Archaeology: Just Add Water

Volume III

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Preface

Dear colleagues,

With great pleasure, we finally give you the third ***Archaeology: Just Add Water***.

For the first time, it is not only the volume of the Supplement Series U: Underwater Archaeology within 'Światowit', University of Warsaw's archaeological journal of great traditions, but also a part of a brand-new trademark, **Warsaw Series in Archaeology**.

The collection of articles 'traditionally' presents some of the papers delivered at the ***Warsaw Seminar on Underwater Archaeology***. Its fourth edition was held at the University of Warsaw on 18–20 November 2020 and was generously funded by the Polish Ministry of Education and Science, this book included.

Both the seminar and the volume were possible thanks to the cooperation with the Polish Chapter of the Explorers Club: in particular, its President Professor Mariusz Ziółkowski and Vice-President Marcin Jamkowski, to whom we are deeply grateful. We would also like to express our gratitude for the support of the University of Warsaw, namely the Vice-Rector for Research, Prof. Zygmunt Lalak, Ph.D., and, especially the authorities of the University of Warsaw's Faculty of Archaeology.

The seminar was also strongly supported by two extraordinary museums: Warsaw University Museum (we are greatly indebted to its Director, Ph.D. hab. Hubert Kowalski, prof. UW) and the Museum of Diving in Warsaw (many thanks to Karina Kowalska — its Curator — and Grzegorz Kowalski, Ph.D., D.Sc. for their assistance and friendship).

We would like to express our sincere thanks to all the authors and reviewers who have met our strict deadlines with extraordinary diligence and punctuality. The entire book was once again supervised by Ph.D. hab. Bartosz Kontny, prof. UW, who devoted a lot of energy. We would like to express our thanks for all his advice and commitment to organizational matters. Last but not least, we would also like to thank our proofreaders, Zuzanna Napieralska and Anna Szolc, for their insightful and detailed work.

The organization of the conference and the development of the book fell during a difficult and confusing period (for everyone, including academia) — the COVID-19 coronavirus pandemic.

With all that said: we truly hope that you will enjoy the results of our efforts and find this volume both informative and satisfying!

Małgorzata Mileszczyk

Magdalena Nowakowska

Magdalena Krzemień

Joanna Staniszewska

IZABELA BODUS-OLKOWSKA, GRZEGORZ ZANIEWICZ, AND PIOTR MALIŃSKI

7. Between Hydrography and Underwater Ethnoarchaeology

Modelling of Selected Wrecks in the Lower Oder as a Part of Research on the Geoclassification Method of Ferromagnetic Bottom Objects

ABSTRACT In August 2020 the authors undertook an interdisciplinary survey of twelve wrecks located and inventoried earlier, as part of the project *Underwater Ethnoarchaeology of the Lower Oder. Preliminary Research on Wrecks in Selected Sections of the River* (grant no. 2018/02/X/HS3/00475, National Science Centre, Poland). The hydrographers from the Maritime University of Szczecin and the ethnologist from the University of Szczecin established cooperation in this regard. The survey was part of the research on the geoclassification method of anthropogenic, ferrous, underwater objects based on magnetic anomaly maps. Data acquisition involved recording data with an interferometric echo-sounder, side-scan sonar, and marine magnetometer. The survey was done by the research vessel *Hydrograf XXI*.

The results provided new datasets of examined wrecks, as well as other, previously unknown bottom objects. This contributed to a better understanding of the underwater cultural heritage resources of the Oder River. Moreover, collected data was used to create the catalogue of underwater ferromagnetic objects, which is the basis of the geoclassification method. The cooperation of the hydrographers and the ethnologist was an interesting and creative experience, whose interdisciplinary value lay in learning about different research methods and techniques — in relation to the same object of research. The collected hydrographic data will also be used in the project *MORGAV: Development of Technology Acquisition and Exploration of Gravimetric Data of Foreshore and Seashore of Polish Maritime Areas* (National Centre for Research and Development, Poland, Smart Growth Operational Programme 2014–2020, competition: 1/4.1.4/2018).

KEYWORDS hydrography, geoclassification, underwater ethnoarchaeology, underwater cultural heritage, magnetic anomaly, remote sensing, sonar imaging, digital bottom model, wrecks, Lower Oder River

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Introduction

In the second volume of *Archaeology: Just Add Water*, a text presenting aims, objectives, methods, and first results of the project *Underwater Ethnoarchaeology of the Lower Oder. Preliminary Research on Wrecks in the Selected Sections of the River* (Maliński 2019a)[1] was published. It should be recalled here that it was a project funded by the National Science Centre, Poland (grant no. 2018/02/X/HS3/00475), carried out by the University of Szczecin (West Pomerania, Poland) between 2018 and 2019. The research lasted twelve months and consisted of gathering information about the wrecks during the ethnological fieldwork and then verifying them, using techniques typical for underwater archaeology.[2] The main goal of the project was to recognize the potential of the underwater cultural heritage resources in the inland waters of the lower course of the Oder River[3] — together with its distributaries, numerous water areas of Międzyodrze (re-naturalized polders between the East Oder and the West Oder), and Lake Dąbie (all located in West Pomerania, Poland).[4]

Resources from the study area were found to be quite rich, and, additionally, the interdisciplinary method used has proven its effectiveness; during the research 102 wrecks were located and inventoried.[5] Moreover, in three selected wreck sites (with the highest number of wrecks), non-invasive underwater archaeological research was undertaken. A team, consisting of commercial divers and an archaeologist,[6] took measurements of and made basic documentation for fourteen wrecks. It seems to be an unprecedented result, as never before has such a number of wrecks been inventoried and archaeologically examined in one season in West Pomerania (Maliński 2020b: 42).

However, this is only the result of the 'preliminary research' on 'selected sections of the river' — as the subtitle of the project states. There are undoubtedly many more shipwrecks in the Lower Oder waiting to be discovered and explored. Also, most of the already located wrecks should be investigated further, with an interdisciplinary approach and the application of advanced underwater exploration techniques (especially non-invasive ones, such as remote sensing). Hence it is clear that the undertaken research was only the first step towards a comprehensive understanding of the Lower Oder's underwater cultural heritage — and it needs to be continued (Maliński 2020c; Maliński *et al.* 2021: 45).

The opportunity to do so came in the summer of 2020, shortly after publishing the project's preliminary results in a local popular science journal (Maliński 2020b). Fortunately, this publication came into the hands of hydrographers from the Chair of Geoinformatics, Faculty of Navigation at the Maritime University of Szczecin[7] (West Pomerania, Poland), who decided that some of the obtained results could be useful to them. They needed bathymetric, sonar, and magnetometric data related to wrecks in order to develop an innovative method of geoclassification of bottom objects based on the magnetic anomaly maps of water areas. This resulted in an interdisciplinary academic collaboration between the authors of the present text: two hydrographers and an ethnologist.

In August 2020 they conducted a measurement campaign at twelve selected wrecks, using *Hydrograf XXI* — a small research vessel of composite construction and hybrid drive, equipped with advanced navigation and measuring devices.[8] The results obtained through the bathymetric, sonar, and magnetometer research made it possible not only to create a catalogue of the selected wrecks' magnetic anomalies but also contributed to the enrichment of knowledge about the cultural heritage submerged in the Lower Oder waters (Kołacz-Rogucka 2021; Maliński 2021a).

Another outcome of the above-mentioned cooperation is this text, which presents the research conducted in detail and its results. It is divided into five parts. The first part contains a description of the equipment used and the whole measurement campaign. The next part

1 The results of this project were also presented by Piotr Maliński on a poster during the 4th Warsaw Seminar on Underwater Archaeology (Maliński 2021b).
2 Ethnological qualitative research consisted of structured interviews, during which data regarding the wrecks and their spatial context was acquired from the respondents. Information about wreck locations, collected in this way, was then verified using remote sensing techniques — side-scan sonar images and aerial photographs taken with an unmanned aerial vehicle (Maliński 2019a: 226–27).
3 Officially, the final section of the Oder River constitutes an area of internal sea waters — and these, on formal grounds, were not included in the study area.
4 Most locations in the present article are in West Pomerania, Poland, unless otherwise stated.
5 There were wrecks of both watercraft (kayaks, boats, yachts, barges, and ships) and cars.
6 The research team consisted of: Sławomir Radaszewski (commercial diver first class, diving works manager second class), and Jakub Radaszewski (commercial diver third class) from the company *NUREK-TECHNIKA Prace Podwodne i Hydrotechniczne*, as well as an archaeologist Przemysław Krajewski from the Chair of Archaeology, Institute of History, University of Szczecin (Maliński 2019b: 179).
7 Polish: Katedra Geoinformatyki, Wydział Nawigacyjny Akademii Morskiej w Szczecinie.
8 Apart from the authors of this text, engineer Adrian Popik, a senior technician (and a member of the *Hydrograf XXI* crew), also participated in the campaign (Maliński *et al.* 2021: 48).

presents the assumptions of the geoclassification method of ferromagnetic underwater objects — why and for what purpose it is to be used — and a brief description of the selected and surveyed wrecks. The third part is devoted to wreck modelling — among other things, the processing of hydrographic and geophysical data.

The fourth part contains the data that has already been processed: the final products from the various used sensors — and some examples of their use in the interpretation of the underwater cultural heritage sites. In the last part, there are some conclusions that the authors made on the basis of the conducted research. Annex 1 is a list of twelve surveyed wrecks. Annex 2 contains a summary table of the studied wrecks' attributes (with two examples: a shipwreck and a car wreck).

Dataset

The survey campaign was carried out on the survey vessel *Hydrograf XXI* (Figs 7.1 and 7.2) — the floating research laboratory — and with the hydrographic equipment of the Maritime University of Szczecin:

- interferometric bathymetric system GeoSwath Plus (Fig. 7.3);
- side-scan sonar — Edgetech 4125;
- towed marine magnetometer — SeaSPY (Fig. 7.4).

