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## Article

# Utilizing Enhanced Bathymetry for BTM Complex Reef Geomorphology Detection

Vasiliki Lioupa <sup>1</sup>, Panagiotis Karsiotis <sup>1</sup>, Thomas Hasiotis <sup>1,\*</sup> and Olympos Andreadis <sup>1</sup>

<sup>1</sup> Department of Marine Sciences, University of the Aegean, 81100 Mytilene, Lesvos, Greece

\* Correspondence: hasiotis@aegean.gr; Tel.: (+30) 22510 36829

**Abstract:** Multibeam echo-sounders provide ideal data for semi-automated seabed feature extraction and accurate morphometric measurements. However, these methods have not been tested in morphologically highly complex environments. In this study, bathymetric and raw backscatter data were initially used to manually map the complex reef morphology found in the semi-enclosed Gera Gulf, in the northern Aegean Sea (Greece). A large number of reefs (more than 7000) were detected, making manual mapping extremely time-consuming. Benthic Terrain Modeller (BTM) was selected as a semi-automated method to map the reefs. The BTM did not function properly in this irregular relief and the results were discouraging. Trying to improve the BTM functionality, both bathymetry and slope were modified (enhanced); this time, the BTM outcome was unexpectedly improved, producing accurate results that appeared to exceed the accuracy of manual mapping. To compare the final maps with the distribution of the reefs, mapcurves were created to estimate the Goodness-of-Fit (GOF), while Precision, Recall, and F1 Score were also calculated. GOF values suggest more than 50% overlap between the resulting polygons while, Precision, Recall and F1 score resulted in values higher than 0.78 suggesting good detection accuracy for the semi-automated method. It becomes apparent that BTM provided more efficient results in comparison to the time-consuming manual mapping. This study asserts that semi-automated mapping stands as an effective method for delineating the geomorphometry of intricate relief and serves as a powerful tool for habitat mapping and decision-making.

**Keywords:** multibeam echosounder; geomorphology; benthic terrain modeler; reef mapping; semi-automatic delineation

## 1. Introduction

Geomorphometry of the seafloor terrain is a common outcome of multibeam echo-sounder (MBES) acoustic data that is required to categorise, visualise and quantify the seabed based on its abiotic characteristics and it can be also associated with benthic habitats [1]. Its results are important for decision making, spatial planning and ecological management by governmental and environmental organisations [2].

The most common and simple method is manual mapping; the expert uses bathymetric and backscatter data to determine the final zone boundaries of the map. Until recently, this method was considered to be the most accurate, although time consuming. Still, many semi-automated methods that have been used for geomorphometry or benthic habitat mapping show promising results, although they also have their challenges [3]. Many different approaches have been tried to date but there is not a unified protocol as each case study and the main focus of each survey may require several modifications [4].

One of those methods is the Benthic Terrain Modeller (BTM), which was developed in 2005 at Oregon State University in collaboration with the NOAA Coastal Services Center (CSC) GIS Integration and Development program [5,6]. This geoprocessing toolbox analyses benthic terrain and produces bathymetric derivatives such as slope, aspect and Bathymetric Position Index (BPI), a variation on the Topographic Position Index [7,8]. The tool is a free add-on for ArcMap, and it is

widely used. Some of the recent studies have used the BTM toolbox to support spatial management [9], habitat mapping [10–13], sediment distribution [14], paleo-geomorphology [15,16], human impacts & geohazards [17], predictive habitat distribution model [18–20] and deriving spatial patterns of hydrodynamic processes [21]. In most of the above-mentioned cases the underwater relief was relatively even, thus BTM could be easily applied. However, there is no information about the use of the modeller in areas exhibiting highly irregular relief.

In this study, the unique geomorphology of a semi-enclosed embayment (Gera Gulf) in Lesvos Island (NE Aegean Sea, Greece) (Figure 1) has been the testing environment for BTM. Manoutsoglou et al., (2018) [22] described a large number of low-relief buildups using information of single-beam echosounder and a side scan sonar mosaic. Ground-truthing by drop-camera, scuba dives and sampling verified the presence of numerous small reefs consisting of benthic assemblages comprising mainly of molluscs in a fine-grained environment. She suggested that 19.27 km<sup>2</sup> of the surveyed area is occupied by about 4400 densely distributed reefs, being 0.2-2.5 m in height. In this study high-resolution MBES data from the gulf are used aiming to (i) compare the results of manual mapping of the odd relief of the gulf with the semi-automated BTM method, (ii) enhance the MBES bathymetry in order to assist BTM to better detect the reefs and (iii) assess the suitability of this semi-automated method for complex low-relief reef mapping, comparing the resulting maps with the Goodness of Fit Index.



**Figure 1.** The location of the study area (Gera Gulf) in Greece and Lesvos Island (red circle).

## 2. Materials and Methods

### 2.1. Data acquisition & processing

The bathymetric survey took place in April and November of 2022 over a dense grid of survey lines, using a Teledyne Reason SeaBat T20-R MBES, pole-mounted in R/V Amfitriti. The MBES comprised of a TC2181 transducer, an EM7219 receiver, a Valeport mini SVS for the correct swath projection, and a rack-mounted sonar processor which is configured with a fully integrated inertial navigation system (INS) Teledyne, Type-20. The INS uses an IMU (IP68) for motion correction (roll, heave, and acceleration measurements) and a RTK GNSS (Trimble) for position, time and high precision navigation. The INS is fully compliant with the Applanix POS MV Wavemaster II integrated into T20R processor. The vessel speed ranged from 3 to 4 knots. An area of about 30 km<sup>2</sup> was surveyed (~ 75% of the total gulf area). The system was recording simultaneously 512 beams at 420 kHz over a swath angle of up to 140°. Sound velocity profiles were collected using a Valeport SWiFT. The bathymetric data were calibrated, sound velocity profiles were applied, and any acoustic noise or artifacts were removed utilizing Teledyne's PDS software. A bathymetric ASCII file with 1 m cell size was exported from PDS. The raw backscatter data were also exported with 1 m cell size.

