data

Data Descriptor

Geomorphological Data from Detonation Craters in the Fehmarn Belt, German Baltic Sea

Svenja Papenmeier *, Alexander Darr and Peter Feldens

Leibniz-Institute for Baltic Sea Research Warnemünde, 18119 Rostock, Germany; alexanderdarr@web.de (A.D.); peter.feldens@io-warnemuende.de (P.F.)
* Correspondence: svenja.papenmeier@io-warnemuende.de

Abstract: Military munitions from World War I and II dumped at the seafloor are a threat to the marine environment and its users. Decades of saltwater exposure make the explosives fragile and difficult to dispose of. If required, the munition is blast-in-place. In August 2019, 42 ground mines were detonated in a controlled manner underwater during a NATO maneuver in the German Natura2000 Special Area of Conservation Fehmarn Belt, the Baltic Sea. In June 2020, four detonation craters were investigated with a multibeam echosounder for the first time. This dataset is represented here as maps of bathymetry, slope angle, and height difference to the surrounding. The circular craters were still clearly visible a year after the detonation. The diameter and depth of the structures were between 7.5–12.6 m and 0.7–2.2 m, respectively. In total, about 321 m^2 of the seafloor was destroyed along the track line.

Dataset: https://doi.org/10.5281/zenodo.6374951

Dataset License: Creative Commons Attribution 4.0 International.

Keywords: multibeam echosounder; ground mines; detonation crater; Fehmarn Belt; Baltic Sea

Citation: Papenmeier, S.; Darr, A.; Feldens, P. Geomorphological Data from Detonation Craters in the Fehmarn Belt, German Baltic Sea. *Data* **2022**, *7*, 63. https://doi.org/10.3390/data7050063

Academic Editors: Sreckovic Vladimir, Dimitrijevic Milan and Mijic Zoran

Received: 22 March 2022
Accepted: 6 May 2022
Published: 11 May 2022

1. Summary

Explosives at the seafloor, including unexploded ordnance and discarded military munition, are a threat in many seas worldwide [1–4]. They are relics of combats and bombing during World War I and II or post-war munition dumping [5,6]. An estimated 1.6 million tons of military munition still exists at the ground of the German marine waters. For the German Baltic Sea, 300,000 tons of conventional and 5000 tons of chemical munition are estimated [5]. A lack of documentation and missing data make the numbers unreliable, and the full amount is not known yet. Between 2013 and 2018, more than 21,500 new objects were reported for the German North Sea and Baltic Sea [7]. In the Baltic Sea, the munitions are predominantly located in the coastal zone and randomly distributed in the Exclusive Economic Zone (EEZ) [5]. The explosives are a threat to marine traffic, fisheries, offshore construction, and the marine ecosystem. In case of contact with, e.g., anchors or fishing gear, there is a risk of uncontrolled explosion. Furthermore, there is the risk of releasing toxic compounds [8]. Several scientific studies have measured explosive compounds and their degradation products in the sediment, water column, and those accumulated in marine invertebrates [2,9–11]. This poses the potential of toxic substances entering the food chain and becoming a risk to human food safety [12,13]. International conventions and directives (e.g., HELCOM, OPSAR, MSFD, MPRSA) rate munitions in the marine environment as a serious source of contamination and pollution, and prohibit the dumping of munition [4,14]. The handling of ordnance (clearing or leaving it untouched) is still under discussion in Germany, and numerous projects are working on the development of monitoring and clearance strategies [15]. However, the salvage of the explosives is often critical. Spending about 80 years underwater and being exposed to saltwater, dissolved oxygen, and microbial activity makes the explosives difficult to recover. The munition housings and fuses are becoming fragile, and chemical changes of the fillers increases the impact sensitivity of the explosive charge [16]. When the object is not suitable for handling, transport, and elimination on land, the explosives are controlled blast-in-place [17]. Representatives of environmental authorities and science demand that this method should be avoided or even stopped altogether [17,18]. The underwater detonation of munition has a catastrophic impact on the organisms living in the surrounding area and their habitat. The shock wave destroys any organisms and can still harm the sensory organs of porpoises many kilometers away [19,20]. Incomplete detonations leave substantial quantities of the explosive material in the environment, which is absorbed by organisms (e.g., mussels) and enters the food chain [17]. Further, the detonations displace large amounts of substrate and leave a detonation crater.

In August 2019, 42 ground mines of type MK 1–7 from World War II were controlled detonated underwater during a NATO maneuver in the Natura2000 Special Area of Conservation (SAC) Fehmarn Belt, the Baltic Sea. This area (EU-code: DE 1332–301), 280 km^2 in size, is located between the Danish island of Lolland and the German island of Fehmarn. Through the 18 km wide strait, 70% of the water exchange between the North Sea and the Baltic Sea takes place [21]. The area has a special ecological function and includes the protected habitats sand reef (FFH-code 1110) and reef (FFH-code 1170). Invertebrates and numerous fish species find ideal breeding and rearing conditions, which make the area an attractive feeding area for harbor porpoises and harbor seals.