The above-mentioned sensors, for proper operation, require information from a number of peripheral sensors, such as: a motion sensor (MRU),[9] GNSS/RTK[10] satellite positioning system, a satellite compass, and sound velocity sensors in water: SVS and SVP[11] (Fig. 7.5).

The survey area covering the Lower Oder was divided into five smaller research areas (two in the East Oder, one in the Regalica, one in the Kanał Leśny, and one in the West Oder; Fig. 7.6).

The interferometric bathymetry system has become an interesting alternative to the typically used multibeam echo-sounders. Its principle of operation is more similar to that of the side-scan sonar. It guarantees a wideband of data coverage even in shallow waters.

An interferometric echo-sounder system consists of the following components: a processor, a transducer system, and a probe to measure the speed of sound in the water horizontally. Additional, so-called peripheral systems are required to operate the bathymetric system, i.e. motion sensor for roll, pitch, and heave measurements, a compass for heading measurements, a positioning system, dedicated acquisition software, and a sound velocity probe to measure the speed of sound at different depths (sound velocity profile; Fig. 7.7). For the research, the GeoSwath Plus bathymetric sonar system operating at a frequency of 250 kHz was used. A two-head transducer together with the motion sensor and SVS sensor were installed on the bow of the survey boat *Hydrograf XXI*. Course data were provided by the Hemisphere V100 satellite compass, while centimetre-precise positioning was guaranteed by the Trimble R6 GNSS/RTK system.

The survey run lines on the Oder River were designed in the location of sunken wrecks; they ran parallel to the shoreline, using 100 per cent coverage. Where objects were detected, additional profiles were often used for data densities. Data acquisition was performed in Hypack software and processing in the Hysweep module.

Underwater side-scan sonar imaging is based on the fundamentals of underwater acoustics. These devices are becoming more and more sensitive and, depending on the system, can image bottom elements smaller than 10 cm. Typical sonar applications include the detection of objects (i.e. mines, shipwrecks and other sunken vehicles, underwater pipelines, lost cargo), seabed classification (i.e. types of sediment, rock assemblages, riprap structures), and inspection of underwater structures (i.e. bridges, pylons, quay walls, and mining infrastructure). The side-scan sonar is towed behind the survey vessel or mounted as an overside pole sonar. The sonar head is often referred to as a 'fish'. The device sends acoustic signals in the form of pulses, perpendicular to the direction of the head's movement. Sensitive signal receivers (also called hydrophones) collect the returned signal and process it into a digital image. The returning echoes from a single pulse are presented as a single line with light and dark colour tones representing weak or strong reflections relative to the passage time of the acoustic pulse (Lekkerkerk and Theijs 2011: 119–50).

Modern towed sonars typically operate at two frequencies: lower and higher, for example: 100/500 kHz, 600/1600 kHz. Generally, high frequency is used where high-resolution imagery is required but is limited in range. Lower-frequency sonar provides a lower-resolution image but has the capability of a longer-range search due to the higher energy of the acoustic signal. As the pulse sent from the sonar reaches a surface of the bottom or an object on the bottom, there is a possibility of the signal's absorption by the material, scattering, backscatter, or mirror reflection. All the aforementioned acoustic reflections are dependent on the material and topography of the imaged area,

9 Motion Reference Unit.
10 Global Navigation Satellite Systems/Real Time Kinematic.
11 Sound Velocity Sensor and Sound Velocity Profiler.

Figure 7.1. Research vessel *Hydrograf XXI* — Maritime University of Szczecin's 'floating laboratory' during side-scan sonar survey in the West Oder (West Pomerania, Poland, photo: P. Maliński).

Figure 7.2. Izabela Bodus-Olkowska and Grzegorz Zaniewicz on the bridge of the survey boat *Hydrograf XXI*, conducting hydrographic and geophysical measurements in the Kanał Leśny (West Pomerania, Poland, photo: P. Maliński).

Figure 7.3. Adrian Popik and Grzegorz Zaniewicz checking the transducer of interferometric echo-sounder GeoSwath Plus (photo: P. Maliński).

Figure 7.4. The researchers (from left: Grzegorz Zaniewicz, Adrian Popik, and Piotr Maliński) with research equipment — towfish transducers of marine magnetometer SeaSPY (in the foreground) and side-scan sonar Edgetech 4125 (photo: I. Bodus-Olkowska).

Figure 7.5. Adrian Popik presenting sound velocity sensor Valeport miniSVP just before taking measurements in the water of the East Oder (West Pomerania, Poland, photo: I. Bodus-Olkowska).

and in the final phase, affect the image content (Mazel 1985: 3–10).

The Edgetech 4125 towed sonar was used as a part of a survey campaign dedicated to the search and verification of wrecks in the Lower Oder River. The sonar operates at two frequencies simultaneously, which allows matching the frequency to the planned bottom search. The described sonar system was positioned by using Trimble R6 GNSS/RTK positioning system and layback method. Data acquisition was carried out in the Discover software, which has the function of adjusting the image display in the form of gain and TVG[12] parameters and the function of navigation support. One to several sonograms were recorded at each wreck location. Data was recorded in .jsf file format, which was imported into Hypack software in the next stage.

The marine magnetometer is designed to detect and locate underwater objects with ferromagnetic characteristics, thanks to the magnetic field they produce. It can easily detect ferrous objects such as anchors, chains, cables, pipes, ships, car or plane wrecks, unexploded ordnance (UXO), engines, or

12 Time Varying Gain.

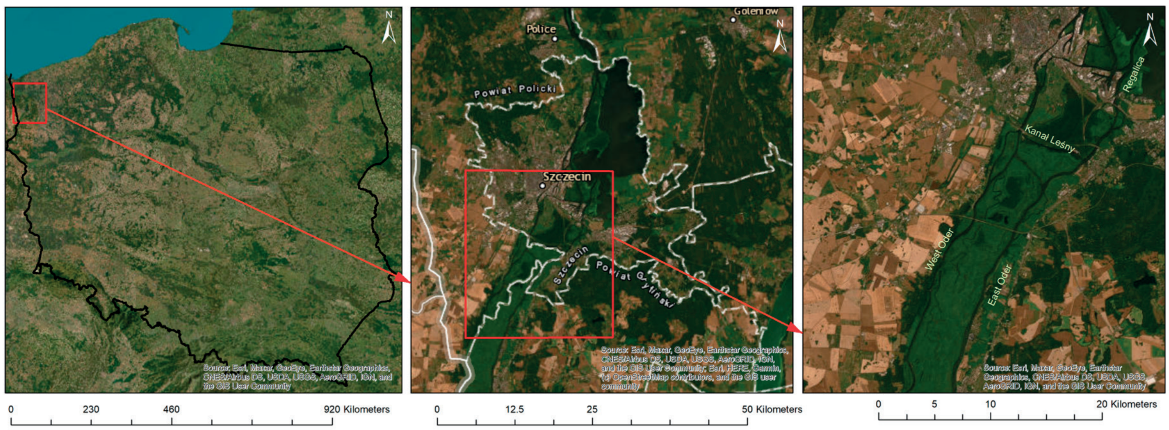

Figure 7.6. Areas of research (source of the map: Esri Basemaps, ArcGIS Desktop software, elaborated by: I. Bodus-Olkowska).

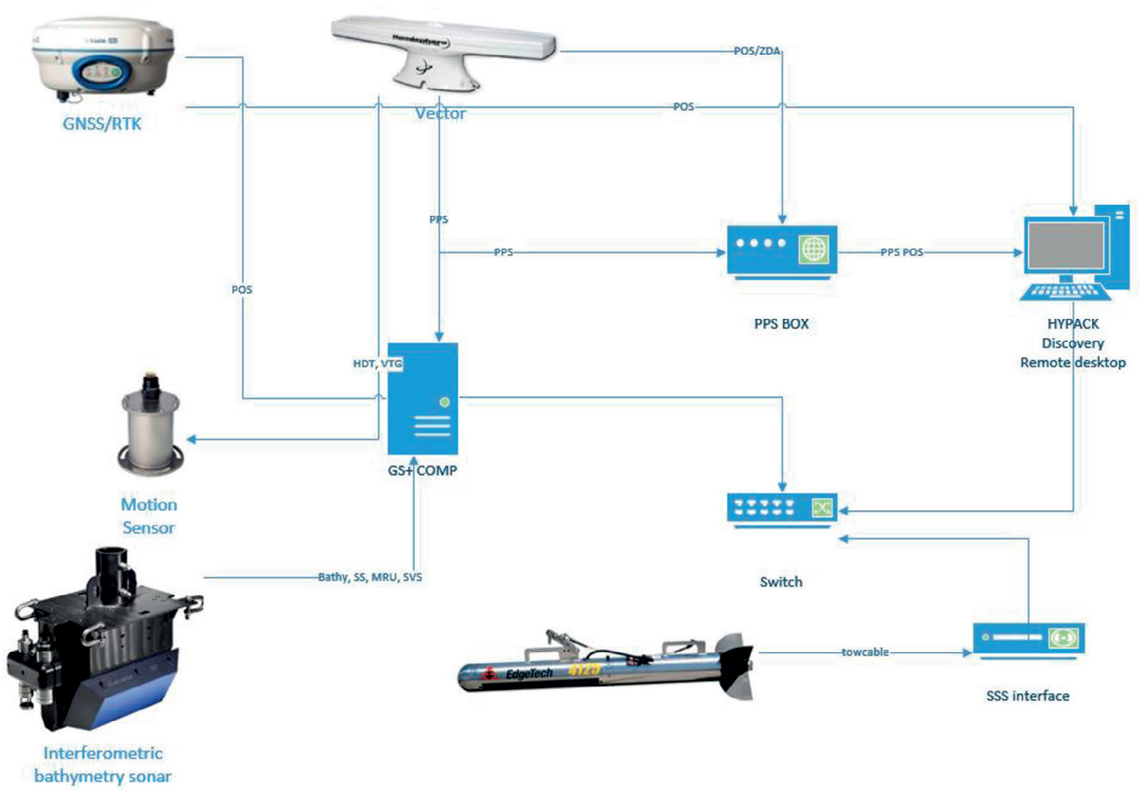

Figure 7.7. Scheme of the bathymetric, sonar, and magnetometric survey system (drawn by: G. Zaniewicz).

other construction elements that belong to wrecks. A marine magnetometer is a towed overboard sensor. It registers the indications of Earth's magnetic field on a survey area. When these values are compared to the value of the magnetic field obtained from the geophysical observatory closest to the survey area — it is possible to determine the occurrence of a magnetic anomaly i.e. a disturbance of the magnetic field and its value.

