Determining hotspots of sonar targets related to chemical munitions dumped in Bornholm Deep and Gotland Deep using GIS

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According to the Helsinki Commission report from 1994 around 15000 tonnes of chemical warfare agents were dumped to the Baltic Sea after World War II as part of the demilitarization process of the former Nazi Germany. Continuing corrosion of metal encasements makes the dumped munitions a ticking time-bomb, which could potentially harm the whole Baltic Basin.

The presented work addresses important aspects for a proper evaluation of the threat; side scan sonar survey data storage and analysis of a spatial distribution of the sonar targets potentially related to chemical weapons. The chosen software environment was GIS oriented. ESRI ArcGIS built-in tools were used to determine the hotspots of the targets on the official post-war munitions dumping sites; Gotland Deep and Bornholm Deep.

The automation process of mapping in GIS was also proposed. Therefore, a holistic approach for digital mapping of the sonar targets related to dumped munitions was created.

Keywords: Chemical Warfare Agents, Side Scan Sonar, Geographic Information System

1. Introduction

Increasing number of economic activities on the Baltic Sea as well as its sensitive ecological structure entailed the necessity of a credible assessment of the threat related to the presence of chemical weapons (CW) dumped after World War II. Fishing, hydrotechnical engineering, construction of objects such as wind farms, gas pipelines (e.g. Nord Stream) or extraction of seabed mineral deposits create a risk of a direct contact of humans with the dumped chemical munitions, or releasing CW from containers on the seabed. Corroding metal encasements containing around 15,000 tonnes of chemical warfare agents (CWA) (HELCOM, 1994) makes the dumped munitions a viable, sleeping threat for the Baltic Sea.

To this day not all the positions of dangerous objects containing CWA are known. However, multiple researches were conducted in terms of international projects – MERCW, CHEMSEA, MODUM and DAIMON (Missaien, Paka, Emalyanov, 2006; Bełdowski et. al, 2015).

One of the most recent initiatives to further develop the knowledge about sea-dumped munitions in the Baltic Sea was "Towards Monitoring of Dumped Munitions Threat" (MODUM) project, which lasted from 2014 to 2016, and was financed by NATO SPS Programme. The aim of the project was to establish a monitoring web of the threat related to the presence of CW in the Baltic Sea. One of the project's key objectives was to investigate the possibility of using Unmanned Underwater Vehicles (UUVs): Autonomous Underwater Vehicle (AUV) and Remotely Operated Vehicle (ROV) to enhance the effectivity of CW detection and monitoring on the Baltic dumpsites.

The application of an AUV with hull-mounted Klein side scan sonar (SSS) provided good quality of the data, with the spatial resolution of the sonar images reaching a few centimeters. This improved the classification of the sonar targets, and enhanced their recognition as potentially CW-related objects.

The vast amount of sonar targets induced a need to elaborate the most efficient and possibly the least time-consuming methodology of the data storage, and their spatial distribution analysis. The important task was to estimate the risk associated with dumping areas, which can potentially pose the highest threat for the marine environment; the hotspots.

The majority of dumped CW in both Bornholm Deep and Gotland Deep contained sulphur mustard, commonly known as mustard gas or yperite (HELCOM, 1994). Based on sediment analyses, the distance of 30m was estimated as an average maximum sediment contamination range from a corroded sulphur mustard containing CW (Bełdowski et. al., 2015).

The presented research concentrated on determining the most significant hotspots in which there are multiple sonar targets lying in the areas where the maximum distance between the targets does not exceed 30m. Such places may represent an important source of mustard degradation products for surrounding sea-bottom and overlaying water layer, creating potential threat to biota.

ESRI ArcGIS software with its built-in geoprocessing tools was used in order to accomplish both tasks; sonar survey data storage and their spatial analysis.

2. Methodology

The hydroacoustical data presented in this work, conducted in terms of the MODUM project, are a part of survey data collected with use of OceanServer Technologies Inc. AUV Iver 2. The survey phase of the project was led onboard R/V Oceania, which belongs to the Institute of Oceanology of Polish Academy of Sciences (IOPAS). It operated on two frequencies: 455 kHz and 900 kHz, usually 3 m above the seabed.

The position of the robot underwater was determined by dead reckoning. The AUV's position estimation accuracy is a resultant of a calibration of DVL (Doppler Velocity Log), heading readings from a digital compass and surface GPS. The survey's set-up allowed for the position estimation accuracy reaching few meters.

