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An Assessment of Potential Beam Trawling Impact on North-Western Black Sea Benthic Habitats Aiming at a Sustainable Fisheries Management

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Abstract: The North-Western Black Sea shelf is extremely vulnerable to disturbances of its habitats and ecosystems. In the past 10 years, this area has become targeted by beam trawl fisheries for the invasive gastropod *Rapana venosa* (Valenciennes, 1846), with a potentially destructive impact on the area's soft bottoms. Not many studies have been performed in the region, and most investigations have focused on gear selectivity and by-catch rates. In this context, our novel research aimed, on the one hand, to assess and quantify the actual impact of beam trawling and, on the other hand, to propose effective spatial/temporal management measures for a sustainable zonation of the North-Western Black Sea shelf (marine zone of the Danube Delta Biosphere Reserve). The methodology used integrated beam trawl catch dynamics information, VMS data, geophysical investigations, and macrozoobenthos sampling. Our findings show that beam trawling activities can cause changes in the benthic habitat structure (lower number of taxa, lower values of ecological indicators, and an overall non-GES status). Further in-depth investigations are needed to underpin the ecosystem-based management of this marine protected area (MPA), aiming to allow the recovery of the affected benthic habitats, by alternating defined areas undergoing fishing with biological recovery polygons.

Keywords: beam trawling; benthic macrofauna; *Rapana venosa*; marine protected area (MPA); ecosystem-based management

Citation: Nenciu, M.; Niță, V.; Teacă, A.; Popa, A.; Begun, T. An Assessment of Potential Beam Trawling Impact on North-Western Black Sea Benthic Habitats Aiming at a Sustainable Fisheries Management. *Water* **2023**, *15*, 2241. https://doi.org/10.3390/w15122241

Academic Editors: Federica Ferrigno and Edoardo Casoli

Received: 28 April 2023
Revised: 7 June 2023
Accepted: 12 June 2023
Published: 14 June 2023

1. Introduction

The Black Sea, which is nearly entirely isolated from the rest of the world's oceans and contains an abyssal basin with a maximum depth of 2300 m next to a large continental shelf area, notably in the north-western half, is one of the most amazing regional seas. Under the effect of fresh water supplied by large rivers, of which the Danube has the greatest influence, and the entrance of Mediterranean water through the Bosphorus and Dardanelles Straits, the Black Sea waters are permanently stratified [1]. Its size and geographical, geological, and ecological peculiarities render the Black Sea the character of a Large Marine Ecosystem (LME) [2]. When compared to the Mediterranean, it exhibits distinct physical, chemical, and ecological properties [3]. In this exceptional ecosystem, life is supported by a 100 m upper layer of lighter marine water with lower salinity and density. A pycnocline divides this layer from the deeper, more dense layers of water, which are saturated with hydrogen sulfide and result in permanent anoxic conditions between 100 and 200 m depth [4]. The coastline and shelf zones of the Black Sea comprise a mosaic of intricate, interconnected ecosystems with significant economic value, abundant natural resources and ecological communities, and a high concentration of human activity [5,6].

The biodiversity of the Black Sea is approximately three times lower than that of the Mediterranean due to the difficult oceanographic circumstances [7], and its unique characteristics (oceanography, location, and climate) render it extremely vulnerable to disruptions of its habitats and ecosystems [8].

An area of particular interest in the north-western part is the Marine Zone of the Danube Delta Biosphere Reserve, a Marine Protected Area (MPA) declared under the Habitats Directive (ROSCI0066). The MPA has its own administration, who elaborated in the past a Management Plan and related Regulations, both currently undergoing a revision process. However, regarding beam trawling, none of the mentioned documents regulates this activity in the extended area (beyond 20 m), this being one of the rationales for performing this study.

The Black Sea habitats off the Danube Delta experience constant change in conditions brought on by the Danube's inputs and anthropogenic influence, just as the species. The salinity, temperature, transparency, and nutrient content of coastal waters are all impacted by freshwater supplies that are transferred south. Due to the muddy substrata, the Danube's plume area really forms a circalittoral bionomic zone (even at depths less than 20 m), which is known as the boundary between the infralittoral and circalittoral zones [9,10].

Since the 1960s, when researchers first described the communities of *Lentidium* in the infralittoral and *Spisula-Syndesmia* (*Abra nitida*)–*Cardium* (*Acanthocardia paucicostata*), as well as the community of *Mytilus* for the circalittoral unit, the benthic communities in front of the Danube Delta have been thoroughly studied [11,12]. Later, Gomoiu [13,14] describes a new community formed by the leading species *Melinna palmata*, which we still meet today in extensive areas in the studied area [9]. The Danube inputs and anthropogenic pressures continuously place stress on the benthic communities. These caused the Black Sea's environmental characteristics to deteriorate between 1970 and 1990. Thus, from the reference 1960–1970 period, when the benthic community numbered about 75 species, Țigănuș [15] and Gomoiu [13,16] recorded only about 45 species in the 1980s. At the beginning of the 2000s—a period of relaxation of anthropogenic pressures—the condition of the benthic communities experienced a slight improvement [9,17–19].