Magnetic data were collected using the SeaSPY marine magnetometer. In the case of surveying with a marine magnetometer, it is crucial to eliminate all possible interference from one's own vessel and to define potential interference from harbour infrastructure facilities, e.g. quays, piers, bridge pillars, aids to navigation, high voltage lines, other moored or passing vessels, etc. *Hydrograf XXI* is built of laminate, hence interference from the vessel's hull was not generated. However, it was

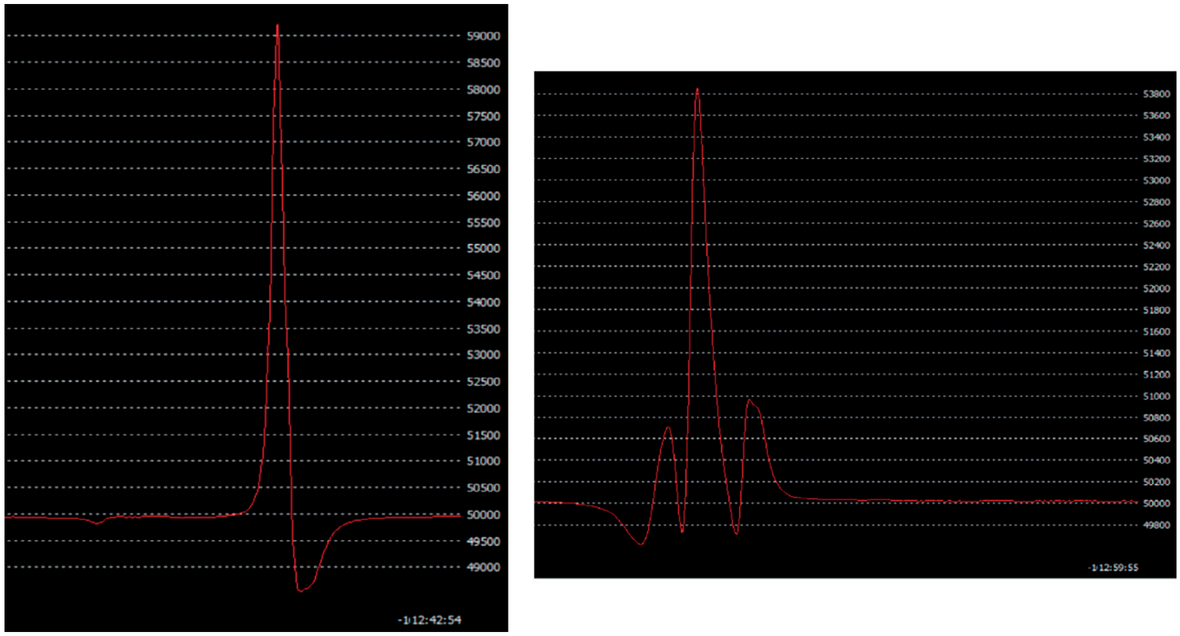

Figure 7.8. Two magnetic anomaly diagrams of SDB3 wreck — view of the data during the acquisition (source: screenshot from Hypack software, I. Bodus-Olkowska).

necessary to choose an appropriate length of cable line to tow the magnetometer to minimize the interference generated by the electric engines.

The marine magnetometer records the local magnetic field values acquired as the vessel moves along a planned measuring line. This sensor propagates an electromagnetic pulse, and thus induces a magnetic field around itself. Its operating frequencies are from 0.5 Hz to 4 Hz. The higher the operating frequency is, the more recorded measuring points of a magnetic field value. The average value of Earth's magnetic field in the survey area is about 48,000 nT. The detection of potential ferrous seabed underwater objects consists of observing the amplitude diagram of the recorded values and marking the places where the diagram deviates from the trend, generating significant deviations in positive or negative values (Fig. 7.8).

As a result of the data acquisition the values of the geodetic coordinates, the measurement time, and the value of the magnetic field were saved. It is extremely important to synchronize the measurement time of the magnetometer sensor with the time of the computer through which the data is saved because the magnetic field is a time-varying value. Collected results are then processed. In this procedure, corrections related to positioning and the ones obtained from a selected geophysical observatory are applied.

During the magnetometer survey, about 33,000 measurement points were collected, and data were recorded on fifty measurement profiles, planned at distances from 5 to 10 m; the collected information was about twelve objects: car and shipwrecks, and others.

Both the configuration of the measurement system, as well as data acquisition and subsequent data processing were made in the Hypack hydrographic software.

Assumptions of the Geoclassification Method

Determination of the areas where magnetic anomalies occur, i.e. those in which the direction of the magnetic field clearly deviates from the average for a given latitude, in hydrography most often aims to determine the potential locations of ferrous objects lying on the bottom.

Such places can be the positions of the sunken objects' remains, like vessels, planes, cars, equipment, anchors, pipelines, or UXO. The Earth's magnetic field is measured in Tesla; in practice, these changes in the magnetic field are so small that the unit nT (nanotesla) is used. The possibility of detecting a ferromagnetic object is determined by the sensitivity of the measuring sensor itself. Producers declare a sensitivity of 5 nT, however, in practice, the detection of an object is affected by many factors, including the survey vessel construction, towing parameters, the distance between the sensor and the object, operating frequency, and profile density (Holt 2019: 14–18).

Since a magnetic anomaly map presents only the location of the source of a disturbance and its value,

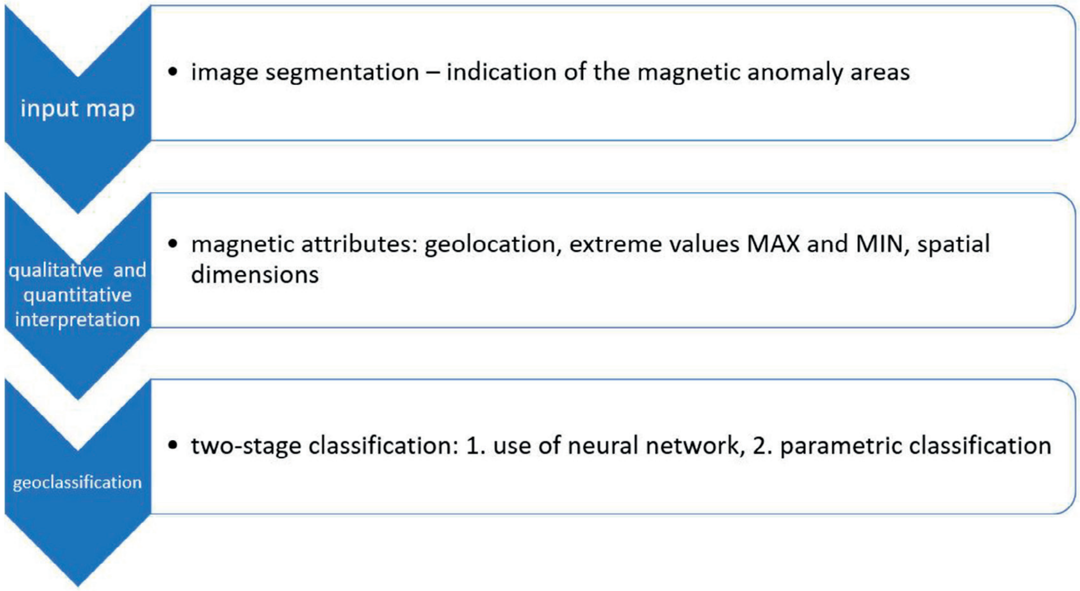

Figure 7.9. The classification method process (drawn by: I. Bodus-Olkowska).

such areas require verification using other techniques of hydrographic measurement. Most often these are sonar imaging and bathymetric acquisition, or simply identification by an underwater camera or a diver (Bodus-Olkowska and Wawrzyniak 2017: 1–10).

The classification method is founded on the development of a technique of object classification based only on an anomaly map presented in .jpg, .png, or .tiff format.

The objects of anthropogenic origin such as pipelines, UXO, anchors, and wrecks are considered. The main aim of the method is an automatic analysis of a map, and, for that purpose, image segmentation is applied (Bodus-Olkowska and Uriasz 2020: 35–45).

In this step, the locations of the anomalies are indicated. The detected aberrations are then subjected to a qualitative and quantitative interpretation, thanks to which they are described with attributes (Bodus-Olkowska and Uriasz 2017: 378–83). Then, these attributes are taken into account in the next step — the process of parametric classification — assigning these anomalies to the appropriate category of objects. The whole process is presented briefly in a scheme (Fig. 7.9).

The anomaly map itself only tells us that a disturbance occurs and on what level. Therefore, for the correct operation of the classification method, it is necessary to create a catalogue of objects along with their parameterization, described by other hydrographic sensors: multibeam echo-sounder and sonar system. Both hydrographic devices make it possible to uniquely identify the object lying on the riverbed by providing underwater imagery and specific attributes, such as dimensions, specific construction parts, etc. Knowing what the object is — thanks to the other two sensors — it is possible to determine the limits of the values of the parameters of anomalies generated from these objects, which is one of the stages of the classification method. The parameters, taken into account, are primarily the value of the minimal and maximal extremum of the anomaly and the value of the difference between these extremes, as well as the area that the anomaly occupies together with its spatial dimension.