The impact of the underwater blasting campaign in the SAC Fehmarn Belt on the environment is not yet fully understood. Siebert et al. [19] documented 24 dead harbor porpoises between September and November 2019 along the coastline of the federal state Schleswig-Holstein. Eight animals indicated blast injuries. For invertebrates, chemical contamination of water and sediment, and sedimentological changes, reports are still missing.

This article represents a multibeam echosounder (MBES) dataset recorded in the SAC Fehmarn Belt in summer 2020, showing four detonation craters. The data acquisition aimed to describe the geomorphology of the detonation craters for the first time. The data will serve as a basis for future monitoring.

2. Data Description

The bathymetric data were collected on the 27th of June 2020 as underway research data during the cruise EMB239 with the German research vessel Elisabeth Mann Borgese. The transit between two study areas was used to record a 1.5 km long track, which is located approximately 2 km south of the submerged river channel Vinds-Grav in the Fehmarn Belt (Figure 1) and runs from northeast to southwest. The water depth along the track line is 20.5 m in the north and 16 m in the south.

For data acquisition, the ship's hull-mounted Sonic 2024 (R2Sonic Inc., Austin, TX, USA) multibeam echosounder (MBES) was used. Acquisition of vertical sound velocity profiles during underway MBES data collection was not possible. However, surface sound velocities for beamforming were supplied by the vessel's self-cleaning monitoring box (-4H-JENA engineering GmbH, Jena, Germany). A Trimble SPS461 system (Trimble Inc., Sunnyvale, CA, USA) provided the GPS information, and the motion source (true-heading, attitude, speed, and position) was an iXblue Photonic Inertial Navigation System (PHINS) (iXblue company, Denver, CO, USA). The vessel speed was 2.8 knots during acquisition.

Raw data, the original packets of the MBES system, was sent to the recording software Quinsy v8 (Quality Positioning Services B.V., Zeist, The Netherlands) and saved as database file (*.db). The sonar operation settings are documented in Table 1. Resolution of the bathymetric data varies depending on water depth and position across-track, but spatial resolution is better than 25 cm. To make the data usable without any specific software and publically available, the raw dataset was converted to an ASCII data file and published in the CERN's Data Centre Zenodo [24]. To do so, the database file was loaded in Qimera v2.4.3 (Quality Positioning Services B.V.) and automatically processed to compute the sounding footprint location under consideration of sound velocity, position, motion, and heading information. The applied vessel parameters (system offsets) are listed in Appendix A. The georeferenced soundings were exported without any bathymetric data cleaning as a comma-separated ASCII file in the coordinate reference system EPSG: 32,632-WGS84/UTM zone 32N. The file entries are listed in Table 2.

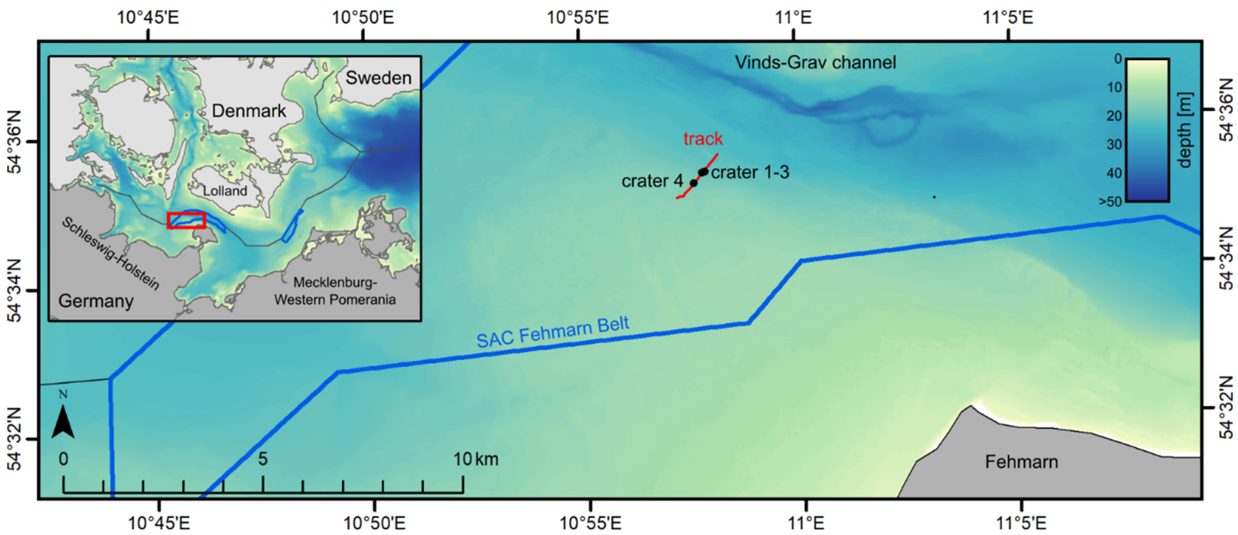

Figure 1. Map showing the location of the track line and detonation craters within the Special Area of conversation (SAC) "Fehmarn Belt". The location of the study area is highlighted by the red box in the overview map. Bathymetry data source provided by [22,23].