## 2.2. Manual mapping

For the manual mapping of the reefs, the bathymetry ASCII file was imported in ArcMap10.4. The *Spatial Analyst Tool* was used to generate slope and curvature. Only one user employed bathymetry, slope, curvature, and backscatter to manually map the reefs. In the shallower areas the reefs had a smaller relief, and their shape became more complex making it harder for the users to map their boundaries. In those areas, the users drew profiles on the bathymetric map to make the correct decision, whilst in some cases changing the contrast of the view was also effective. 7115 reefs were finally detected occupying an area of 10.4 km<sup>2</sup> (Table 1). The shapefile that was created from the manual mapping was used to extract the bathymetry for each of the polygons with the *Spatial Analyst* tool *Extract by Mask*. Next, geomorphometry characteristics (maximum-minimum and average depth, maximum and minimum slope, area, perimeter, depth stand. deviation, slope stand. deviation) were extracted (Table 1) and matched to the polygon shapefile using *Join* and *Statistics* tool was used to extract statistical information about the geomorphometry of the reefs.

**Table 1.** The geomorphometry results of manual, BTM, BTM-B4 and BTM-B4S2 mapping.

	Number of Reefs	Mean reef perimeter (m)	Max reef area (m <sup>2</sup> )	Sum. Area (km <sup>2</sup> )	Max. Height (m)	Mean Height (m)	Max. Slope (°)	Mean Slope (°)
Manual	7115	147	215743	10.4	4.5	0.65	15	2.4
BTM	3576	60	7899	1.1	3.0	0.25	15	3.6
BTM-B4	7441	120.5	35478	6.8	2.7	0.47	13	2.1
BTM-B4S2	8923	141.8	147497	10.3	3.7	0.54	15	2.2

## 2.3. Semi-automated mapping

For the semi-automated mapping, the *Benthic Terrain Modeler* toolbox (Walbridge et al., 2018) was used, an easy add-on toolbox for ArcMap. Initially, the reef detection with BTM was not successful (Table 1), since only 50.3% of the reefs were detected to occupy an area about 90% smaller compared with that of the manually mapped reefs, some of them also found with considerable differences in shape and geomorphometric characteristics. Then, the *Raster Calculator* was used in order to modify the bathymetry, aiming to better discriminate and isolate the small reefs of this peculiar seafloor relief. Two attempts were tested, namely the BTM-B4 and the BTM-B4S2.

### 2.3.1. BTM-B4

During the first attempt to adjust the bathymetry, the following expression was used: `square(square("bathymetry"))`. With this modification the divergence of the bathymetry values between pixels was increased, resulting in the discretization of the reefs. Then the standard BTM workflow was followed, creating broad (inner radius: 10, outer radius: 100) and fine (inner radius: 10, outer radius: 25) Bathymetric Position Index (BPI) that found to work best for the study area after trying many different neighbourhood sizes. The classification dictionary (Table 2) was edited according to the study area and the features to be delineated. As the reefs were detected in water depths deeper than 10 m, a boundary was placed along the 10 m isobath in the classification dictionary to avoid redundant artifacts.

**Table 2.** Classification dictionary used for creating BTM-B4.

Class	Zone	Broad BPI Lower	Broad BPI Upper	Fine BPI Lower	Fine BPI Upper	Slope Lower	Slope Upper	Depth Lower	Depth Upper
1	reef	-2000	1	-6000	0	0	15.08		12.5
2	other	1	2000	-20	6000	0	68		10

In order to eliminate artifacts of the semi-automated method created in areas of successive MBES swaths overlap, polygons with an area of less than 8 m<sup>2</sup> (the maximum extend of observed false polygons in areas of overlapping bathymetry) were deleted. As a final “touch-up”, *Eliminate Polygon Parts* was used to fill in any gaps in some small polygons, *Smooth Polygon* to smooth the polygons, *Buffer* to create a small buffer of 0.1 m around the reefs, and then *Dissolve* and merge any overlapping polygons. To calculate the geomorphology, the next steps are the same as described in the manual method followed by the rejection of reefs with a height of less than 5 cm, the majority located along the swath overlapping areas.

### 2.3.2. BTM-B4S2

The second attempt used *Raster Calculator* to change the bathymetry with the following expression: “bathymetry” – *square*(“slope”) \* 100. This modification places more emphasis on the variation of the slope of the reefs rather than on the overall bathymetry of the gulf, making it easier for both the user and the BTM to detect the reefs. Then, the broad (inner radius: 10, outer radius: 100) and fine (inner radius: 10, outer radius: 25) Bathymetric Position Index (BPI) were created, which was found to work best for the study area after trying many different neighbourhood sizes. The classification dictionary (Table 3) was modified in relation to the surveyed region and the features to be distinguished.

**Table 3.** Classification dictionary used for creating the reef slopes for BTM-B4S2.

Class	Zone	Broad BPI Lower	Broad BPI Upper	Fine BPI Lower	Fine BPI Upper	Slope Lower	Slope Upper	Depth Lower	Depth Upper
1	reef	-20000	2	-20000	0	0.001	15.08		10
2	other	2	20000	0	20000	0	68		10

This resulted in a good outline of the reefs, but in order to fill them out the same procedure was carried out this time using the expression: *square*(*square*(“bathymetry”)). In this way, by increasing the divergence of bathymetry values between pixels, the reefs were discriminated. Following, broad and fine BPIs were created with the same neighbourhood size used for the reef outline and a modified classification dictionary (Table 4).