The main goal of the survey campaign in August 2020 was to complete the existing catalogue with the necessary data for the objects from the wreck category. During the survey, twelve wrecks — previously selected by the ethnologist on the basis of criteria determined by the hydrographers — were surveyed (Maliński *et al.* 2021: 46–47). Already at the survey planning stage, it had been established that the wrecks should meet the following criteria:

- be ferromagnetic, i.e. constructed of steel (for the magnetometer examination);
- be located at a suitable distance from objects generating magnetic anomalies: quays, locks, bridges, and high-voltage power lines (Embriaco *et al.* 2009: 459, 461, fig. 2; Schmidt *et al.* 2020: 12–13);
- approximately half of the thus selected wrecks should be car wrecks and the other half shipwrecks;
- each wreck must be located at such a distance from the research vessel's home port (Basen Młyński on

the West Oder in Szczecin), that it was possible to reach it, survey it, and return within one working day.

The conditions set in this way were not easy to meet,[13] but finally, a list of twelve wrecks in five locations was compiled (Annex 1).

The list of wrecks requires a brief explanation at this point. First of all, the individual designations of each sunken vessel and vehicle should be clarified. These designations were given following the system used in Polish archaeology, in which shipwrecks resting in inland waters are designated with the names of the villages or towns in which (or in the vicinity of which) they were found. When several wrecks are located in one village or town, numbers are added to the wreck designations, reflecting the chronological order of their discoveries (Maliński 2019b: 180). Such a designation system makes it possible not only to easily determine the general locations of all wrecks and recognize the chronological sequence in which they were found but also to extend the inventory in an orderly manner when new finds appear in the future.

In the case of the wrecks described here, two more operations were performed to facilitate the use of their designations. Firstly, in marking the wrecks located in Szczecin, the names of administrative districts (auxiliary units of the municipality) were used in order to determine the location of each wreck more accurately within the urban agglomeration. Secondly, as the names of these settlements are sometimes quite long, appropriate acronyms were created, e.g. 'Szczecin Międzyodrze-Wyspa Pucka 18 wreck' is simply 'SMW18 wreck'.[14]

It also needs clarification as to why the included list of wrecks (Annex 1) does not provide their geographical coordinates. This is a conscious decision, taken after consultation with the specialists of the West Pomeranian Voivodship Heritage Office in 2019. It was agreed not to make public the precise locations of the wrecks, as they may become the site of underwater predatory excavations (carried out by groups of illegal explorers operating in West Pomerania) or be unlawfully dismantled in order to be sold for scrap metal (this applies precisely to wrecks of steel vessels and cars).

The purpose of omitting the coordinates of wrecks on the list is therefore to protect Poland's underwater cultural heritage — and at the same time to protect the health and lives of people who, when exploring or salvaging wrecks in an unauthorized manner, may find inside deadly 'souvenirs from the past', e.g. ammunition, weapons, explosives, toxic substances, etc. (Maliński 2019a: 230–31; Maliński and Mikołajewski in this volume). For the same reason, this text does not include any general map on which all the investigated wrecks are marked.

Modelling of Selected Objects Lying on the Bottom

For further analysis, data collected by interferometric bathymetry sonar GeoSwath Plus, side-scan sonar Edgetech 4125, and marine magnetometer SeaSPY were used. The recorded bathymetric data was processed in the same software in which the recording was performed. The data processing operation begins with verifying the correctness of the data from the peripheral systems, i.e. navigation data (position, heading), motion sensor data, and sound velocity sensors in the water (Fig. 7.10). Any incorrect records or missing data should be edited to obtain the desired effect.

The next step is to edit the depth data (Fig. 7.11). In the software it is possible to edit the data through a predefined filtering or manual editing. It is the manual editing that is most often used when measuring wrecks or other objects lying on the bottom. The operator decides on his own whether a given point from the measurement is a false or true reflection.

After editing the data, the stage of creating the final products follows. A number of different formats are available for exporting georeferenced point clouds in XYZ[15] form. Other products include GRID[16] models, TIN[17] (Fig. 7.12), vector products, or cross-sections.

The entire sonar data processing procedure starts with importing input. The software processes the raw data into files that will be edited (raw data remains unchanged). In the first stage, there is an indication of the first reflection from the bottom. This distance also determines the height of the towed sonar above the riverbed. The result of this process is the elimination of the dead zone and, at the same time, the geometric correction of the sonar image. The apparent position of pixels in close proximity to the sonar is remapped

13 Considering that about one-third of the 102 wrecks registered during the project mentioned at the beginning of the text were not made of steel at all, but of other, non-ferromagnetic materials, such as laminate (kayaks, anglers' boats, sailing yachts, etc.) or wood (traditional fishing boats, cutters, etc.; Maliński 2020c).

14 Three-letter acronyms refer to the city of Szczecin (their first letter is always 'S' for 'Szczecin'), while acronyms with two letters refer to villages outside Szczecin.

15 Data format for 3D space.

16 Form of storage of numerical terrain model based on regular grid of squares.

17 Triangulated Irregular Network.

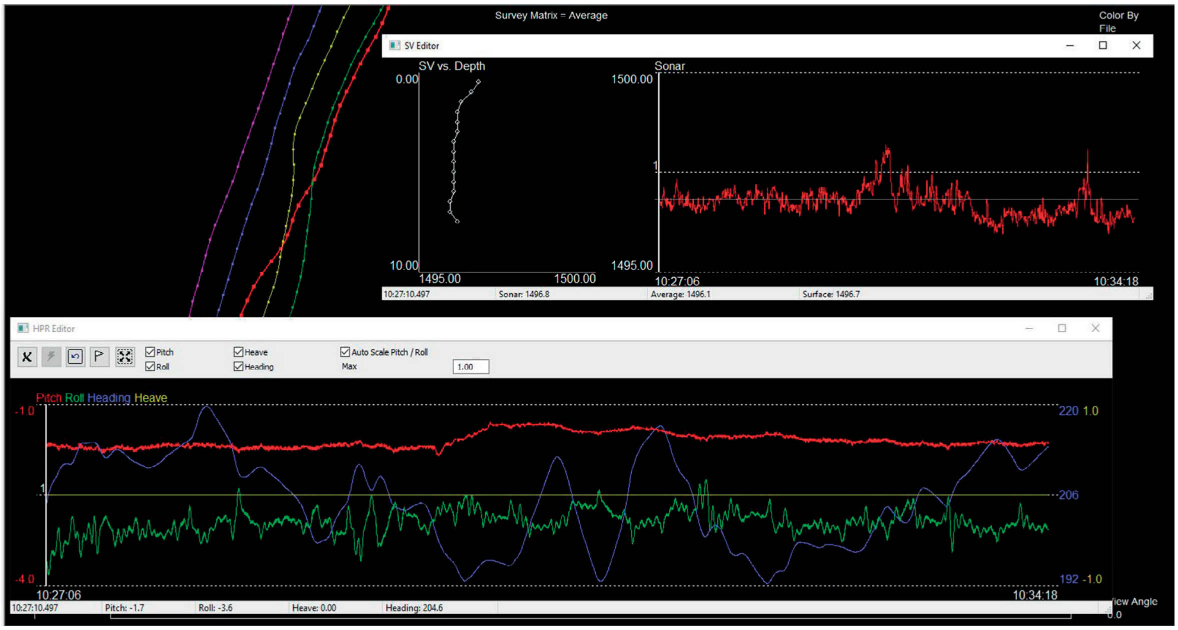

Figure 7.10. Example of graphs in editing data from peripheral sensors of a bathymetric system (elaborated by: G. Zaniewicz).

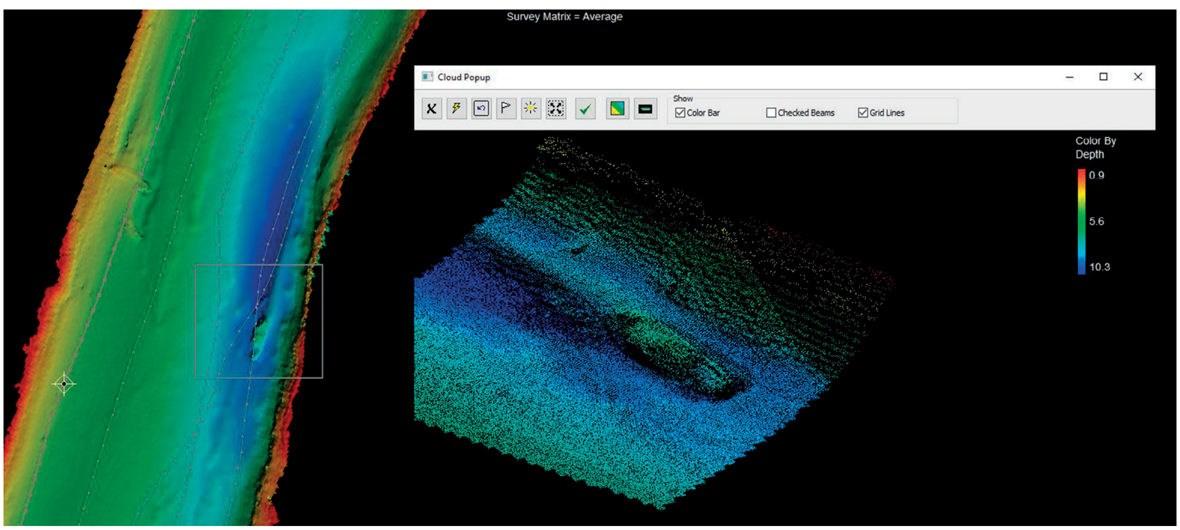

Figure 7.11. Example of bathymetric data editing – point cloud editing (elaborated by: G. Zaniewicz).

to the correct position due to the beam reflection time and the height of the sonar above the bottom (Blondel and Murton 1997: 23–41).