Table 1. Multibeam echosounder operation settings.

Parameter	Setting
Frequency	400 kHz
Raw sampling rate	20 Hz
Sector coverage	120°
Sounding pattern	Equal distance
Number of soundings	256
Pulse-type	Shaped continuous wave

Table 2. Entries of the ASCII data file published in the CERN's Data Centre Zenodo [24]. All coordinates are given in the coordinate reference system EPSG: 32,632-WGS84/UTM zone 32N.

Entries	Description	Unit
Beam	Beam number (1–256)	Dimensionless
Date time	Recording date time	yyyy-MM-dd hh:mm:ss.zzz
Footprint X	X location at seafloor	UTM coordinate
Footprint Y	Y location at seafloor	UTM coordinate
Footprint Z	Depth (positive upward)	Meters
Ping	Ping number	Dimensionless
Sound speed	Surface sound velocity	Meters/second
Transducer heading	Heading calculated for transducer	Degree
Transducer pitch	Pitch calculated for transducer	Degree
Transducer roll	Roll calculated for transducer	Degree
Transducer X	X location of transducer	UTM coordinate
Transducer Y	Y location of transducer	UTM coordinate

Table 2. *Cont.*

Entries	Description	Unit
Transducer Z	Transducer height relative to sea surface (positive upward)	Meters
Two-way travel time	Elapsed time for acoustic wave to travel from transducer to seafloor and back to receiver	Seconds

3. Methods

To display the detonation craters, MBES data were used to prepare maps of bathymetry, derived slope angle, and height difference to the surrounding as well as cross-sections profiles. To do so, the sounding footprints computed from the loaded database file were further processed in Qimera v2.4.3 (Quality Positioning Services B.V.). First, the outer 20 beams on the port and starboard side, which provide bad data quality, were excluded. Afterward, a gridded bathymetric surface model with a resolution of 0.25 m was created. This dynamic surface was then filtered with a pre-configured filter. The weak spline function, configured for a depth range of 0–20 m, first fits a 3D spline to the dynamic surface and then rejecting points that lie too far from the spline [25] After large spikes were automatically removed, the dataset was cleaned in more detail by hand. Before exporting the bathymetric grid as a raster file (GeoTIFF), the surface was interpolated with the settings: minimum 5 neighbors, 4 iterations, average interpolation type. With the tool "Create Profile", cross-sections were generated for each detonation crater and saved as an image. Additionally, the geographical coordinates of the profiles were exported as ASCII files to display the profile locations later in the maps.

Further data handling was performed with ArcGIS Desktop 10.8.1 (1999–2020 Esri Inc., Redlands, CA, USA). The slope angle from each cell of the raster surface was calculated with the spatial analyst tool "slope". Slope contour lines were generated afterward with the spatial analyst tool "contour" with intervals of one degree. Since the seafloor surrounding the detonation craters has a slope angle of 0–5°, the outer boundary of the craters was defined with the 5° isoline. These isolines were used as masks to extract the bathymetry of the detonation craters. For these bathymetric snippets, the crater height difference to the surrounding seafloor was calculated with the means of the ArcGIS Desktop Raster Calculator. The volume was calculated with the 3D analyst tool "Surface Volume".

4. Results and Discussion

Four circular detonation craters were observed along the track line in a water depth of 17.5–20.2 m. Maps of bathymetry, slope angle, and height difference to the surrounding are shown in Figure 2. Detonation craters numbering 1 to 3 are about 20–30 m away from each other (Figure 2A). A fourth crater exists approximately 330 m to the southwest (Figure 2D). All craters are located at the edge of the abrasion platform northwest of Fehmarn Island (Figure 1). Sediment maps [26,27] indicate for this region coarse sediments and lag deposits that are on top of glacial till [28]. Coarse sediments are defined as gravelly sand, sandy gravel, and gravel [29]. The lag deposits, a mixture of coarse sand, gravel, and boulders, are residue left-behind material. Fine material was winnowed from the glacial till, which originates from Pleistocene glaciations [30,31]. About 300–500 m further east, a high density of boulders is known. For this region, the maps do not show any boulder occurrences [32]. However, in the bathymetric data, individual larger boulders (60–160 cm across, 10–60 cm high) are visible in the vicinity of the craters (Figure 2A,D). They are even more evident in the slope maps derived from bathymetry data (arrows in Figure 2C,F). Boulders and lag deposits are categorized as substrates being relevant for the mapping of the habitat type "reef" in the sense of the flora–fauna–habitat (FFH) directive [33].

