Deep sea habitats in the chemical warfare dumping areas of the Baltic Sea

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HIGHLIGHTS

- Habitats in three Baltic Sea Chemical Warfare dumpsites were described as Deep-Sea Muddy Sands.
- All investigated basins belong to so-called “benthic-deserts”.
- Multidisciplinary studies have been performed.
- Dumpsites were investigated before, during and after a Major Baltic Inflow event.
- Temporary Return of benthic macrofauna was observed in one basin.

ABSTRACT

The Baltic Sea is a severely disturbed marine ecosystem that has previously been used as a dumping ground for Chemical Warfare Agents (CW). The presence of unexploded underwater ordnance is an additional risk factor for offshore activities and an environmental risk for the natural resources of the sea. In this paper, the focus is on descriptions of the marine habitat based on the observations arising from studies linked to the CHEMSEA, MODUM and DAIMON projects. Investigated areas of Bornholm, Gotland and Gdańsk Deeps are similarly affected by the Baltic Sea eutrophication, however, at depths greater than 70 m several differences in local hydrological regimes and pore-water heavy metal concentrations between those basins were observed. During the lifespan of presented studies, we were able to observe the effects of Major Baltic Inflow, that started in December 2014, on local biota and their habitats, especially in the Bornholm Deep area. Reappearance of several meiofauna taxa and one macrofauna specimen was observed approximately one year after this phenomenon, however it’s ecological effects already disappeared in March 2017. According to our findings and to the EUNIS Habitat Classification, the three reviewed areas should be characterized as Deep Sea Muddy Sands, while the presence of suspicious bomb-like objects both beneath and on top of the sediments confirms their CW dumpsite status.

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administrative, political and military issues left the dumpsites unmonitored for many decades (Knobloch et al., 2013). Ongoing natural processes together with offshore activities such as fishery have significantly expanded the areas of potential exposure (Sanderson et al., 2009). Not only do the munitions contain explosives and toxic agents, but they are also considered as a source of heavy metals and metabolites, mainly arsenic, to the environment (Beldowski et al., 2016b). Every dumping area is characterized by a different set of environmental parameters and various types or quantities of disposed warfare material. Site-specific risk assessments should be performed on a case-by-case basis.

Covering a surface area of 415,000 km², the Baltic Sea is relatively shallow, with an average depth of 52 m. It was formed during the last glaciation and the present level of salinity stabilized 2000 years ago, becoming one of the largest brackish ecosystems in the world. Salinity values in the Baltic Sea range between 1 and 20 PSU, with an average of 7 PSU. This young ecosystem provides multiple natural services for a large human population living in the catchment area, while being highly sensitive to many forms of human impact (Elmgren, 2001).

Numerous reports and reviews including Knobloch et al. (2013), Beldowski et al. (2016a) and Greenberg et al. (2016) indicate that soon after the end of World War II, the Baltic Sea began to be used as a dumpsite for at least 40,000 tons of chemical warfare agents (CWA). The toxic loads accounted for up to 15,000 tons, 80% of it which was mustard gas (Knobloch et al., 2013). It was during the pioneering MERCW project - Modelling of Ecological Risks Related to Sea-Dumped Chemical Weapons (http://mercw.org) - when the existence of submerged munitions in the Bornholm Deep area was confirmed. It has resulted in first scientific observations of several completely corroded casings (Missiaen et al., 2010) and allowed researchers to indicate potential site-specific hazards related to the CWA presence in the sediments (Sanderson et al., 2010). In subsequent CHEMSEA project - Chemical Munitions, Search and Assessment (www.cheumsea.eu) - both CWA and their degradation products were detected in pore-water and sediments detected in roughly 40% of cases (Beldowski et al., 2016a) thanks to the newly-developed methods (Popiel et al., 2014). Also, first indications of adverse effects on Baltic Fish were reported (Beldowski et al., 2016a). Follow-on work under the MODUM project - Towards the Monitoring of Dumped Munitions Threat (http://www.iopan.gda.pl/MODUM) - focused on creation of monitoring network and assessing the environmental risk of CWAs in the Baltic Sea which included testing the toxicity of selected degradation products (Christensen et al. 2016) and Weight of Evidence (WoE) analyses (Beldowski et al., 2017). Interdisciplinary research is nowadays continued in the DAIMON project - Decision Aid for Marine Munitions (http://www.daimonproject.com) - with the aim to develop the risk assessment algorithms and the decision support system.