After the geometric correction of the image, the signal processing step follows. Applying all available tools (gain and TVG settings), the image should be normalized in terms of intensity while preserving its details, e.g. elements lying on the bottom (Łubczonek and Zaniewicz 2013: 59–68; Fig. 7.13). Objects lying on the bottom can be analysed in detail. For this purpose, the Target Viewer tool is used, thanks to which the operator can identify, among other things, the exact geographical position of the object, its length, latitude, and height above the bottom (Fig. 7.14). What is also important is the interpretation by the operator, where the type of object can be initially determined, e.g. wreck, boulder, pipe, etc.

The final stage, after the above elements are done, is to create a sonar mosaic, i.e. a georeferenced form of overlapping sonograms (Fig. 7.15). For this purpose, researchers determine the resolution value of the resulting image, the method of overlapping sonograms, and most often export the data to the .geotiff format.

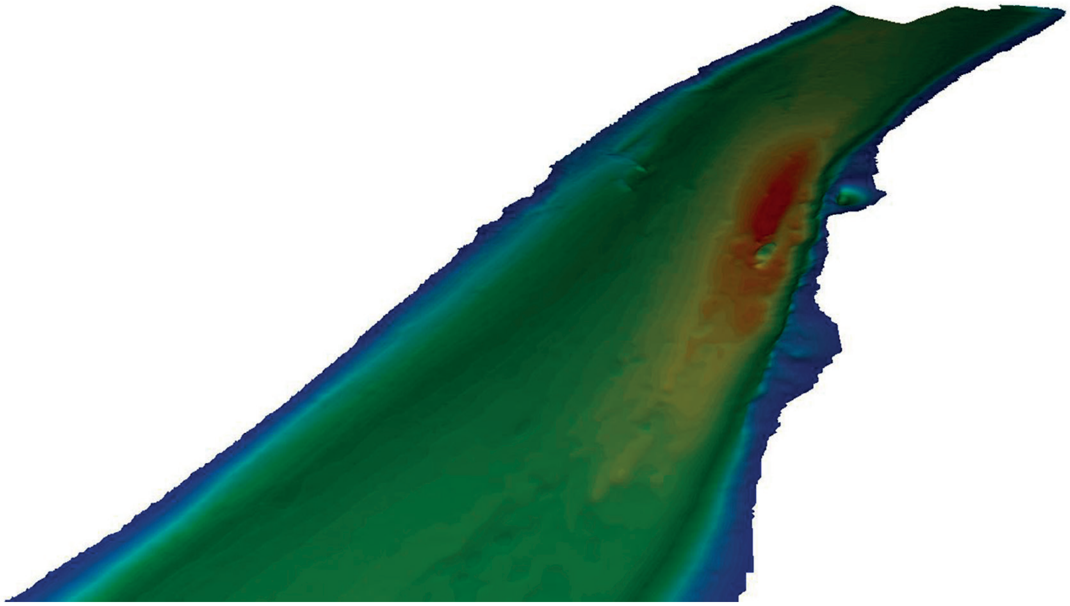

Figure 7.12. Bathymetric product TIN 3D model (elaborated by: G. Zaniewicz).

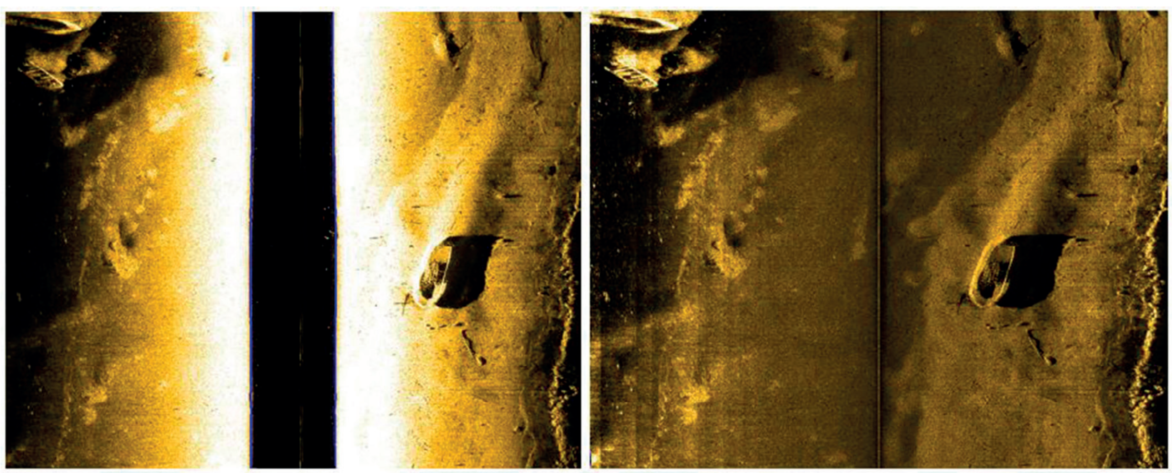

Figure 7.13. Sonogram before (left) and after correction (right) (elaborated by: G. Zaniewicz).

The first step in the magnetometer data processing procedure is their correction with the magnetometric data recorded at the geophysical observatory closest to the measurement area. In this case, it was the Adolf-Schmidt-Observatory for Geomagnetism in Niemegk (Brandenburg, Germany). Corrections from the observatory, as well as the one for disturbances of the survey vessel, are identified, then the raw and total magnetic anomaly is calculated.

Any value greater than 35–40 nT is considered information on the occurrence of the interference source of a magnetic field. During the data processing, it is possible to initially analyse them and later mark the places where potential disturbances occur.

Then, the surfaces are modelled; on their basis, a contour map and, subsequently, the plan illustrating magnetic anomalies point values is generated. Those three are considered the final product of magnetometer surveying.

The results achieved for two types of object: shipwreck ŁB1 and car wreck RA2 are presented in the figures (Figs 7.16 and 7.17). Knowing the value of an anomaly it is possible to initially classify it — suggesting what the disturbance might have been caused by. According to Hall's equation (Hall 1966: 32–43), it is possible to assess the mass of the iron of the detected object, knowing the length/width ratio, the altitude of the magnetometer, and the total magnetic anomaly (Fig. 7.18).

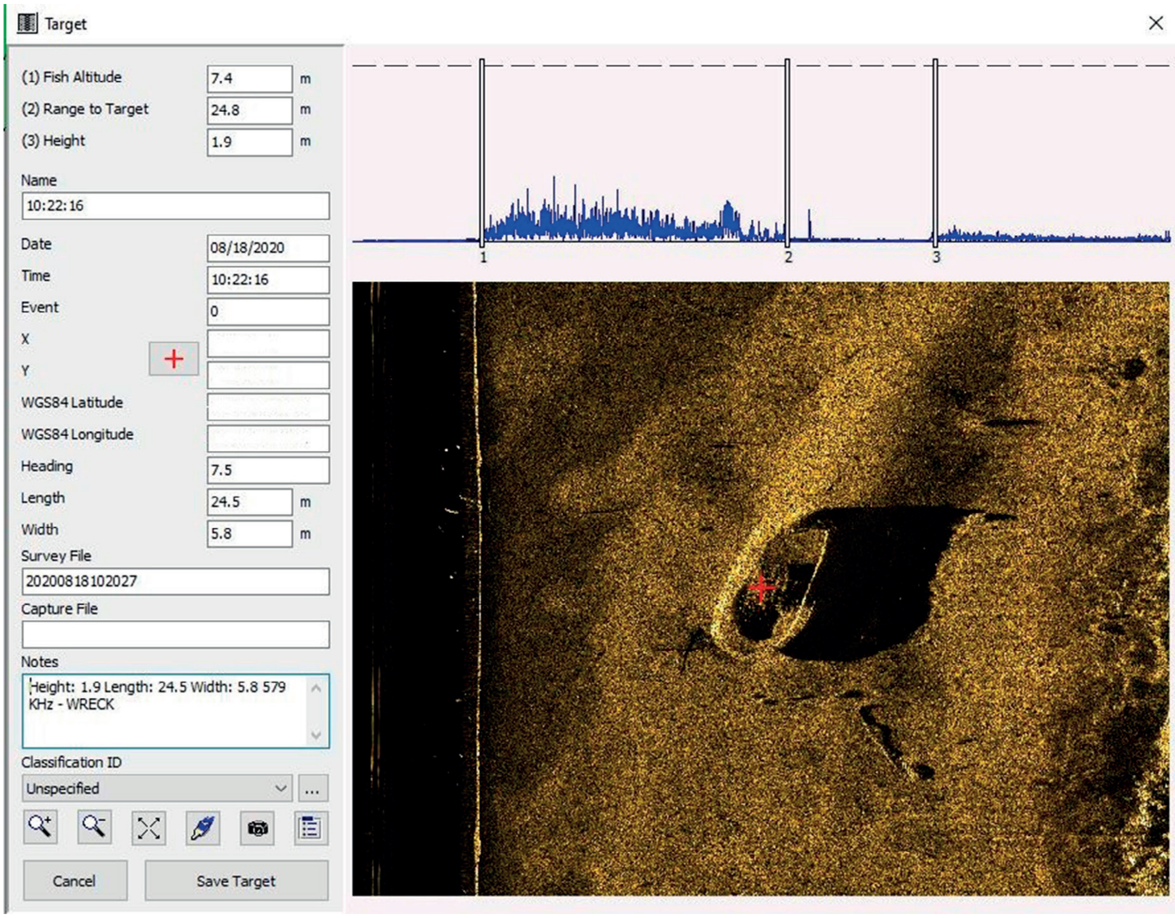

Figure 7.14. Object measurement module from side-scan sonar (elaborated by: G. Zaniewicz).