The geometric dimensions of the detonation craters are given in Table 3. Cross-sections for all four detonation craters are displayed in Figure 3. The structures are 7.5–12.6 m across at the top of the craters. The largest extension was crater 2. The relief of the detonation craters is conically shaped. The angle of the slopes averages 13–20°, in places the slopes are inclined up to 65° (Figure 2C,F). The bottoms of the craters are almost flat and have a diameter of 2.2–3.2 m. The depth of the craters ranges between 0.7 and 2.2 m (Figure 2B,E). The deepest crater is crater number 4. Similar dimensions and shapes have been described for detonation craters at the munition dumpsite Kolberger Heide (Kiel Bay, Germany), which originate from blast-in-place detonations for bubble curtain experiments [6].

Table 3. Position (EPSG: 32,632-WGS84/UTM zone 32N) and geometric dimensions of the detonation craters.

Crater	Easting, Northing	Water Depth	Depth Crater	Diameter Top	Diameter Bottom	Area Top	Mean Slope	Max Slope	Volume
1	626,925.7 6,050,889.2	20.2 m	0.7 m	7.5 m	2.2 m	46 m^2	13.1° ± 7.7°	36.1°	14 m^3
2	626,894.7 6,050,868.9	19.8 m	1.8 m	12.6 m	3.2 m	120 m^2	18.2° ± 13.9°	60.3°	76 m^3
3	626,866.8 6,050,859.4	19.6 m	1. 0 m	9.5 m	3.0 m	66 m^2	16.8° ± 8.1°	35.6°	36 m^3
4	626,659.4 6,050,586.1	17.5 m	2.2 m	11.0 m	2.5 m	89 m^2	20.6° ± 15.5°	65.4°	66 m^3

The measurements have been taken place about one year after detonation. At this time a total surface area of about 321 m^2 along the profile had been destroyed by the four detonations, and about 192 m^3 of sediment had been relocated. The mobilized sediments must have been deposited in the immediate vicinity. However, sediment accumulations at the edge of the craters are not visible one year after detonation. Assuming the sediment was deposited in a 5 m buffer around the crater, the height of the accumulation would range between 7 and 30 cm.

Whether a morphological regeneration has taken place within one year is unclear but considered to be low. Results from studies monitoring dredging pits have shown that these depressions, which were comparable in size and located in a similar sedimentary environment to the detonation craters, recovered hardly within one year [34]. Only the edges became more diffuse because of wall-collapsing, and some fine material was trapped in the center of the pits. Similar observations were made for dredging pits in the North Sea [35].