At greater depths, the North-Western Black Sea shelf is of tremendous interest due to its singularity in terms of habitats—it shelters mussel beds on Pontic circalittoral terrigenous muds, which form a unique biocoenosis: deep-sea black mussel biogenic reefs [20]. *Mytilus galloprovincialis* Lamarck, 1819 creates these reef-like formations by aggregating both living and dead mussels together. Between the isobaths of 25–70 m depth, deep-sea mussels used to cluster around the Black Sea continental shelf (it is the only location where mussel associations on muddy bottoms have been documented). One of the primary features of this basin is the presence of mussels on soft, muddy bottoms [20]. In these muddy areas, mussels congregate in "clumps" formed of (sub)fossil shell accumulation and live individuals bound together by byssal threads. Living mussel colonies connect to a hard substratum that forms over time and is higher than the surrounding silt. Numerous elongated patches and/or continuous ridges make up the reef. Between them is the organically rich "mussel mud," which is made up of the accumulated feces and pseudofeces of the mussels [20].

These deep-sea mussels have more rounded, wider valves, also presenting some physiological differences compared to mussels inhabiting rocky areas: due to the particular environmental conditions, they spawn only once a year compared to mussels from the shore area, which breed twice [21].

On soft sea bottoms, deep-sea mussel beds play a crucial ecological role because they create a hard surface where there would otherwise be mud. This draws and sustains a wider variety of marine life than would otherwise be present there, including echinoderms, polychaetes, anemones, barnacles, and other mollusks [9,19,22–25].

All these characteristics indicate this habitat type as a potential Vulnerable Marine Ecosystem (VME) in the north-western part of the Black Sea, whereas it complies with the VME Criteria as defined in the International Guidelines for the Management of Deep-sea Fisheries in the High Seas, fulfilling most of the indicated criteria: uniqueness or rarity; functional significance of the habitat; life-history traits of component species that make recovery difficult; structural complexity [26]. Mollusks and other macrobenthic invertebrates help to build the structured habitats that make up the so-called Vulnerable Marine Ecosystems (VMEs) [27].

Where the substrate was adequate, the North-Western Black Sea shelf was reported to have been almost entirely covered by this deep-sea mussel bed habitat before 1965. Since then, there has been a significant decline in the mussel population and, as a result, in the size of this habitat (more than 50%), first as a result of the consequences of eutrophication and, more recently, as a result of invasive fishing methods (bottom and beam trawling, dredging) [28,29].

In the past 10 years, the NW Black Sea soft bottoms (especially areas in the vicinity of deep-sea mussel beds) have become targeted by beam trawl fisheries for the rapa whelk—the invasive gastropod *Rapana venosa* (Valenciennes, 1846), with a potentially destructive impact. In 2013, the use of the towed fishing gear beam trawl for the industrial exploitation of the rapa whelk was legalized in Romania, and, since then, these fishing gears have been extensively used in the center and northern part of the Romanian coast, on sandy and muddy substrates [30]. Moreover, circalittoral muds (extremely soft bottoms) are documented to be the habitat type most affected by mobile bottom-contacting gears (MBCG), beam trawls included [18,31].

International research shows that beam trawling has an impact on benthic communities, sediment suspension, and bottom biogeochemistry [32]. Recent years have seen the development of a better comprehension of the physical interaction between towed demersal fishing gear and the seafloor. These gears' physical effects on soft sediments can be broadly divided into geotechnical and hydrodynamic effects. Geotechnical effects include substrate penetration and piercing, lateral displacement of sediment, and the influence of the pressure field transmitted through the sediment. Hydrodynamic effects include the mobilization of sediment into the water column [33]. Yet, a thorough evaluation of these gears' actual effects on benthic organisms is absolutely necessary.

Despite decades of trawling in this particular brackish environment and the common occurrence of trawling in regions where hypoxia and low and variable salinity already operate as ecosystem stressors, very few studies on trawling effects have been conducted in the Black Sea. Most investigations focused on gear selectivity and by-catch rates [30,34], and less on the overall impact on bottom habitats [35].

In this context, our research was aimed in two directions: on the one hand, assessing and quantifying the actual impact of beam trawling on soft bottoms (by integrating catch dynamics information, Vessel Monitoring System/VMS data and macrozoobenthos sampling) and, on the other hand, proposing effective spatial management measures for a sustainable zonation of the north-western area of the Black Sea shelf.

2. Materials and Methods

2.1. Study Area

The investigated area comprised the extended part of ROSCI0066 Danube Delta—Marine Zone, between the 20 and 40 m isobaths (Figure 1), since most of the beam trawling fishing operations on the Romanian coast are concentrated there.