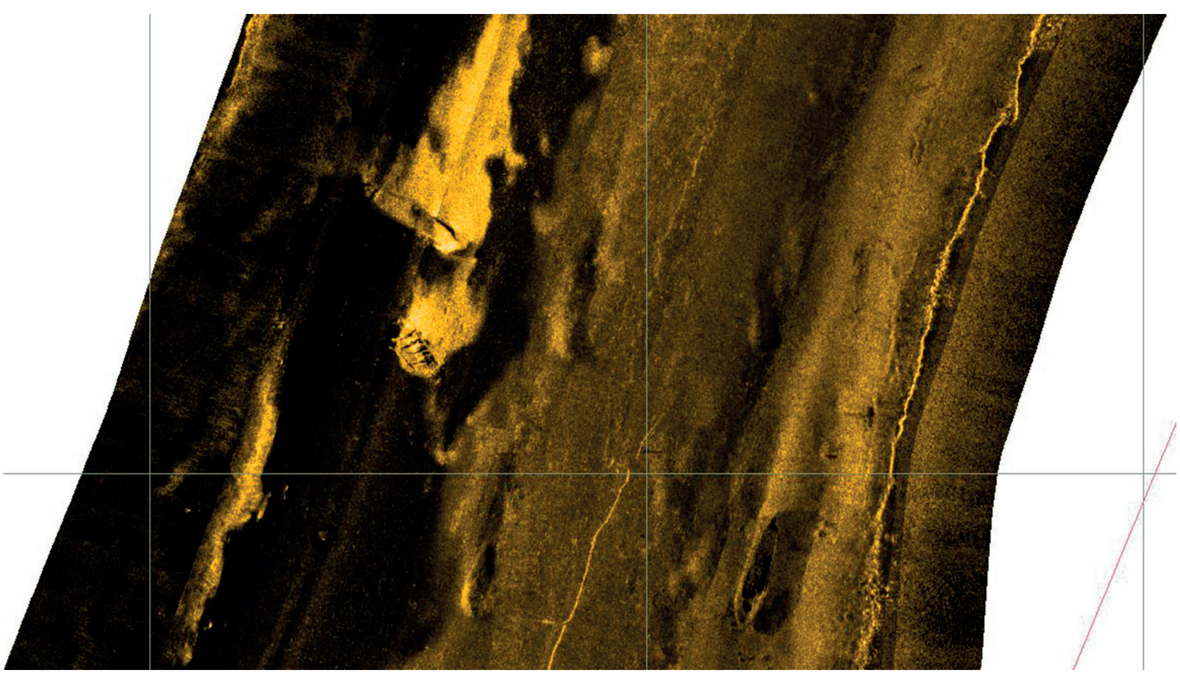

Figure 7.15. Side-scan sonar mosaic (elaborated by: G. Zaniewicz).

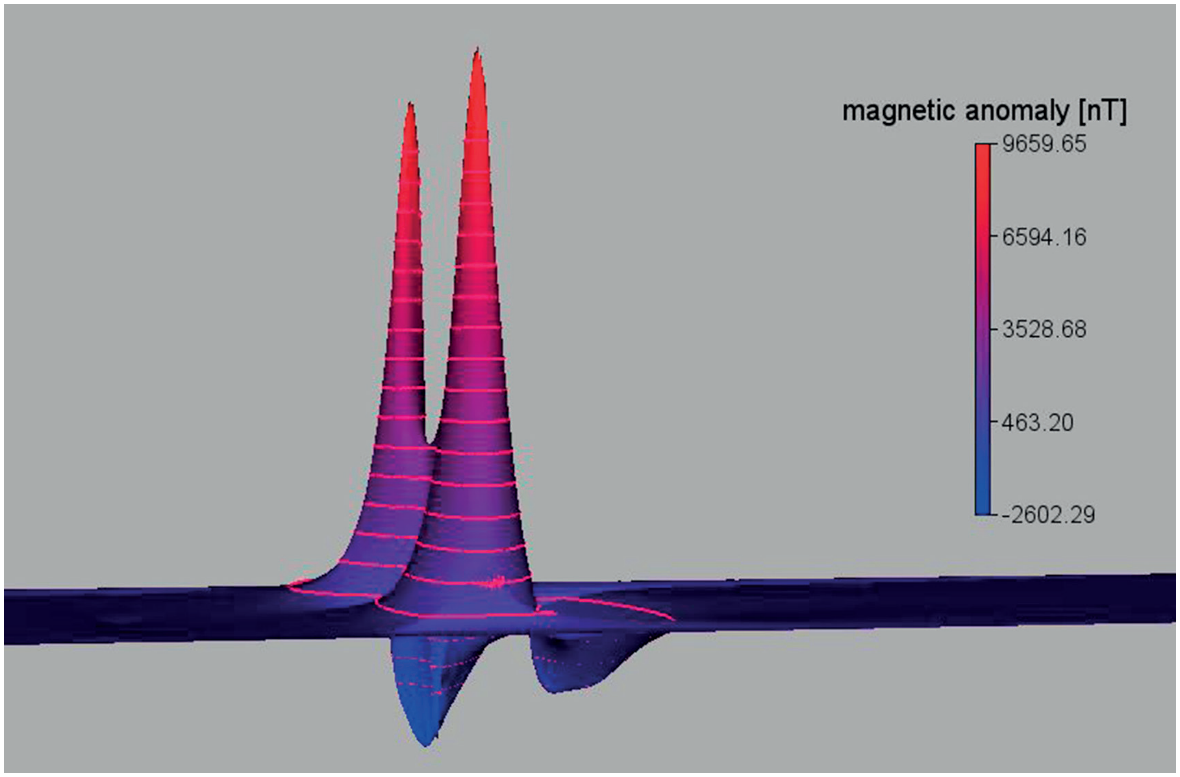

Figure 7.16. Magnetic anomaly from the ŁB1 shipwreck: 3D visualization (source: own development in Voxler software, I. Bodus-Olkowska).

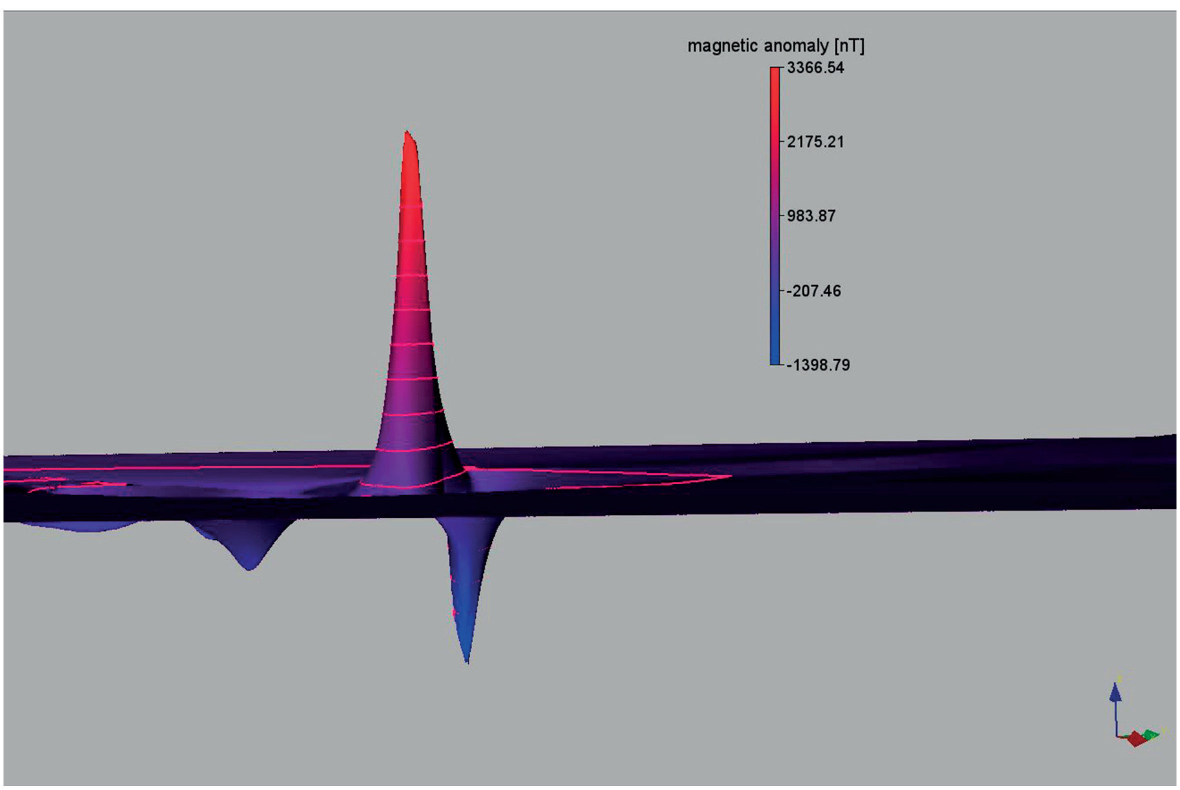

Figure 7.17. Magnetic anomaly from the RA2 car wreck: 3D visualization (source: own development in Voxler software, I. Bodus-Olkowska).

Since the data and research from the marine magnetometer provide only information about the disturbance (location) and the size of the disturbance in the local Earth's magnetic field — how ferromagnetic the object is, without giving a clear and unambiguous indication of what object it comes from, it is necessary to combine this information with the results of bathymetric data analysis and sonar imaging.

$$\Delta M = \left(10 \cdot \frac{a}{b}\right) \cdot \frac{w}{d^3} \quad \rightarrow \quad w = (\Delta M \div \frac{a}{b} \div 10) \cdot d^3$$

Figure 7.18. Hall's equation, where: ΔM — is the anomaly size in [nT], a/b — is aspect ratio length to width in [m], w — is mass of the iron in [kg], d — slant distance from magnetometer to object in [m] (source: elaborated by I. Bodus-Olkowska on a basis of Hall 1966).

Results

During the research, to collect data, different hydrographic sensors were used, such as interferometric bathymetric sonar, side-scan sonar, or marine magnetometer. All of the data was processed to obtain final hydrographic products, like a bathymetry map, digital bathymetry model, sonar mosaic, magnetic anomaly surface model, and contour map, and to gather specific information about the surveyed object.

All research and information on the two examples of bottom objects: shipwreck ŁB1 and car wreck RA2, obtained from individual hydrographic and geophysical sensors, are presented in Annex 2. The results of the research also contributed to a better knowledge and understanding of the underwater cultural heritage of the Lower Oder. High-resolution sonar imaging was particularly useful in this respect, as it made it possible to identify structural details of the investigated wrecks and to know their precise dimensions.