The survey's areas were chosen based on previous studies (Bełdowski et. al, 2015) as the most abundant in potentially CW-related sonar targets. Detailed survey was performed with use of AUV hull-mounted SSS Klein 3500. Targets were selected and pre-classified as CW-related objects by the human operator based on processed data. The identity of the detected objects in some cases was also determined by means of chemical analyses of sediment samples collected 0.5 m from objects in questions. Presence of degradation products of chemical warfare agents, such as mustard, adamsite and clark was confirmed in ca. 40% of cases (Beldowski et al. 2016a), also elevated arsenic concentrations were observed close to many objects (Beldowski et al. 2016b). Targets for further visual inspection with ROV were determined according to their acoustic properties and dimensions (Klusek, Grabowski, 2018). The suitability of the AUV mounted SSS system used in this research for detecting bottom-placed objects, was tested in the first part of the MODUM project (Grabowski et al. 2018). All of the AUV's sonar polygons were marked on the maps presented below (fig. 1, fig. 2).

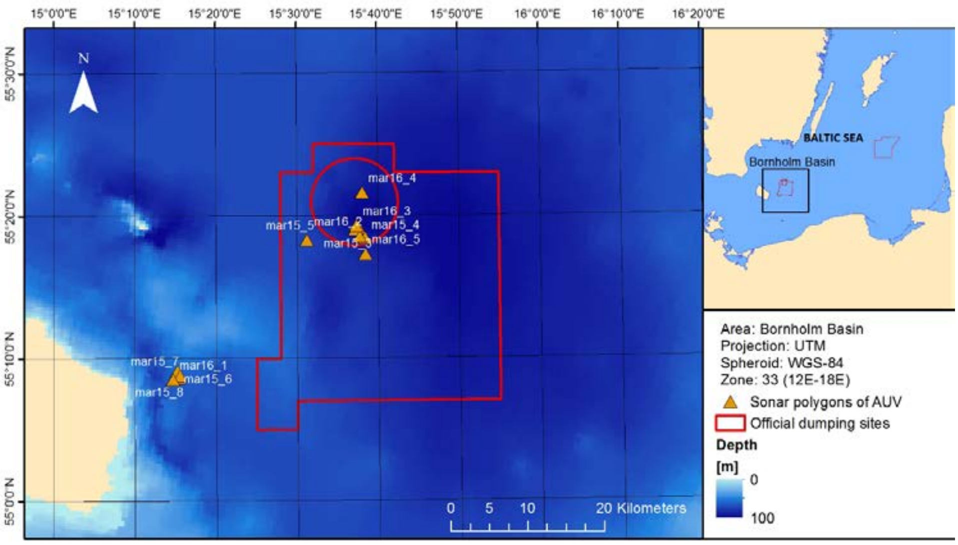

Fig. 1. Map of the Bornholm Deep survey conducted with AUV Iver 2 with side scan sonar.

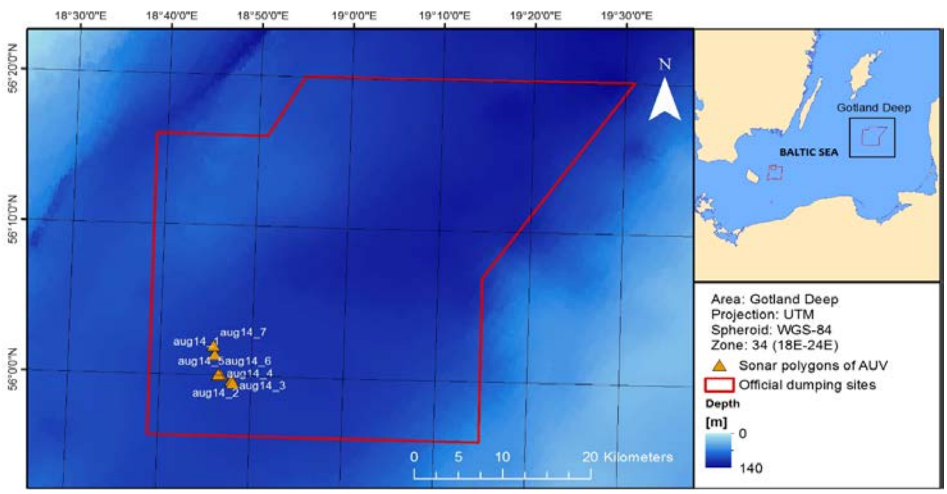

Fig. 2. Map of the Gotland Deep survey conducted with AUV Iver 2 with side scan sonar.