1.1. Study area

Little Belt, Bornholm and Gotland Deepes are recognized to be the most important, officially designated CWA dumpsite areas in the Baltic Sea. The CW dumping area commonly referred to as the ‘primary dumpsite’, is located in the Bornholm Deep centred on a point with surface coordinates 55°20′N, 15°37′E. Its northern part is currently marked on sea charts as ‘larger explosives dumping ground’. Sea-dumping operations in the Gotland Deep took place between May and September 1947, when approximately 2000 tons of CW material consisting of 1000 tons of CWA were dumped. On the other hand, studies performed in CHEMSEA project confirmed the existence of an unofficial dumpsite in the Gdansk Deep (Beldowski et al., 2016a). The suspicion about CWA presence in Gdask Deep arose after two incidents, the first with a mustard gas bomb recovered by a fishing trawler and a second with similar bomb being washed ashore on the Hel Peninsula in 1954 (Szarejko and Namieśnik, 2009). The CWA presence was finally verified by pore-water (Beldowski et al., 2016a). The total volume of dumped conventional munitions in Gdask Deep until 1954 was approx. 60 tons, however the load of CWA is still unknown (Knobloch et al., 2013).

Although the loads of sea-dumped CWA are believed to pose a possible threat to the Baltic Sea ecosystem, there is already an existing environmental degradation linked with nutrient overload that caused reduction of dissolved oxygen (DO) concentrations in bottom waters and creation of a “benthic deserts” below the halocline (Diaz and Rosenberg, 2008). Water stagnation has negative impacts on marine ecosystems, especially in accumulation basins, since states of hypoxia and anoxia not only negatively influence organisms (Vaquer-Sunyer and Duarte, 2008), but also their habitats (Conley et al., 2009).

During more than 100 years of Baltic Sea research (Elmgren, 2001), the areas of Bornholm, Gdansk and Gotland Deepes have been widely studied. Among studies of singular basins, several comparisons have been performed (i.e. Villius and Kuzendorf, 2001, Christoffersen et al., 2007). The aim of this study was a site-specific identification of the ecological status of CW dumpsites located in those three deeps of the Baltic Sea. A detailed description of factors governing the conditions in the dumpsite areas can be a useful tool for researchers representing various scientific fields. The presented set of environmental and modelling data relies on recent findings and is designed to serve as background information for researchers and stakeholders engaged with the issue.

2. Materials and methods

Presented habitat characterization is based on the location of the CWA dumpsites in Baltic Proper, exceeding depths of 70 m (Fig. 1). Datasets were collected during the CHEMSEA, MODUM and DAIMON – Decision Aid for Marine Munitions research projects. Three deep-sea Baltic CW dumpsites were investigated during 10 expeditions of S/Y Oceania, R/V Walther Herwig III and R/V Nord 3 between 2012 and 2017 (Table 1). While the CHEMSEA project focused on locating suspicious looking objects, in both MODUM and DAIMON projects those stations where CWA were detected have been revisited.

2.1. Depth, salinity and dissolved oxygen profiles of water column

The CTD (Conductivity, Temperature, Depth) probe SeaBird 49, additionally equipped with an oxygen sensor was used during all cruises. Measurements were performed at every sampling station. The accuracies of the conductivity and pressure sensors were 0.005 mS·cm⁻¹ and 0.1% of the full-scale range, respectively. The conductivity sensor is calibrated annually by the manufacturer to ensure accuracy. The profiles of DO concentration were obtained with the Rinko-I sensor. The accuracy of the sensor was ± 2% (1 Atmosphere, 25 °C) with a resolution of 0.01 to 0.4% (2 to 8 μg·L⁻¹).

2.2. Water exchange and bottom currents modelling

Baltic Sea water exchange forecasts and suitable representations of actual bottom current are available thanks to employment of the POP - Parallel Ocean Program (Smith and Gent, 2004). For bottom currents modelling, the hindcast was based upon a 20-years simulation period. The POP model is widely used and refers to global and regional models and was successfully applied for the Baltic Sea. It has a horizontal resolution of 2 km and 66 vertical levels, 50 of which are 5 m in depth.

2.3. Acoustic sediment characterization, sea bottom and sub bottom mapping

Two types of sonars were used to collect acoustic data. The EdgeTech DF-1000 towed sonar was used for preliminary sea bottom mapping,
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