This enabled, for example, progress in the interpretation of the SI3 wreck. Already in 2019 it was preliminarily identified as a semi-pontoon (element of a Soviet pontoon-bridge park) that sank in the West Oder during fights in 1945 (Batow 1966: 97–132). Data obtained from the magnetometer showed conclusively that the hull of the SI3 wreck is made of steel, and the side-scan sonar imagery allowed researchers to determine its dimensions (length *c.* 6.30 m, width *c.* 2.45 m). Taking into account a measurement error of *c.* 5 per cent, these dimensions match the frontal semi-pontoon of the TMP[18] heavy pontoon-bridge park (length 5.98 m, width 2.40 m), used by the Red Army engineering troops to build ferries and floating bridges with a carrying capacity of up to 100 tons (Veremeev 2017; Maliński *et al.* 2021: 48).

In addition, previously unknown underwater objects have also been discovered on the side-scan sonar mosaics. For example, in the East Oder, near the ŁB1 shipwreck, the remains of a right-bank abutment of the Soviet floating bridge from the Second World War have been found. Previous investigations in 2019 had failed to find them, although the remains of the left-bank abutment of this bridge were located and inventoried then, as an underwater object OP3/19 (Maliński 2020a: 8–9, figs 4, 5).

Furthermore, the collected magnetic data also proved its usefulness for better recognition of the underwater cultural heritage (Camidge *et al.* 2010: 17–23). The case of shipwreck SDB3 is a good example of this.

During the 2019 qualitative ethnological research, a structured interview was conducted, during which an anonymous respondent provided information about a ship hull lying on the bottom of the Regalica River near its mouth. The informant pointed out that on the sonar imagery taken there a few years ago, the outlines of the sunken hull were clearly visible on the bottom, but later it was buried by sediment carried by the river current. A sonar survey was carried out at the site later the same year, but, unfortunately, sonograms showed no outline of the ship's hull — only small, damaged structures protruding above the bottom in several places, which were difficult to identify. However, the wreck was assumed to exist and was registered as SDB3. Revisiting this site with a marine magnetometer in August 2020, the authors of this text have found an extensive magnetic anomaly whose value and shape correspond to the anomaly of the steel hull of the ship (Fig. 7.19). Thus, the magnetic data confirmed an earlier assumption based on the results of the ethnological fieldwork.

Conclusions

The main goal of this research was to gather information about wrecks in order to complete the catalogue of ferromagnetic objects. This register was essential for the development of the geoclassification method. An additional aim of the research was to increase knowledge of the underwater cultural heritage of the Lower Oder. For those purposes, a survey campaign was needed, during which magnetometer data was collected and then verified by using other hydrographic systems: interferometric bathymetry sonar and side-scan sonar. During the survey, twelve wrecks of ships and cars were

18 TMP is an acronym for the Russian term тяжёлый мостовой парк (heavy bridge park).

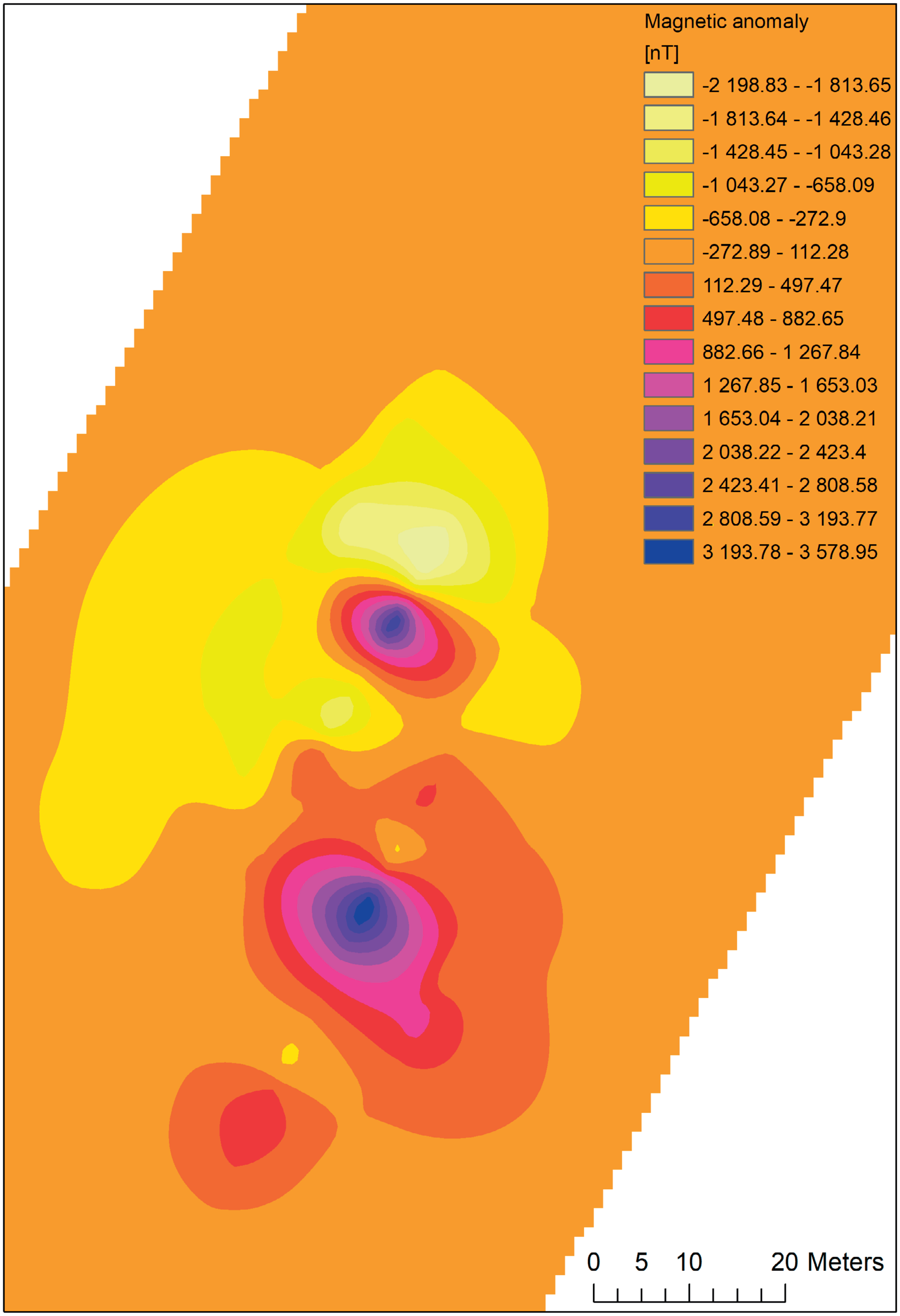

Figure 7.19. Mapping of magnetic anomaly of the SDB3 shipwreck (source: own development in ArcGIS Desktop software, I. Bodus-Olkowska).

investigated and precisely described by hydrographic data such as a cloud of depth points, sonar imaging, and magnetic anomaly. The research results are shown in the form of a tabular summary, where the attributes of the detected objects are presented together with the final underwater multilayer visualization (Annex 2).

The research and survey campaign were a collaboration between hydrographers from the Maritime University of Szczecin and an ethnologist from the University of Szczecin. For the participants, this mutual effort was an interesting and creative experience, whose interdisciplinary value lay in learning about diametrically opposed research methods and techniques — concerning the same object of research. The wrecks, which the ethnologist once located on the basis of collected oral information, have now been plotted by hydrographers on magnetic anomaly maps and three-dimensional riverbed models. Thus, despite the different disciplines and separate fields of study, the obtained results were complementary.

For further work, underwater visual inspection is facilitated through the use of a mini ROV and underwater camera. In the case of wrecks completely covered by bottom sediment, a sub-bottom profiler should be used. These techniques would enable researchers to continue their study of the Lower Oder's underwater cultural heritage, which still needs to be better understood, effectively protected, and consciously disseminated.

Acknowledgements

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Data acquisition was carried out using equipment and software provided by the Laboratory for the Positioning of Underwater Construction and Robots which is part of the equipment of the Centre for Operation of Floating Objects at Maritime University of Szczecin.