Sonar target mosaics were processed in ESRI ArcGIS's application: ArcMap. They went through a process of vectorization: conversion from raster GeoTIFF format files to point layers containing each of the targets with its coordinates. The process of vectorization was automated with use of ArcMap's visual programming language; Modelbuilder. It allows a user to combine various tools from ArcMap's Toolbox in a continuous sequence (model) instead of applying each of them separately. There is a possibility to use iteration, which automatically picks raster files from a folder specified by the user and sets them as input data to a model. These functionalities of the ESRI's software allowed creating models, which make the vectorization process significantly quicker and more effective than it is when performed in a manual way, using ArcMap's Editor tools. Raster files of the sonar targets were extracted from sonar mosaics in the way that sonar targets were allocated in the center of the images (fig. 3.). Thus, during the automated vectorization process, the points were always put in the center of the input raster image.

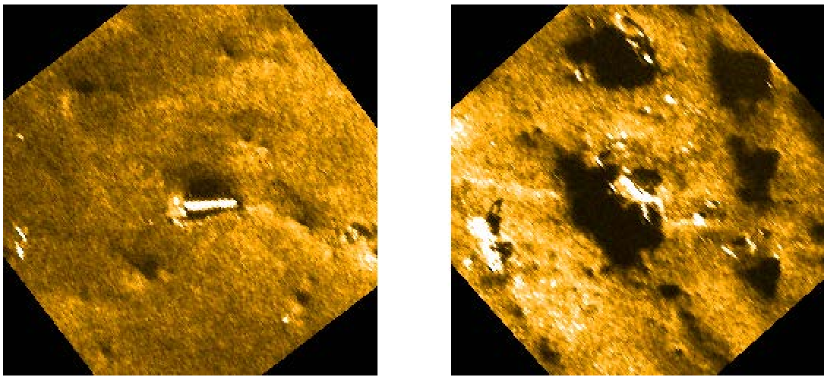

Fig. 3. Example of sonar targets extracted from mosaics. The objects potentially related to chemical weapons are allocated in the center of the images in raster, GeoTIFF format.

During the process of vectorization, the ESRI geodatabase was being organized into separate datasets, corresponding to the specified CW dumping zones: Bornholm Deep and Gotland Deep (fig. 4). In each of the datasets ("Missions_BOR" and "Missions_GOT") sonar target point layers, corresponding to the AUV's survey polygons were stored. Two separate datasets for the polygon layers of the Baltic Sea ("Baltic") and official dumpsites boundaries ("Areas_boundaries") were also created.

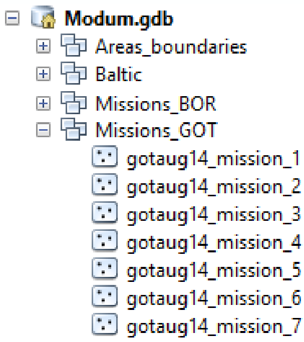

Fig. 4. Structure of the geodatabase titled "Modum.gdb", which was created in order to store the spatial data. The geodatabase was divided into two main datasets corresponding to official CW

dumpsites: Bornholm Deep ("Missions_BOR") and Gotland Deep ("Missions_GOT"). Inside the datasets there are point layers corresponding to AUV's survey polygons. Each point inside the point layers is a sonar target vectorized from sonar mosaic.

In order to determine the hotspots of the potentially CW-related sonar targets, a geoprocessing Buffer tool was applied. The application of this tool creates circles, with a predefined radius, around points chosen by a user. The chosen radius for buffer circles was 30 meters, same as the estimated average range of sediment contamination caused by an yperite-containing CW (Bełdowski et. al., 2015). Areas of the 30m buffers created around the targets were also calculated in ArcMap.

The total areas of sonar coverages on each of the AUV's polygons were determined in ArcMap application: the count of pixels in each of the assembled sonar mosaics was multiplied by spatial resolution of the side scan sonar. This operation gave the total area covered with sonar swaths, which are not overlapping.

3. Results

The application of the described GIS methodology resulted in the creation of a digital mapping system of the sonar targets composing of the spatial data container for hydroacoustic surveys: ESRI geodatabase, and automation tools for data conversion from raster sonar mosaics to point layers (models designed in ArcMap's ModelBuilder). The elaboration of this methodology allows its potential users to quickly create maps with sonar targets in a specified area of interest.