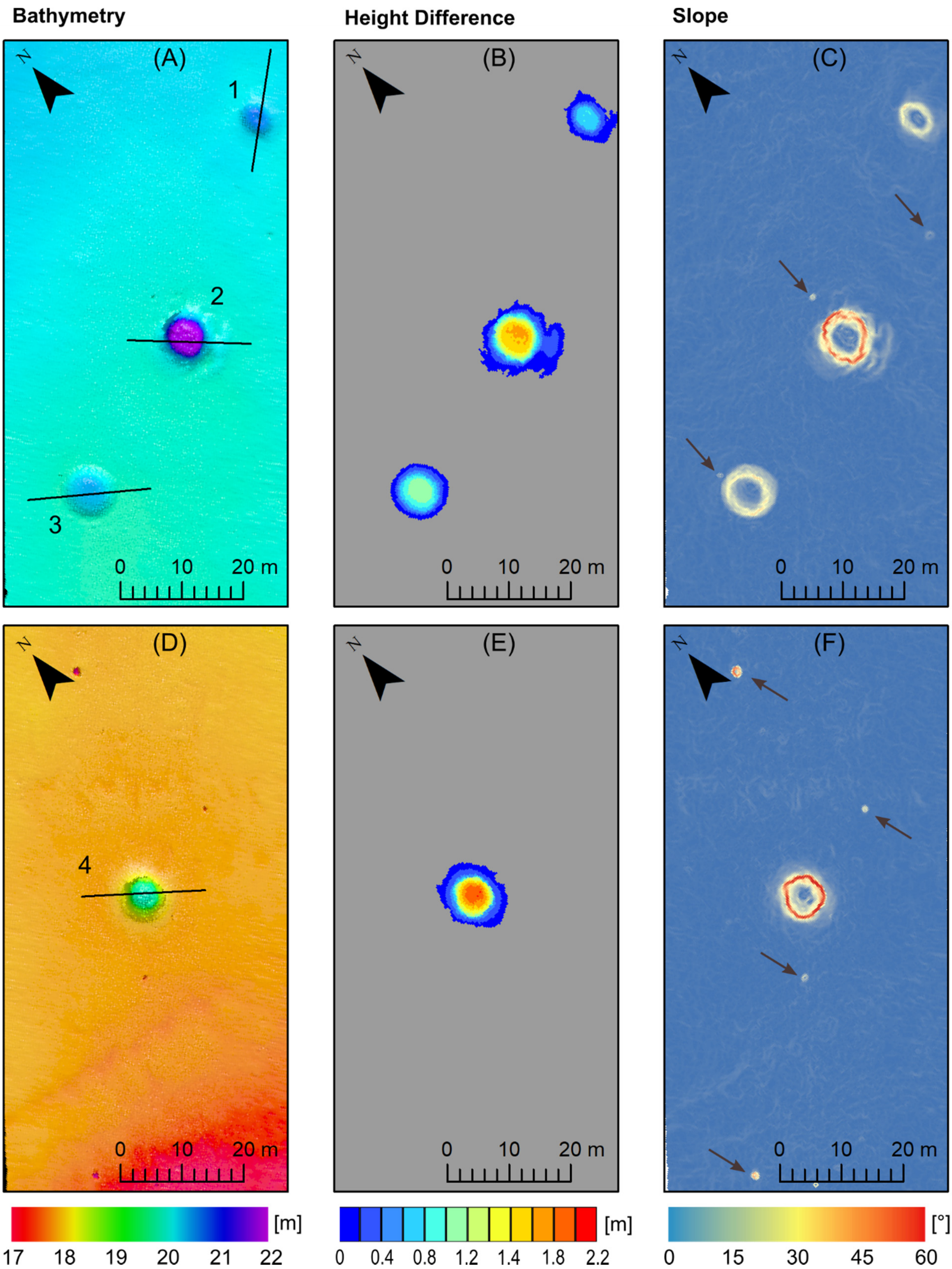

Figure 2. Maps of morphology (**A**,**D**), height difference to the surrounding seafloor (**B**,**E**), and slope angle (**C**,**F**). Four detonation craters were observed within the multibeam echosounder dataset. The black lines mark the position of the cross-sections in Figure 3. The arrows in (**C**,**F**) highlight boulders in the vicinity of the detonation craters.