**Table 4.** Classification dictionary used for creating the reef peaks for BTM-B4S2.

Class	Zone	Broad BPI Lower	Broad BPI Upper	Fine BPI Lower	Fine BPI Upper	Slope Lower	Slope Upper	Depth Lower	Depth Upper
1	reef	-2000	5	-6000	0	0	15.08		12.5
2	other	1	2000	0	6000	0	68		10

The two rasters were merged creating the final reef raster, which was then converted into a polygon shapefile. As with BTM-B4, polygons with an area smaller than 8 m<sup>2</sup> were eliminated to remove artifacts of the semi-automated approach that were produced in the MBES swath overlap areas. For a final “touch up”, *Eliminate Polygon Parts* was used to fill in any gaps in some small polygons, *Smooth Polygon* to smooth the polygons, *Buffer* to create a small buffer of 0.1 m around the

reefs in order to use after the *Dissolve* and merge any overlapping polygons. The following procedures are the same as those outlined in the manual technique, followed by the rejection of reefs with a height of less than 5 cm, to determine the geomorphology.

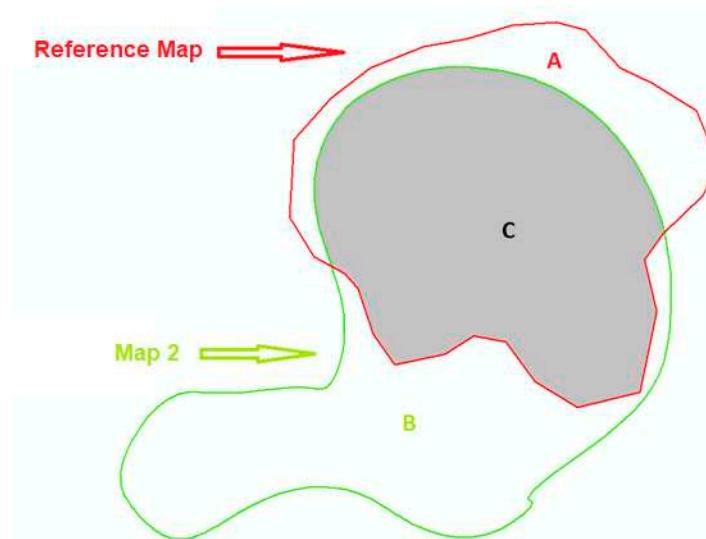
## 2.4. Statistical comparison

### 2.4.1. Polygon overlap comparison

Mapcurves, a quantitative Goodness-Of-Fit (GOF) method, was chosen for the map (manual, BTM-B4, BTM-B4S2) overlap comparison. The method presents the degree of spatial concordance between two or more maps [7] and it is based on the degree of spatial overlap between the maps. The Reference Map (RF or Map 1) to which another map (Map 2) is compared determines the direction of the comparison, and the combination that produces the best degree of fit is considered to be the level of similarity between the maps. The GOF algorithm (equation 1) is based on two values (Figure 2): (1) the proportion of the intersecting area (C) to the total area of the intersecting category from Map 2 (B+C), and (2) the proportion of the intersecting area (C) to the total area of the category from Map 1 (A+C). The first term gives the proportion of “insideness” that the reference category shares with the tested category, and itself represents a GOF term. The second term weights this degree of fit by the fractional share of the Map 1 category’s area that is intersected. Without that area weighting, the presence of many large intersecting categories, each one of which might share only a small spatial intersection with the category being tested, would result in a high degree of fit. Multiplying these two values, a single number for the total percentage of overlap for the reefs in each map arises. All possible combinations were tested in order to determine the optimum one.

$$\text{Goodness - Of - Fit} = \sum \left( \frac{C}{B+C} \right) \times \left( \frac{C}{A+C} \right) \quad (1)$$

*Intersect* was used to merge each polygon pair, *Calculate Geometry* to calculate the polygon area and finally *Spatial Join*. Using the Join command and the FID as a criterion, the attribute tables of the polygons were matched. The FID and area values of the attribute table were exported into an Excel file, where GOF values were calculated. After, the percentage of polygons that satisfied a series of increasing values (every 0.01) of the GOF index (COUNTIF command) was found and the according mapcurve graph was created. The area under the curve of the graph was calculated giving a unique GOF value for the entire map.



**Figure 2.** Sketch of overlapping maps (reefs) representing the values of GOF.

#### 2.4.2. Detection accuracy

For the polygons that were not detected by the semi-automated or manual methods and vice versa, Precision, Recall and F1 Score statistical indexes were calculated. Precision is the quotient of the successfully detected reefs with the total number of reefs detected from the method tested. Recall is the quotient of the successfully detected reefs with the total number of reefs detected from the reference method. F1 Score (equation 2) is a weighted average of Precision and Recall, taking values from 0 to 1 (1 corresponds to the highest precision).

$$F1 = 2 \times \frac{Precision \times Recall}{Precision + Recall} \quad (2)$$

For calculating these indexes, manual mapping was considered as the reference method.