This method of sonar data archiving (as geodatabase's point layers) has also a significant advantage, which is low data storage memory occupation in comparison to raster files with mosaics/single targets. The folder from one sonar survey with sonar targets in GeoTIFF format can occupy gigabytes of a computer space. The geodatabase folder with all the targets in point layers occupies several dozen of megabytes.

The geodatabase's vector layer with sonar targets as points can also be easily exported to a shapefile (.shp format), which is recognizable by other GIS and survey related software like QPS, QGIS, SonarWiz, HYPACK etc. This fact ensures feasibility of data transfer and analysis in multiple software environments.

In each of the official dumpsites the biggest hotspots were determined based on the highest number of sonar targets lying within the maximum distance of 30 meters between them. These hotspot areas can potentially pose the most viable mustard gas contamination threat in the Bornholm Deep and Gotland Deep.

The hotspot maps prepared for the research (fig. 6, fig. 7) can practically serve as navigational charts for ROV operator in case of further visual inspections of the targets as it contains grids with coordinates and scale bar. 30m buffers around the targets can also help to estimate the distance from one target to another.

The Bornholm Deep's hot spot is depicted on the map (fig. 6) with 30m buffer circles, point layer of sonar targets and sonar mosaic in raster format, obtained by the AUV with the mounted SSS. The hot spot contains 41 sonar targets, lying in intersecting 30m potential yperite contamination buffers. There are also 4 peripheral targets, lying no farther than 100 meters from the rest (fig. 6: Targets 42, 43, 44, 45). The target distribution in general seems to be dispersed, with no specific pattern visible. Hence, these are probably munitions, which do not originate from single dumping operation. The calculated area of the background sonar mosaic and total area of 30m buffer zones were respectively 108972 m^2 and 66358 m^2.

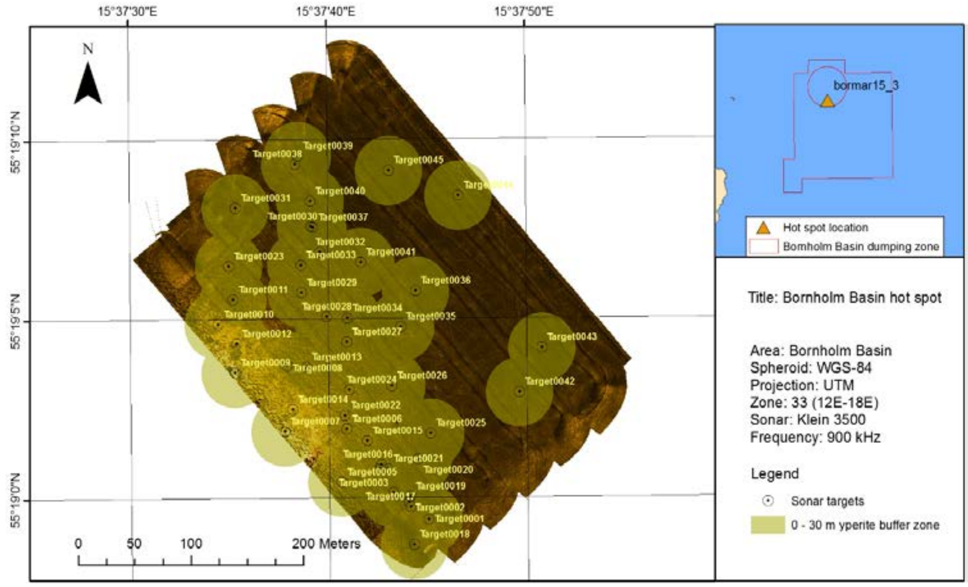

Fig. 6. Map of the Bornholm Deep sonar targets hotspot containing 45 targets in total. 41 of them lie in one buffer zone. The area of the SSS mosaic in the background is 108972 m^2.

