018. A thorough work was carried out before the survey, for planning purposes, and data processing and analysis, after the survey. The comprehensive archival work done by the Romanian Mine Warfare Data Center contributed to the success of this project.

Marine Industry development is strongly related to the UXO assessment on the areas of interest. Offshore wind farms are constantly growing around the globe and various studies in the Western Black Sea area demonstrated significant wave energy resources [50]. A rigorous UXO assessment and clearance must be conducted to install future offshore wind farms or submarine cables and pipelines in the studied area.

A significant number of underwater contacts, laying on the seafloor were discovered using side-scan sonar technology: naval mine anchors, metallic fragments of naval mines, wrecks and debris, Unexploded Ordnance.

With the increase in knowledge about the potential UXO impacts, an urge to address the challenge has been created strategically. Historical UXO still represent a threat to navigation due to their explosive charge. However, the case of a naval incident caused by hitting a UXO is improbable to take place. The war wrecks and UXO identified during this survey can pose an environmental threat if chemical substances leak from the munitions. More research is required, such as an extensive biochemical sampling campaign and a solid policy framework needs to be developed.

As a result, following the study, the next direction on target classification is to identify based on intrinsic physical features of the objects rather than external features such as location and orientation of the source object. Also, library matching techniques to determine the similarity between the existing database and unknown sources will become a powerful tool in classifying UXO vs. non-hazardous objects and, in some instances, identifying the UXO type. The project is still undergoing, to carry out all the mine-hunting stages, a considerable number of underwater contacts still need to be identified with the help of divers, ROV (Remotely Operated Vehicle) or AUV (Autonomous Underwater Vehicle), and those identified as real sea mines to be neutralised by the Romanian Navy EOD divers.

## Acknowledgements

We thank **Navy Captain(ret) Sorin GRECU**, former head of the Romanian Mine Warfare Center and **Lieu-**

**tenant Commander Radian TRUFAȘU**, head of the Nautical Cartography branch, from Romanian Maritime Hydrographic Directorate, for their great effort to gather information from the National Military Archive, regarding the Mine Warfare actions on the Romanian Black Sea coast, during and after World War II.

We thank **Lieutenant Commander Valentin DEMENTE, Lieutenant Nina Camelia SANDU, Lieutenant Fabian CIUBOTARIU, Lieutenant Leonard JIANU** and **Petty Officer Marian SIMION** for their great contribution to collect and process the side-scan sonar and oceanographic data.

We thank **Captain(ret) Rogers CASIAN**, former Commanding Officer of the Romanian Hydrographic Ship "Commander Alexandru CĂTUNEANU" and all the crew that was present for the long days of survey.

This work was carried out in the framework of the research project DREAM (Dynamics of the Resources and technological Advance in harvesting Marine renewable energy), supported by the Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding-UEFISCDI, grant number PN-III-P4-ID-PCE-2020-0008.

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