#### 2.4.3. Correlation of geomorphological characteristics

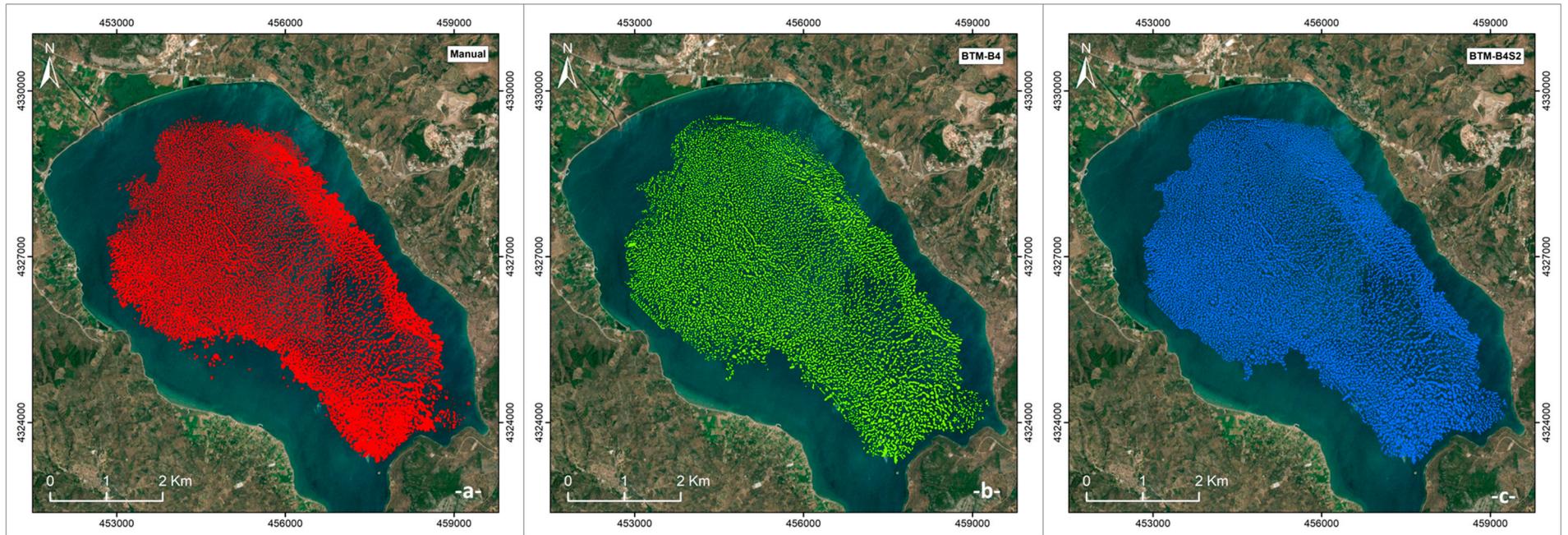
Further, using Excel, scatter plots of the various geomorphological characteristics and the GOF index were created, and trend lines were plotted to detect if there are correlations between the geomorphological characteristics of the reefs and the depth they are located. The scatter plots that were generated were: depth/height, slope/depth, area/depth, maximum slope/height, area/height, GOF/height, GOF/depth.

### 3. Results

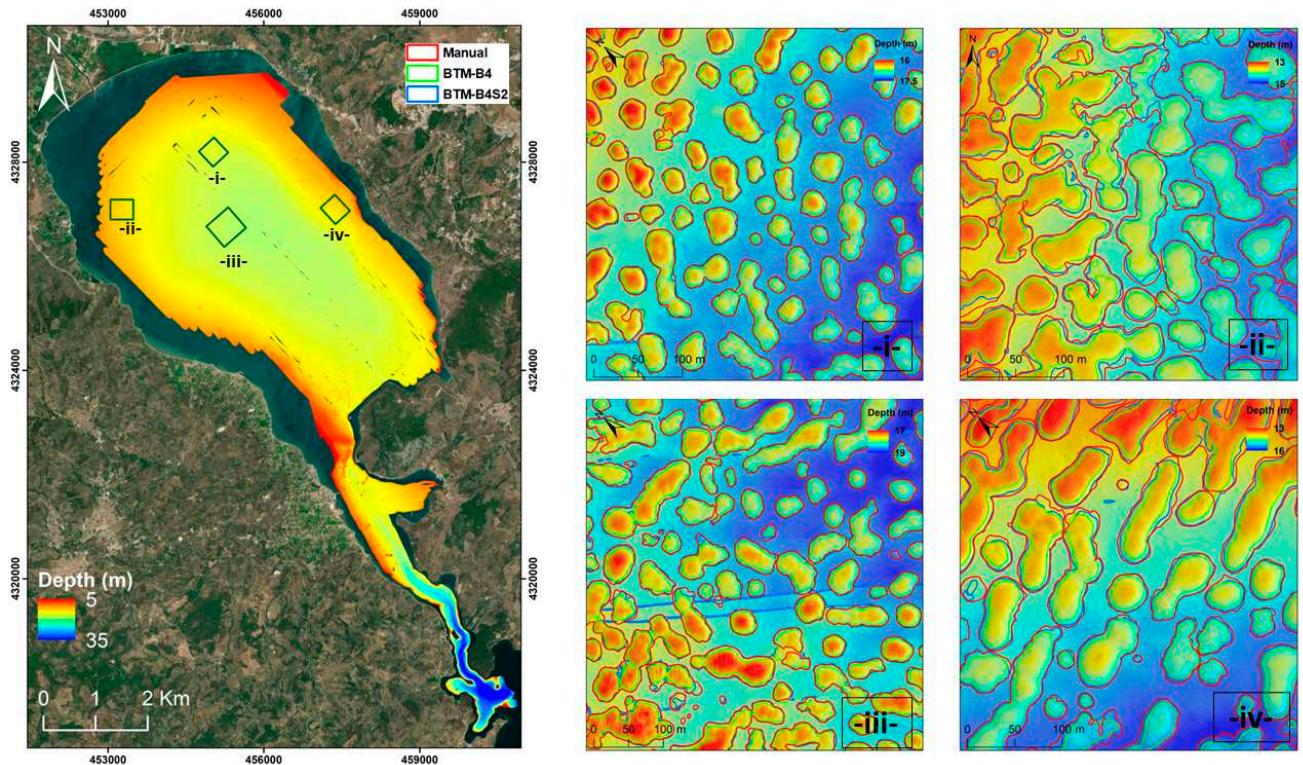
The 3 methods used for the Gera Gulf reef detection resulted in 3 polygon shapefiles (Figure 3) and for each one the geomorphological features were extracted (Table 1). An example of the overlapping polygons in 4 different areas along the gulf is shown in Figure 4. After rejecting polygons with area less than 8 m<sup>2</sup> and height less than 5 cm for all methods, the reefs detected by the manual mapping were 7115, by the BTM-B4 were 7441 and by the BTM-B4S2 were 8923.