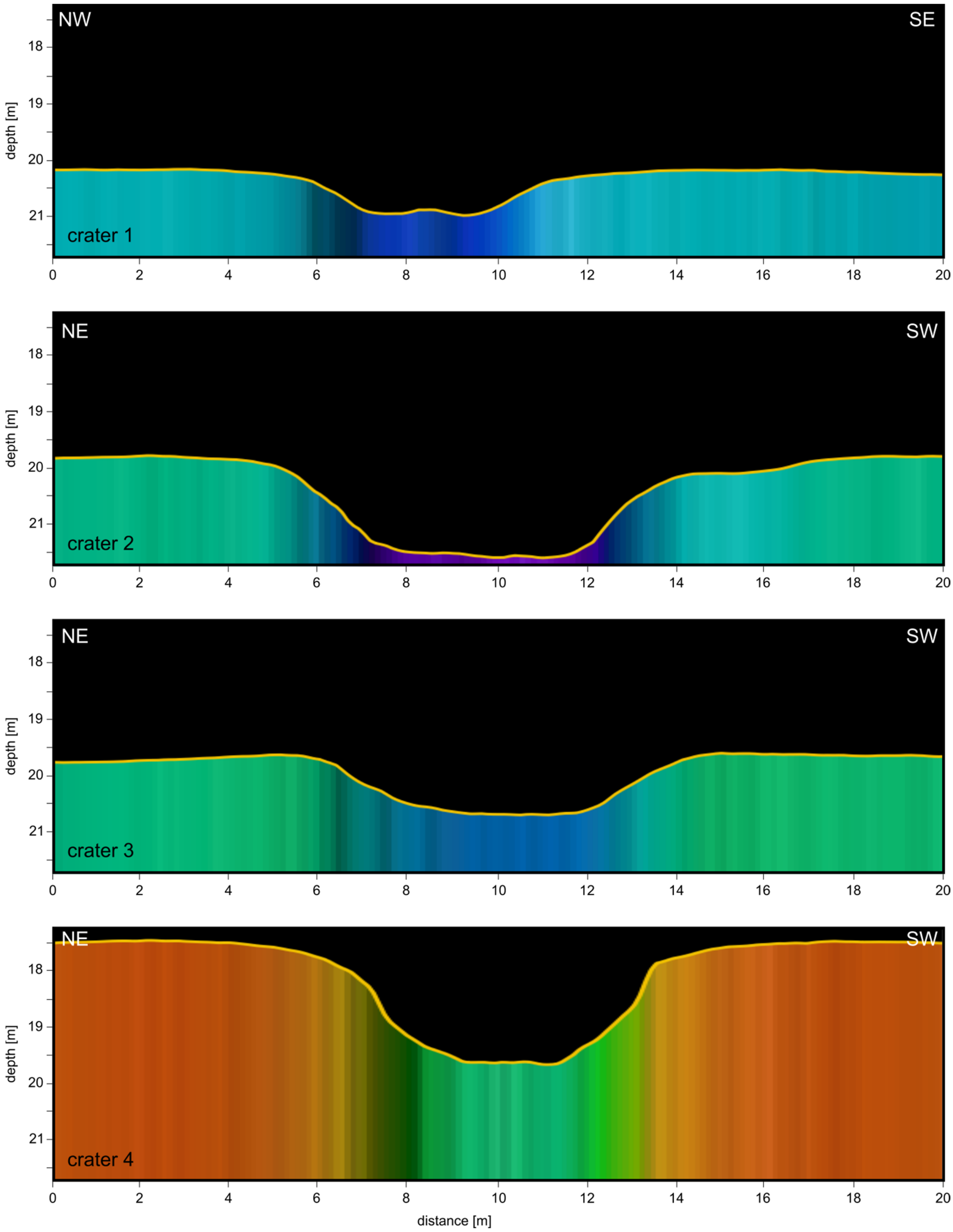

Figure 3. Cross-sections for detonation craters 1–4. The coloring changed with bathymetry level.

5. Conclusions

The craters caused by the ground mine detonation were detectable in detail, and the geometric dimensions were calculable by the first-time multibeam echosounder survey. The explosive force caused depressions so large that they still existed a year after the detonations. This dataset is the basis for future investigations. To understand the full impact of the detonation on the environment, it is planned for this survey to be repeated together with sedimentological and biological investigations. Since the craters are located in a special area of conservation, it is of special interest to determine the time needed to re-establish the habitat integrity.

Author Contributions: Conceptualization, S.P., P.F. and A.D.; data acquisition, P.F. and A.D.; data processing, S.P.; data curation, S.P.; writing—original draft preparation, S.P.; writing—review and editing, A.D. and P.F.; visualization, S.P. All authors have read and agreed to the published version of the manuscript.

Funding: The publication of this article was funded by the Open Access Fund of the Leibniz Association.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The bathymetric data used for this work are archived as an ASCII dataset with open access in the CERN's Data Centre Zenodo: https://doi.org/10.5281/zenodo.6374951 (accessed on 21 March 2022).

Acknowledgments: We would like to thank the captain and the crew of the RV Elisabeth Mann Borgese for their excellent work and assistance.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Vessel parameters describing the system offsets. Positive motion values: roll port up, pitch bow down, heave up. Positive direction: forward, to starboard.

System	Offsets
Transducer	Roll −0.14°, Pitch 0.65°, Heading 1.15°, Starboard 1.109 m, Forward 11.057 m, Up −2.394 m
Receiver	Roll −0.14°, Pitch 0.65°, Heading 1.15°, Starboard 1.109 m, Forward 10.796 m, Up −2.394 m
GPS antenna	Latency 0 s, Starboard −3.348 m, Forward 4.24 m, Up 10.942 m
Motion sensor	Latency 0 s, Heave Delay 0 s, Roll 0.1°, Pitch 0.3°, Heading 0°, Heave 0 m, Starboard 0.5 m, Forward −2.6 m, Up 1.08 m
Motion sensor	Latency 0 s, Heave Delay 0 s, Roll 0.1°, Pitch 0.3°, Heading 0°, Heave 0 m, Starboard 0.5 m, Forward −2.6 m, Up 1.08 m

References

1. Beddington, J.; Kinloch, A.J. *Munitions Dumped at Sea: A Literature Review*; Imperial College London Consultants: London, UK, 2005.
2. Bełdowski, J.; Brenner, M.; Lehtonen, K.K. Contaminated by War: A Brief History of Sea-Dumping of Munitions. *Mar. Environ. Res.* **2020**, *162*, 105189. [CrossRef] [PubMed]
3. Bełdowski, J.; Klusek, Z.; Szubska, M.; Turja, R.; Bulczak, A.I.; Rak, D.; Brenner, M.; Lang, T.; Kotwicki, L.; Grzelak, K.; et al. Chemical Munitions Search & Assessment—An Evaluation of the Dumped Munitions Problem in the Baltic Sea. *Deep. Sea Res. Part II Top. Stud. Oceanogr.* **2016**, *128*, 85–95. [CrossRef]
4. Carton, G.; Jagusiewicz, A. Historic Disposal of Munitions in U.S. and European Coastal Waters, How Historic Information Can Be Used in Characterizing and Managing Risk. *Mar. Technol. Soc. J.* **2009**, *43*, 16–32. [CrossRef]
5. Böttcher, C.; Knobloch, T.; Rühl, N.-P.; Sternheim, J.; Wichert, U.; Wöhler, J. *Munitionsbelastung der Deutschen Meeresgewässer–Bestandsaufnahme und Empfehlungen*; Sekretariat Bund/Länder-Messprogramm für die Meeresumwelt von Nord- und Ostsee (BLMP): Hamburg, Germany, 2011; p. 174.
6. Kampmeier, M.; van der Lee, E.M.; Wichert, U.; Greinert, J. Exploration of the Munition Dumpsite Kolberger Heide in Kiel Bay, Germany: Example for a Standardised Hydroacoustic and Optic Monitoring Approach. *Cont. Shelf Res.* **2020**, *198*, 104108. [CrossRef]
7. Böttcher, C.; Knobloch, T.; Sternheim, J.; Weinberg, I.; Wichert, U.; Wöhler, J. *Munitionsbelastung der Deutschen Meeresgewässer–Entwicklungen und Fortschritt (Jahr 2018)*; Für die Bund/Länder-Arbeitsgemeinschaft Nord- und Ostsee (BLANO): Hamburg, Germany, 2019; p. 60.