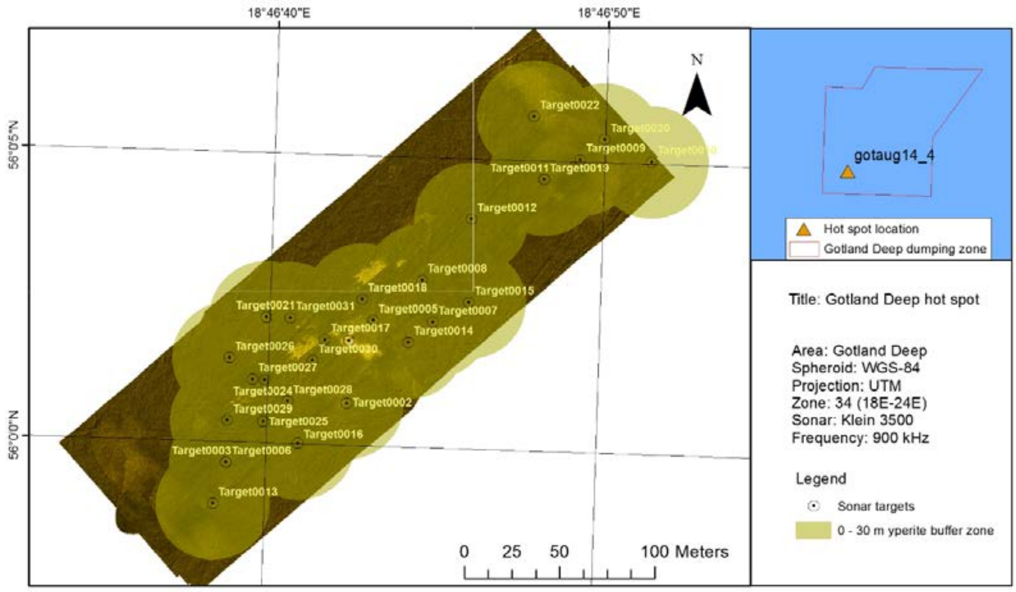

Fig. 7. Map of the Gotland Deep sonar targets hotspot containing 30 targets in one buffer zone. The area of the SSS mosaic in the background is 36548 m^2.

In the Gotland Deep, the biggest 30m hotspot contains 30 targets (fig. 7). The distribution of the targets is oriented along the line, extending from south-west to north-east. It is possible that it corresponds to a track of a vessel, which performed the CW dumping en route. Similar lines were observed in chemical munition dumpsite close to Pearl Harbor in Hawaii, and objects there were attributed to a piece-by-piece disposal from a drifting vessel (Edwards et al., 2016). The calculated area of the background sonar mosaic and total area of yperite buffer zones were respectively 36548 m^2 and 29876 m^2.

Summary

Despite the numerous studies conducted in order to extend the knowledge about sea-dumped chemical munitions (e.g. HELCOM, 1994; Missaien, Paka, Emalyanov, 2006; Knoboch et al., 2013; Bełdowski et. al., 2015; Edwards et al., 2016) the scale of the problem is so big, that it requires constant monitoring and further research. The continuing corrosion of the metal encasements containing deadly chemical warfare agents may cause an environmental disaster, and also harm human marine activities (Korotenko, 2000).

Any research on the dumping zones results in the production of spatially allocated data. Sediment sampling is performed in specified points, sonar surveys on a chosen areas etc. Therefore, there was a need to propose an effective spatial data storage method. This research confirmed that ESRI geodatabase can serve well to accomplish this task. It can be easily divided into multiple datasets containing e.g. point layers with sonar targets in an organized manner.

The geodatabase's layers with targets marked as points can be exported to shapefiles, which can be opened in multiple software environments. Moreover, the computer space occupation using this method is significantly lower than it is when the sonar data is stored as raster GeoTIFF files with mosaics/single sonar targets.

Automation of SSS data vectorization from raster format GeoTIFF files to point layers with use of ArcMap's ModelBuilder enhanced the effectivity of the sonar targets mapping process. The method is less time-consuming than manual vectorization.

The average maximum range of yperite sediment contamination assessed during previous researches (Bełdowski et. al., 2015) led to the evaluation of sonar targets hotspots, which can potentially be the main sources of sediment contamination in the future.

The application of ArcMap's geoprocessing Buffer tool resulted in determination of two major hotspots. In the Gotland Deep, the hot spot composes of 30 sonar targets, possibly related to yperite containing chemical weapons. All of them lie in distances not exceeding 30m between the targets. In the Bornholm Deep, the hot spot gathering 41 targets lying in a respective manner was found.

These sonar target hot spot areas should be taken in particular consideration when next researches and surveys will be planned in the dumping zones. As the classification of the sonar targets still cannot be performed with a complete certainty, there is a need to conduct more visual verifications with use of ROV. The sediments in the hot spot areas should also be frequently sampled in order to confirm the potential contamination and sustain the monitoring of the threat. The maps and geodatabase produced in this research can serve well to enhance the effectivity of such actions.

Acknowledgements

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