In areas where the relief is complex, manual mapping considered that the reefs were united, whilst the semi-automated methods tended to fragment these large reefs into smaller polygons, thus resulting in more reefs. Consequently, manual mapping produced polygons with very large area, perimeter and height, reaching 0.26 km<sup>2</sup> and 4.5 m respectively, near the gulf entrance, contrasting with the semi-automated methods polygons. The results of area and height distribution were visualized into the same categories for all methods used (Figure 5 and Figure 6). It appears that the geomorphology detected by the BTM-B4S2 method is closer to the results of the manual mapping (Table 1). Even if the number of reefs between the manual and the BTM-B4S2 has the biggest difference, because the semi-automated method tended to fragment the polygons, the total area of the reefs differs just 0.01 km<sup>2</sup>.

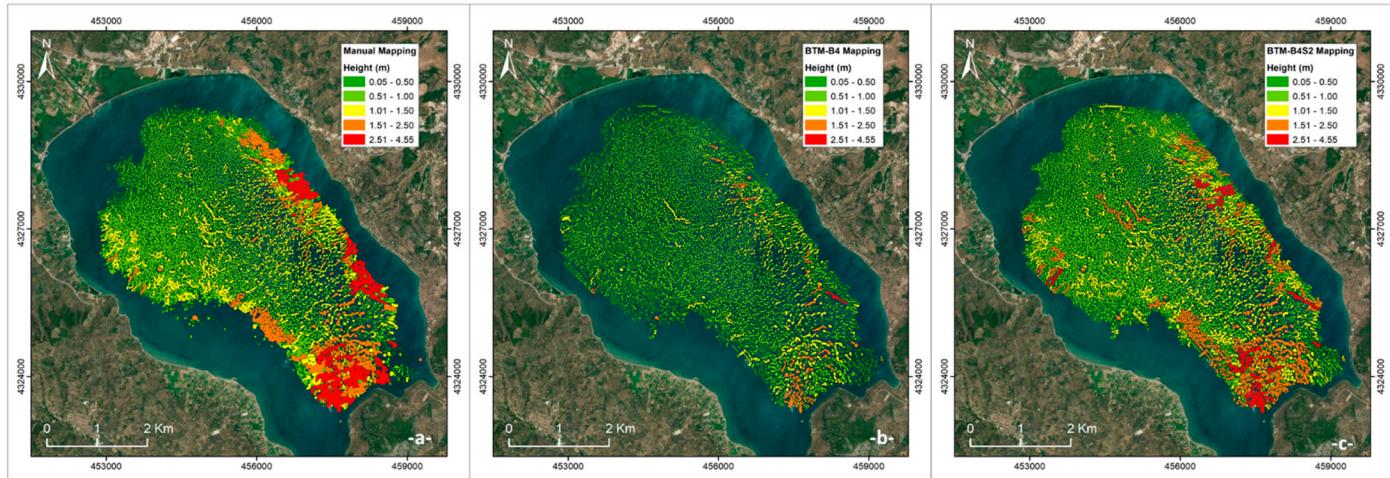
The polygons detected from manual mapping were also compared with those not detected from BTM-B4 and BTM-B4S2 and vice versa (Figure 7 and Table 5). Manual mapping failed to detect 567 reefs distinguished by BTM-B4 and 1939 reefs detected by BTM-B4S2, most of which are in the shallower part, where complex morphology is observed. BTM-B4 failed to detect 993 reefs and BTM-B4S2 failed to distinguish 236 reefs noticed by manual mapping. These reefs are small in height and area.



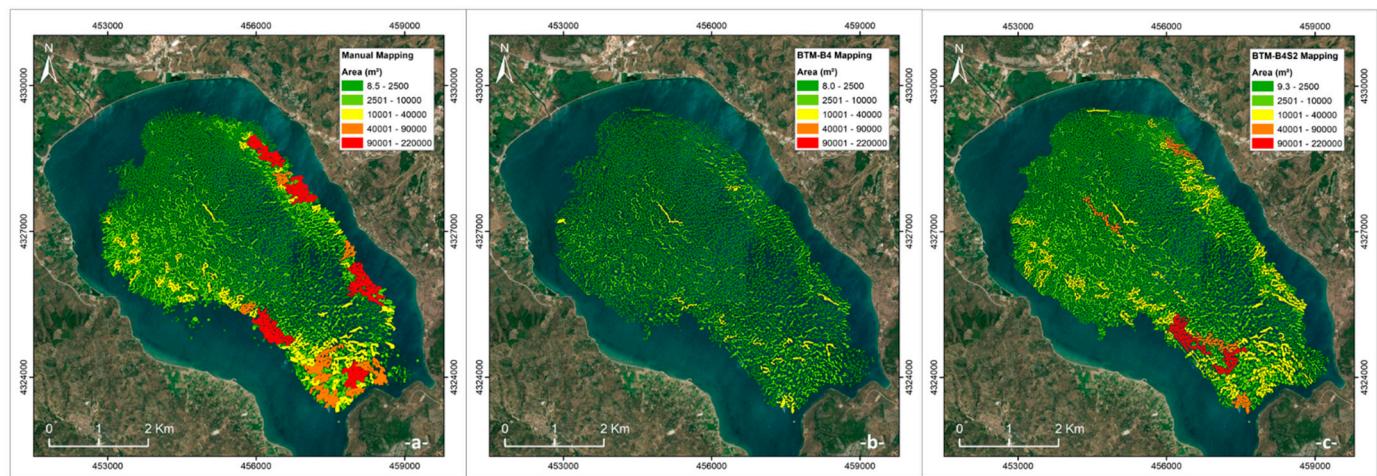
**Figure 3.** Polygons (reefs) produced by (a) manual, (b) BTM-B4, and (c) BTM-B4S2 mapping.