8. Beck, A.J.; van der Lee, E.M.; Eggert, A.; Stamer, B.; Gledhill, M.; Schlosser, C.; Achterberg, E.P. In Situ Measurements of Explosive Compound Dissolution Fluxes from Exposed Munition Material in the Baltic Sea. *Environ. Sci. Technol.* **2019**, *53*, 5652–5660. [CrossRef]
9. Beck, A.J.; Gledhill, M.; Schlosser, C.; Stamer, B.; Böttcher, C.; Sternheim, J.; Greinert, J.; Achterberg, E.P. Spread, Behavior, and Ecosystem Consequences of Conventional Munitions Compounds in Coastal Marine Waters. *Front. Mar. Sci.* **2018**, *5*, 141. [CrossRef]
10. Briggs, C.; Shjegstad, S.M.; Silva, J.A.K.; Edwards, M.H. Distribution of Chemical Warfare Agent, Energetics, and Metals in Sediments at a Deep-Water Discarded Military Munitions Site. *Deep. Sea Res. Part II Top. Stud. Oceanogr.* **2016**, *128*, 63–69. [CrossRef]
11. Koske, D.; Goldenstein, N.I.; Kammann, U. Nitroaromatic Compounds Damage the DNA of Zebrafish Embryos (Danio Rerio). *Aquat. Toxicol.* **2019**, *217*, 105345. [CrossRef]
12. Koske, D.; Straumer, K.; Goldenstein, N.I.; Hanel, R.; Lang, T.; Kammann, U. First Evidence of Explosives and Their Degradation Products in Dab (*Limanda limanda* L.) from a Munition Dumpsite in the Baltic Sea. *Mar. Pollut. Bull.* **2020**, *155*, 111131. [CrossRef]
13. Strehse, J.S.; Appel, D.; Geist, C.; Martin, H.-J.; Maser, E. Biomonitoring of 2,4,6-Trinitrotoluene and Degradation Products in the Marine Environment with Transplanted Blue Mussels (M. Edulis). *Toxicology* **2017**, *390*, 117–123. [CrossRef]
14. Law, R.; Hanke, G.; Angelidis, M.; Batty, J.; Bignert, A.; Dachs, J.; Davies, I.; Denga, Y.; Duffek, A.; Herut, B.; et al. *Marine Strategy Framework Directive: Task Group 8 Report Contaminants and Pollution Effects*; European Commission, Joint Research Centre: Luxenburg, 2010.
15. Frey, T.; Greinert, J. Bomben Am Meeresgrund-Der Umgang Mit Den Kriegsaltlasten in Der Deutschen Ostsee. In *Altlasten 2021-Beiträge zum Seminar, 18. und 19. Mai 2021, Online Seminar*; Egloffstein, T., Burkhardt, G., Schumacher, K., Eds.; ARRAY(0x558c301daad8): Karlsruhe, Germany, 2021; pp. 87–96. ISBN 978-3-939662-28-0.
16. Pfeiffer, F. Changes in Properties of Explosives Due to Prolonged Seawater Exposure. *Mar. Technol. Soc. J.* **2012**, *46*, 102–110. [CrossRef]
17. Maser, E.; Strehse, J.S. "Don't Blast": Blast-in-Place (BiP) Operations of Dumped World War Munitions in the Oceans Significantly Increase Hazards to the Environment and the Human Seafood Consumer. *Arch. Toxicol.* **2020**, *94*, 1941–1953. [CrossRef] [PubMed]
18. Umwelt Bundesamt Ammunition in the Sea. Available online: https://www.umweltbundesamt.de/themen/wasser/meere/nutzung-belastungen/munition-im-meer#schadstoffbelastung-durch-konventionelle-munition (accessed on 16 March 2022).
19. Siebert, U.; Stürznickel, J.; Schaffeld, T.; Oheim, R.; Rolvien, T.; Prenger-Berninghoff, E.; Wohlsein, P.; Lakemeyer, J.; Rohner, S.; Aroha Schick, L.; et al. Blast Injury on Harbour Porpoises (*Phocoena phocoena*) from the Baltic Sea after Explosions of Deposits of World War II Ammunition. *Environ. Int.* **2022**, *159*, 107014. [CrossRef] [PubMed]
20. von Benda-Beckmann, A.M.; Aarts, G.; Sertlek, H.Ö.; Lucke, K.; Verboom, W.C.; Kastelein, R.A.; Ketten, D.R.; van Bemmelen, R.; Lam, F.-P.A.; Kirkwood, R.J.; et al. Assessing the Impact of Underwater Clearance of Unexploded Ordnance on Harbour Porpoises (*Phocoena phocoena*) in the Southern North Sea. *Aquat. Mamm.* **2015**, *41*, 503–523. [CrossRef]