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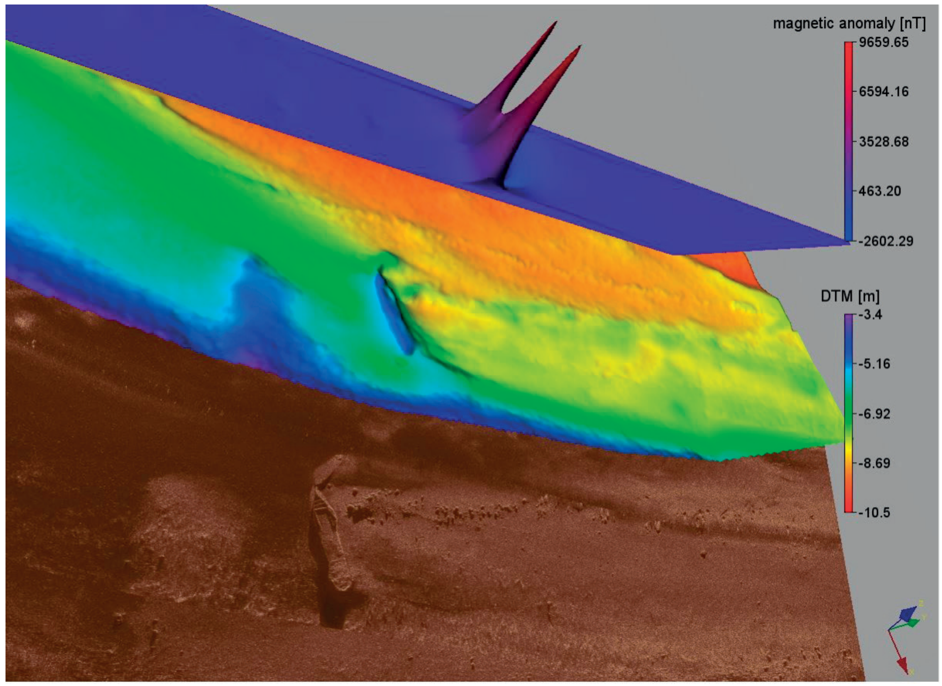
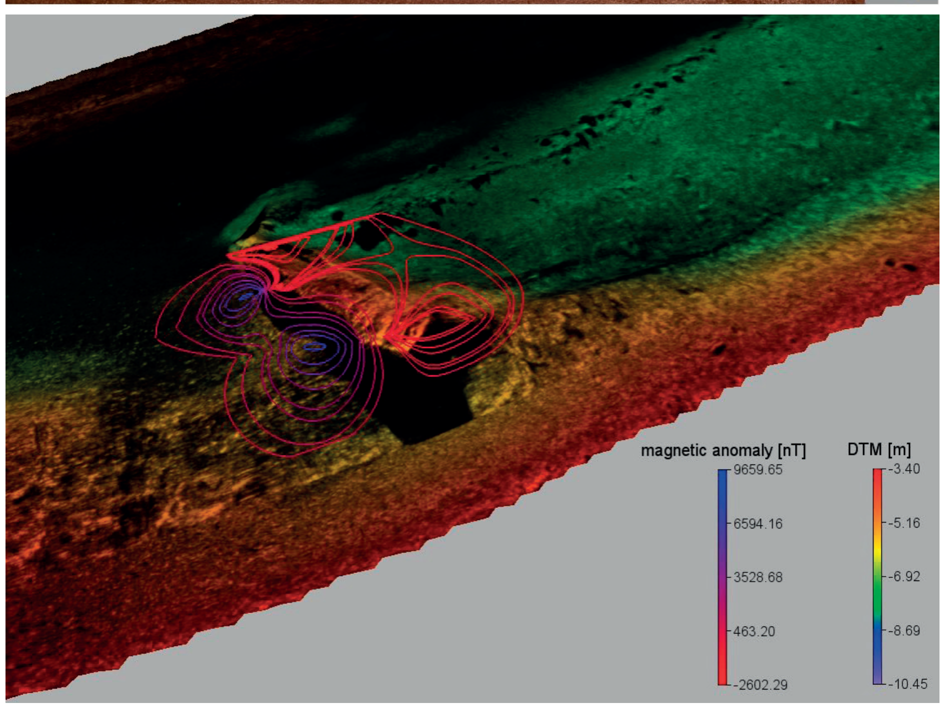
Annex 1

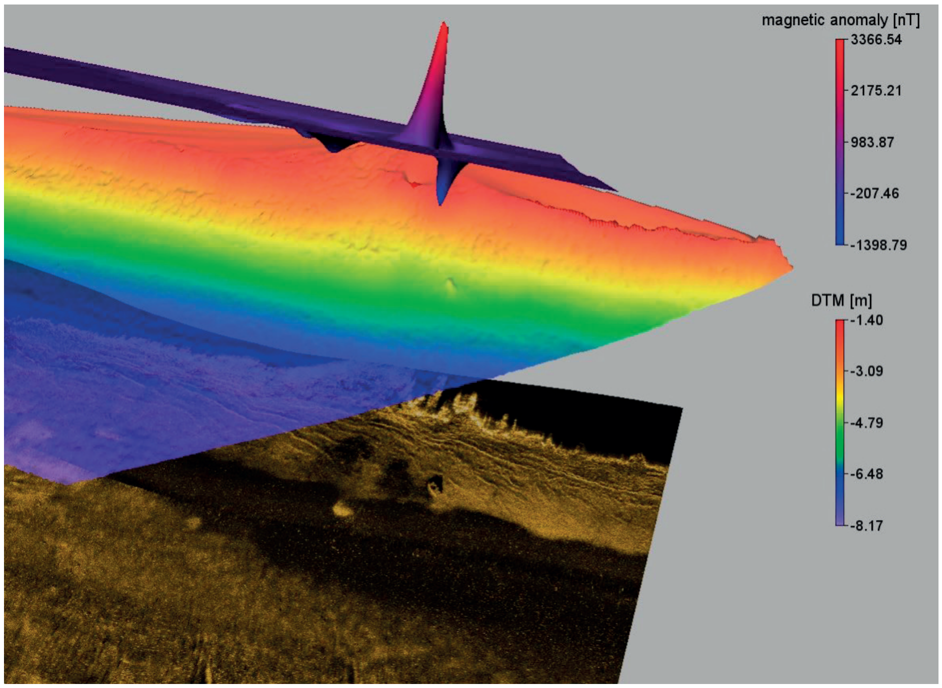
List of surveyed wrecks (selected, compiled, and described by: P. Maliński).

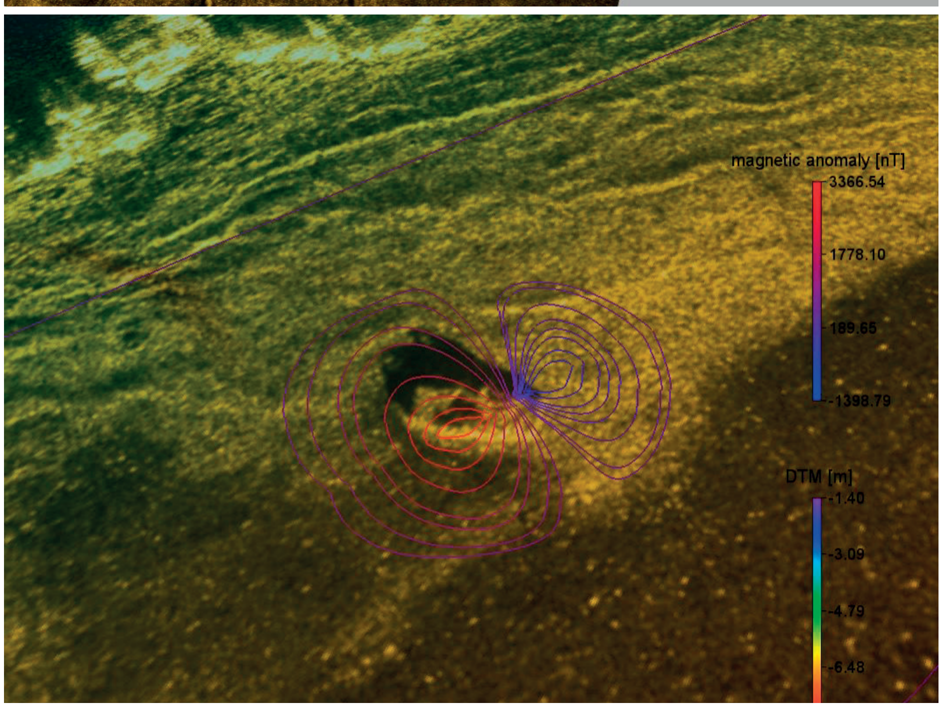
No.	Wreck designation	Acronym	Watercourse	Description
1.	Łubnica 1	ŁB1	East Oder	Ship hull without superstructures, length approx. 27 m
2.	Łubnica 2	ŁB2	East Oder	Probably a pontoon or float, almost completely buried by river sediment
3.	Radziszewo 2	RA2	East Oder	Car, investigated by diver in 2019 and identified as FSO 125p, sedan body-style
4.	Szczecin Dąbie 3	SDB3	Regalica	Unidentified shipwreck, almost completely buried by river sediment
5.	Siadło Dolne 1	SI1	West Oder	Car, lying upside down
6.	Siadło Dolne 2	SI2	West Oder	Car
7.	Siadło Dolne 3	SI3	West Oder	Probably a semi-pontoon from Red Army pontoon-bridge park
8.	Siadło Dolne 4	SI4	West Oder	As above
9.	Szczecin Międzyodrze-Wyspa Pucka 15	SMW15	Kanał Leśny	Car, probably fastback body-style
10.	Szczecin Międzyodrze-Wyspa Pucka 16	SMW16	Kanał Leśny	Car, station wagon body-style
11.	Szczecin Międzyodrze-Wyspa Pucka 17	SMW17	Kanał Leśny	Car, sedan body-style, most probably Polski Fiat (or FSO) 125p
12.	Szczecin Międzyodrze-Wyspa Pucka 18	SMW18	Kanał Leśny	Car, lying upside down

Annex 2

Research results on the two examples of wrecks: multilayer visualization, attribute information, and visual classification (elaborated by: I. Bodus-Olkowska).

Wreck ŁB1			
hydrographic sensor	side-scan sonar data	bathymetric data	magnetometric data
	Edgetech 4125	GeoSwath Plus	SeaSPY
cartographic visualization	 		
attributes	length: 26.5 m width: 4.3 m height: 1.5 m	depth clearance: max: -7.31 m min: -5.46 m mean: -4.76 m	MA(max): 9659.65 nT MA(min): -2602.29 nT ΔMA: 12261.94 nT
visual classification	shipwreck	shipwreck	shipwreck

<table>
<tr><th colspan="4">Wreck RA2</th></tr>
<tr><td>hydrographic sensor</td><td>side-scan sonar data</td><td>bathymetric data</td><td>magnetometric data</td></tr>
<tr><td></td><td>Edgetech 4125</td><td>GeoSwath Plus</td><td>SeaSPY</td></tr>
<tr><td>cartographic visualization</td><td colspan="3">




</td></tr>
<tr><td>attributes</td><td>length: 2.3 m
width: 1.7 m
height: 1.3 m</td><td>depth clearance:
max: -5.24 m
min: -4.12 m
mean: -4.64 m</td><td>MA(max): 3366.54 nT
MA(min): -1398.79 nT
ΔMA: 4765.33nT</td></tr>
<tr><td>visual classification</td><td>car wreck</td><td>car wreck</td><td>car wreck</td></tr>
</table>