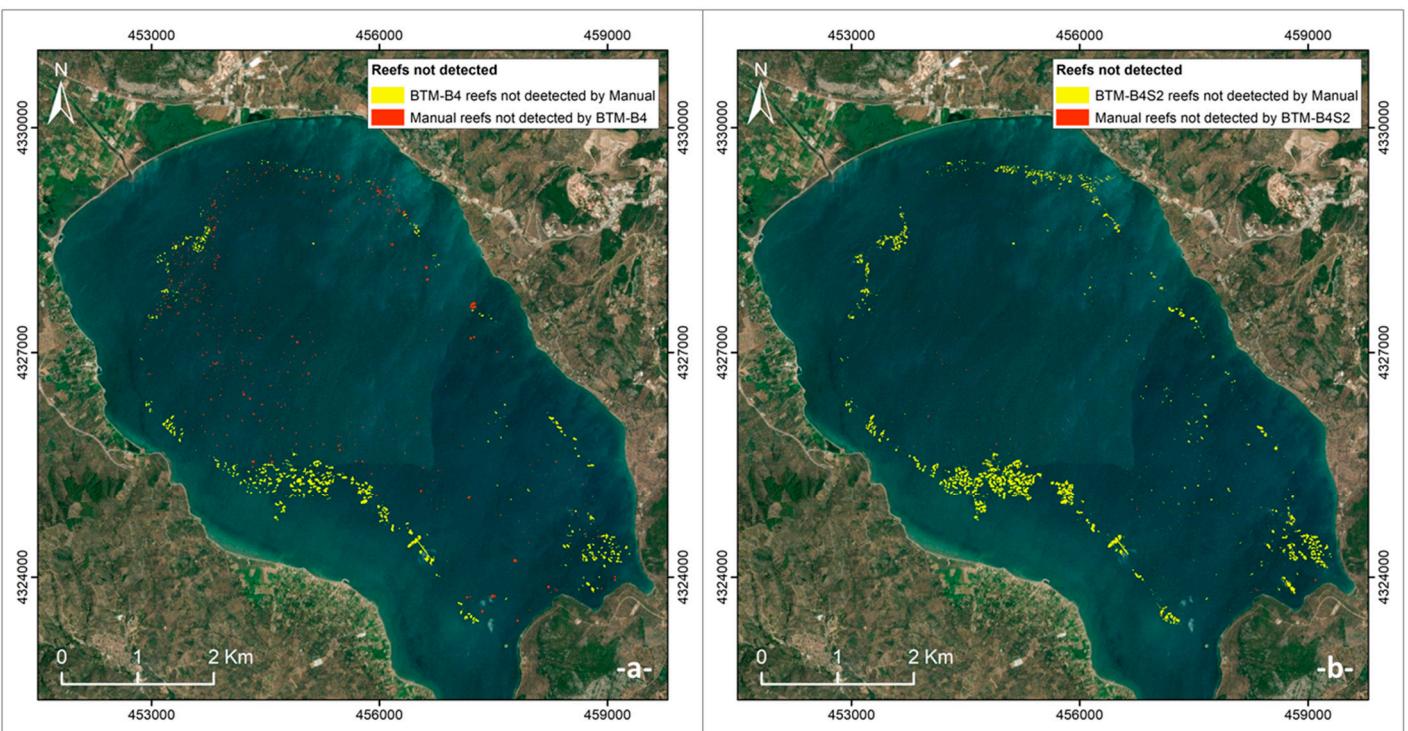
**Figure 4.** Bathymetric map of Gera Gulf, with zoom-in areas showing the resulting polygons for all methods (red polygons: manual, green: BTM-B4, blue: BTM-B4S2).



**Figure 5.** Categorization of reef heights, created by (a) manual, (b) BTM-B4, and (c) BTM-B4S2 mapping.



**Figure 6.** Categorization of reefs area, created by: (a) manual, (b) BTM-B4, and (c) BTM-B4S2 mapping.



**Figure 7.** Map of the reefs not detected by (a) manual BTM-B4 mapping, and (b) by manual or BTM-B4S2 mapping.

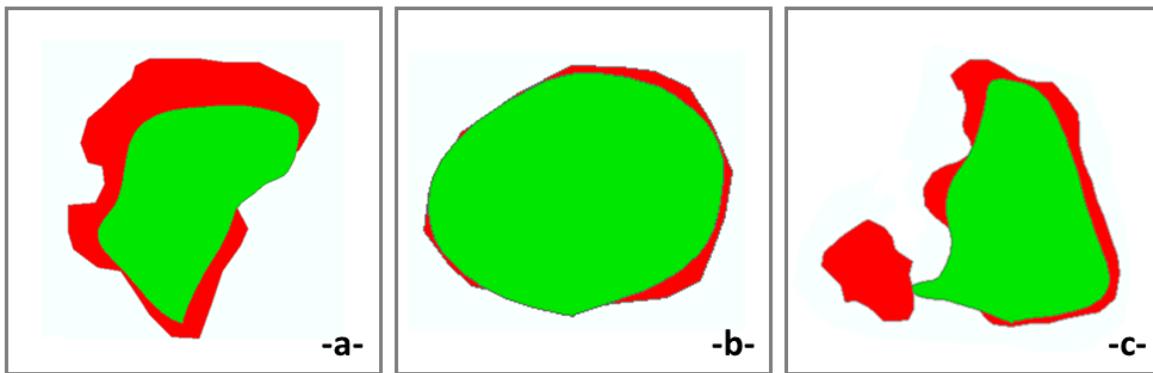
**Table 5.** Results of geomorphometry comparison between the methods used.