21. Lass, H.U.; Schwabe, R.; Matthäus, W.; Francke, E. On the Dynamics of Water Exchange between Baltic and North Sea. *Contrib. Mar. Sci. Res.* **1987**, *56*, 27–49.
22. Federal Maritime and Hydrographic Agency Batyhmetrie (BSH). Available online: http://bio-50.io-warnemuende.de/iowbsa/index.php?go=neu%20Laden&gast=36&thema33=1&group_16=1 (accessed on 16 March 2022).
23. Leibniz Institute for Baltic Sea Research Bathymetrie (IOWTOPO). Available online: http://bio-50.io-warnemuende.de/iowbsa/index.php?go=neu%20Laden&gast=35&thema10=1&group_16=1 (accessed on 16 March 2022).
24. Papenmeier, S.; Darr, A.; Feldens, P. Bathymetry Data from Detonation Scars in the Fehmarnbelt, German Baltic Sea. *Dataset. Zenodo* **2022**. Available online: https://zenodo.org/record/6374951#.YnoeR_gRVPY (accessed on 21 March 2022).
25. Bookstein, F.L. Principal Warps: Thin-Plate Splines and the Decomposition of Deformations. *IEEE Trans. Pattern Anal. Mach. Intell.* **1989**, *11*, 567–585. [CrossRef]
26. Höft, D.; Feldens, A.; Tauber, F.; Schwarzer, K.; Valerius, J.; Thiesen, M.; Mulckau, A. Map of Sediment Distribution in the German EEZ (1:10,000). 2020. Available online: https://www.geoseaportal.de/mapapps/rescources/apps/sedimentverteilung_auf_dem_meeresboden/index.html?lang=de (accessed on 16 March 2022).
27. Schwarzer, K.; Diesing, M. Erforschung Der FFH-Lebensraumtypen Sandbank und Riff in der AWZ der deutschen Nord-und Ostsee. Abschlussbericht FKZ-Nr. 80285270. *Bundesamt Für Nat.* **2006**, 68.
28. Feldens, P.; Diesing, M.; Schwarzer, K.; Heinrich, C.; Schlenz, B. Occurrence of Flow Parallel and Flow Transverse Bedforms in Fehmarn Belt (SW Baltic Sea) Related to the Local Palaeomorphology. *Geomorphology* **2015**, *231*, 53–62. [CrossRef]
29. BSH. *Guideline for Seafloor Mapping in German Marine Waters Using High-Resolution Sonars*; BSH: Munich, Germany, 2016.
30. Heinrich, C.; Anders, S.; Schwarzer, K. Late Pleistocene and Early Holocene Drainage Events in the Eastern Fehmarn Belt and Mecklenburg Bight, SW Baltic Sea. *Boreas* **2018**, *47*, 754–767. [CrossRef]
31. Novak, B.; Björck, S. A Late Pleistocene Lacustrine Transgression in the Fehmarn Belt, Southwestern Baltic Sea. *Int. J. Earth Sci. (Geol Rundsch)* **2004**, *93*, 634–644. [CrossRef]
32. Höft, D.; Richter, P.; Valerius, J.; Meier, F.; Schwarzer, K. *Map of Boulder Distribution in the German EEZ*; The Federal Maritime and Hydrographic Agency Batyhmetrie (BSH): Hamburg, Germany, 2020; (Personally provided by the Federal Maritime and Hydrographic Agency Batyhmetrie (BSH)).

33. Heinicke, K.; Bildstein, T.; Reimers, H.-C.; Boedeker, D. *Leitfaden zur Großflächigen Abgrenzung und Kartierung des Lebensraumtyp "Riffe" in der Deutschen Ostsee (EU-Code 1170; Untertyp: Geogene Riffe)*; Bundesamt für Naturschutz: Vilm, Germany, 2021; p. 45.
34. Manso, F.; Radzevicius, R.; Blažauskas, N.; Ballay, A.; Schwarzer, K. Nearshore Dredging in the Baltic Sea: Condition after Cessation of Activities and Assessment of Regeneration. *J. Coast. Res.* **2010**, *51*, 187–194.
35. Mielck, F.; Hass, H.C.; Michaelis, R.; Sander, L.; Papenmeier, S.; Wiltshire, K.H. Morphological Changes Due to Marine Aggregate Extraction for Beach Nourishment in the German Bight (SE North Sea). *Geo-Mar. Lett.* **2019**, *39*, 47–58. [CrossRef]