	Manual VS BTM-B4	BTM-B4 VS Manual	Manual VS BTM-B4S2	BTM-B4S2 VS Manual
Reef Number	993	567	236	1939
Min. Area (m <sup>2</sup> )	8.47	9.67	8.47	9.31
Max. Area (m <sup>2</sup> )	2111.9	9011.68	548.76	24384.7
Mean Area (m <sup>2</sup> )	114.93	534.3	47.48	275.83
Min. Height (m)	0.05	0.05	0.05	0.05
Max. Height (m)	0.815	1.35	0.81	1.7
Mean Height (m)	0.177	0.18	0.1	0.16

Regarding the detection accuracy, for BTM-B4 the Precision index is 0.92, the Recall index is 0.97, and the F1 Score (the accuracy of mapping) is 0.94. For BTM-B4S2 Precision index is 0.78, Recall index is 0.98, and F1 Score is 0.87, suggesting that this method is quite precise but less accurate than the BTM-B4. The difference in F1 Score results from the bigger number of reefs detected by the semi-automated methods compared to the number of reefs detected manually. However, the fragmentation of the reefs in the semi-automated methods also plays an important role, leading to a partial distortion of the true value of the index (tending to reduce the F1 Score). It is, of course, important to note that even in manual mapping it is very likely that errors are still present. Some reefs not found by the semi-automated methods may indeed not be present but may be also due to human error. It is possible that in some cases the results of semi-automated mapping are more valid than those of manual. However, the most valid and proven methodology available to date is manual mapping and this is considered to be the basis of any comparison in order to determine the accuracy of the “more modern” semi-automated seabed mapping techniques.

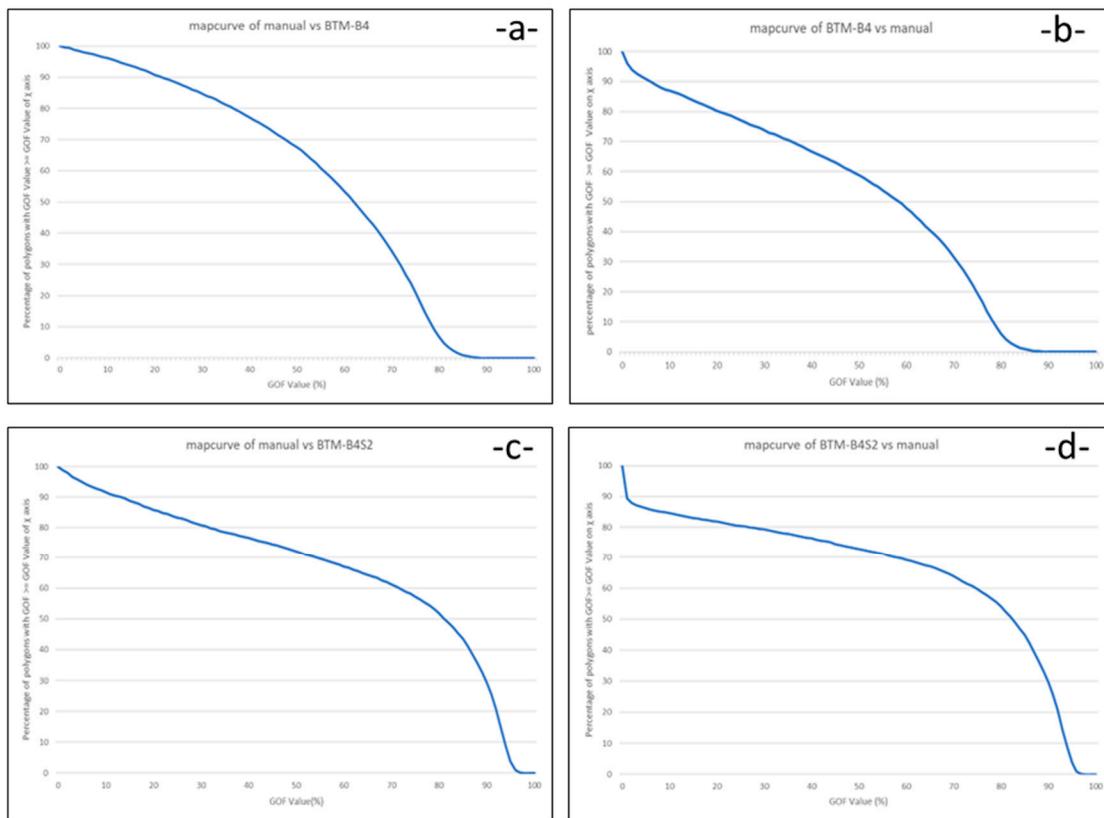
Reefs not detected by manual mapping but only by BTM-B4 and BTM-B4S2 (**Figure 7**) are, as indicated by their mean values, of small area and height. Of course, there are some exceptions, especially from the semi-automated methods. These reefs are concentrated at the shallower part of the study area (around the perimeter of the gulf) and especially near the channel connecting the gulf with the open sea, where the topography becomes more complex. The total area of reefs detected by the semi-automated methods is much larger than the total area of reefs detected by the manual method. Observing the resulting BTM reefs, they exhibit a fairly realistic pattern of shape, structure and distribution, consistent with the patterns of reef development in this area of the gulf. It is therefore possible that the semi-automated methods were able to identify some reefs that the user failed to map due to the complexity of the topography.

As for the reefs detected from both manual and BTM methods, GOF index was calculated (**Figure 8**) and Mapcurves were plotted (**Figure 9**). From the level of similarity between the methods, the best degree of fit resulted when the manual method was used as the RF producing a GOF of 0.56 with BTM-B4 and 0.66 with BTM-B4S2. This shows that we had more than 50% overlap for the polygons, and the BTM-B4S2 polygons overlapped better with the manual. The extremely low GOF values, reduced the unique GOF value to some extent. These low GOF values were either due to reefs not detected by the semi-automated methods with minimal overlap with adjacent detected reefs, or to vessel routes overlap (**Figure 4 -iii-**). The reefs of the semi-automated methods that exhibited this issue at the overlap parts are problematic not only in their GOF value, but also in their geomorphological characteristics since they are perceived by ArcMap as one reef instead of several individuals.



**Figure 8.** Sketch showing polygons with (a) unique, (b) maximum and (c) low GOF values (red polygon: manual mapping, green polygon: BTM-B4).

Concerning the potential relationships between the geomorphological characteristics of the reefs, the statistical testing showed that there is no significant correlation between the geomorphological parameters, neither with the depth at which the reefs are located, nor with their height or with their area (with a standard deviation  $R^2<0.4$ ). However, the only correlation identified was between maximum slope and height, with standard deviation  $R^2=0.62$  for the manual,  $R^2=0.67$  for BTM-B4 and  $R^2=0.68$  for BTM-B4S2. This indicates that high slopes are mainly observed in reefs of a big relief, meaning that "tall" reefs tend to have steeper slopes, rather than gentle slopes.



**Figure 9.** Mapcurve for GOF calculation using (a) manual as RF compared to BTM-B4, (b) BTM-B4 as RF compared to manual, (c) manual as RF compared to BTM-B4S2, and (d) BTM-B4S2 as RF compared to manual.

#### 4. Discussion

Two methods, manual and semi-automated (Benthic Terrain Modeller), were utilized for the detailed mapping of the Gera Gulf reefs, using a 1x1 m bathymetric grid and raw backscatter data.

Slope, curvature, and raw backscatter were used, while in areas of complex morphology, bathymetric profiles helped to identify reef boundaries. Manual mapping is a time-consuming and intense method, subject to the experience of the user. On the other hand, semi-automated methods are time-efficient, and not subject to the user, making it harder to "miss a spot". For this project manual mapping took about 400 hours of work, while semi-automated mapping took about 30-35 hours, not accounting for the time initially needed for studying the basic principles and learning / understanding how to use BTM. Therefore, it is profound that there is an about twelvefold increase in the human effort during manual mapping, however not securing accurate results.

In this study, BTM initially did not seem to work properly with the small scale of the reefs. However, by modifying the bathymetry and slope, to increase the height difference between the reefs and the seabed, the reefs became detectable by the BTM. Depending on the morphology of the seabed, it is possible that different modifications of bathymetry and slope may help to achieve very satisfactory results. This can be also tested / applied in other peculiar relief seafloor environments, i.e., densely distributed pockmark areas, or zones of outcropping rocks etc.

Furthermore, the quality of the data is also important for the semi-automated methods, as it affects the accuracy of the polygons (shape, detectability), and especially for BTM-B4S2 noise in areas of overlapping bathymetry was easy to detect. It is possible to remove most of these errors by manual correction, but this can be time consuming. The accuracy of the BTM-B4 was lower, but the noise errors were eliminated, and the time required to complete the entire process was less.

In any case, either by modification of the initial bathymetry or by subsequent correction of the polygon, we can obtain much more reliable and accurate results. Depending on the accuracy requirements of the research question, one method may be chosen over the other. In both cases, however, the semi-automated methods gave precise results.

As mentioned above, the time and effort required for both semi-automated methods were about twelvefold lower the time required for manual mapping and the results were satisfactory. BTM appears to be a good solution for mapping complex relief features and should probably be preferred. In some cases of highly complex micro-relief, the semi-automated methods may work even better by identifying morphological anomalies that the user may miss.

Most of the studies that applied BTM are just for extracting bathymetric parameters (BPI, slope, curvature, etc). The only works that have used manual mapping and BTM for feature delineation are by Jarna et al., (2019) [25] and Menandro et al., (2020) [10]. The first authors applied their methodology for cold water carbonate mounds. They detected about 3500 mounds over 6.01 km<sup>2</sup> with manual mapping and over 7.35 km<sup>2</sup> with BTM mapping distributed along an extensive study area of 76 km<sup>2</sup>. Also, Menandro et al., (2020) [10] detected reefs with a total area of 2.96 km<sup>2</sup> with manual and 6.85 km<sup>2</sup> with BTM mapping in an area of 20 km<sup>2</sup>. In this study the surveyed area was about 30 km<sup>2</sup> and more than 7000 reefs detected to occupy the seafloor, covering an area of 10.4 km<sup>2</sup> as found by manual mapping. Even if BTM was initially unsuccessfully applied for the feature detection, the modified bathymetry assisted to observe the reefs with high accuracy. Consequently, the BTM-B4 detected reefs that cover an area of 6.8 km<sup>2</sup>, whilst BTM-B4S2 distinguished reefs over 10.3 km<sup>2</sup>. It can therefore be understood that the density and number of reefs in Gera Gulf provide a real 'crash test' environment not only for BTM but probably, also, for testing / comparing other semi-automated and automated feature extraction methods.

Our results are consistent with those of the previous study in the area (Manoutsoglou et al., 2018) [22], but this time covering with detailed data the majority of the gulf where reefs occur. The spatial distribution of reef height and size in Gera Gulf was confirmed, adding more information to the puzzle. Also, even with the new higher accuracy MBES data, the lack of a strong correlation between the morphological characteristics of the reefs and depth was again confirmed.

## 5. Conclusions

In this study, high quality MBES bathymetric and raw backscatter data were used to map manually and with BTM the reefs of a unique and morphologically complex area that provides an ideal “crash test” environment for semi-automated methods to test their feature detection capabilities. Over 7000 reefs were distinguished and their geomorphometric characteristics were extracted. Following bathymetric enhancement, the semi-automatic method was able to detect the relief of the reefs even better than the manual method in areas where the terrain was really complex. The difficulty for BTM was tracked in areas where the bathymetric data overlapped and created artifacts. The time required to clean up these artifacts is easily compensated for by the extremely time-consuming manual mapping. It becomes apparent that, although with caution, the semi-automated methods can, either independently or with slight bathymetric data modifications, give reliable morphological and morphometric results in highly complicated submarine terrains, also contributing to benthic habitat and sensitive ecosystems mapping.

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**Data Availability Statement:** Research data could be shared from e-mail query.

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