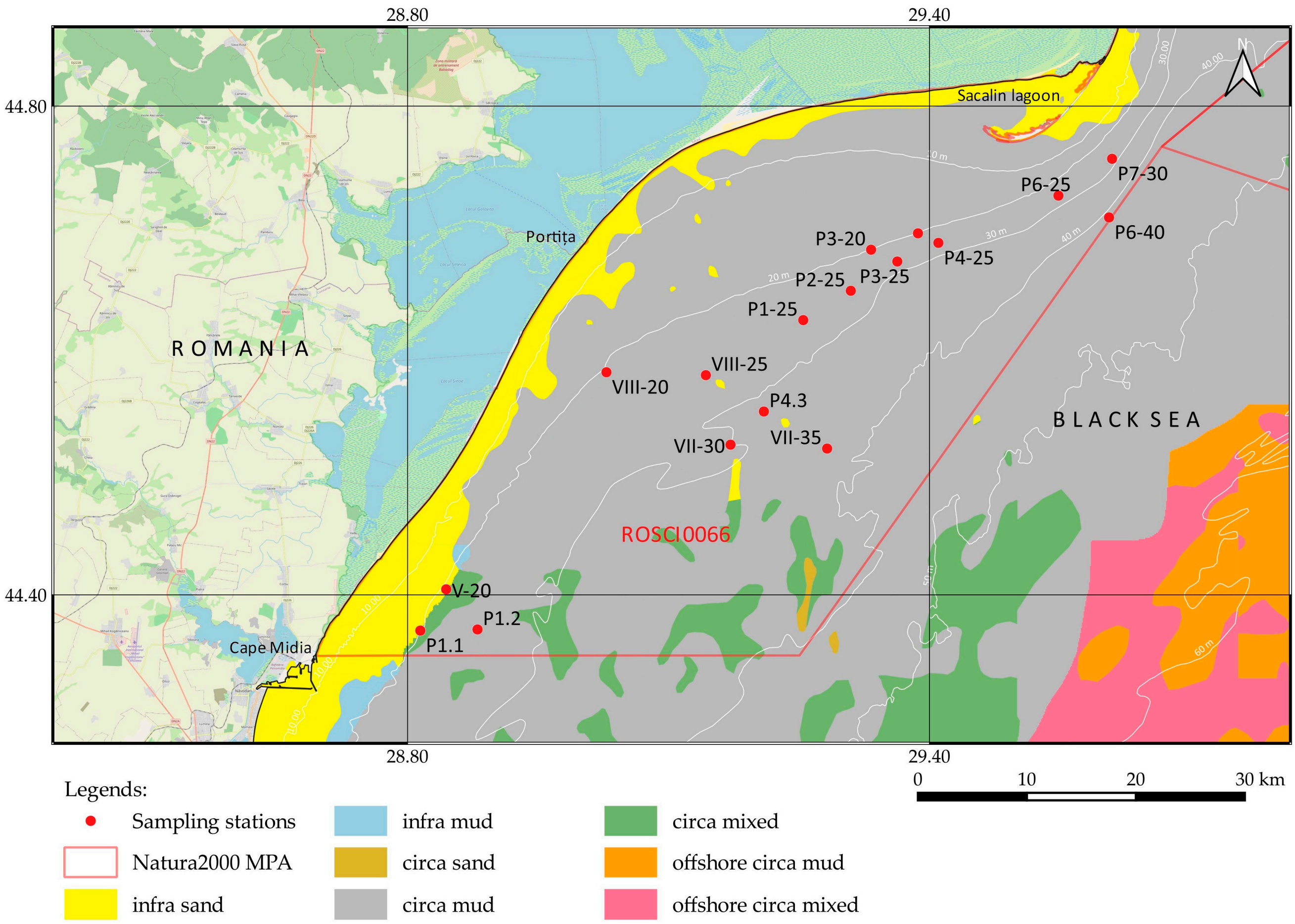

Figure 1. Study area—Danube Delta Marine Zone (ROSCI0066 extended area, 20–40 m). Sampling stations for macrozoobenthos with broad-scale benthic habitat according to the EMODnet Seabed Habitats.

The study area lies within the infralittoral and circalittoral bionomic zone, where, according to the National Habitat types—Romanian Black Sea and the EMODnet—Seabed habitats Lot classification translated into EUNIS 2019 code, there are 6 benthic habitats [10]:

1. Lower infralittoral sand and muddy sand with *Upogebia pusilla*, *Micronephthys longicornis*, *Prionospio maciolekae*, *Nephtys hombergii* and *Chamelea gallina* (MB543),
2. Circalittoral mud and sandy mud with *Upogebia pusilla* (MC64),
3. Danube plume area (Mud with *Melinna palmata*, *Mya arenaria*, *Anadara kagoshimensis*, *Alitta succinea*, *Nephtys hombergii*) (MC641),
4. Circalittoral mud dominated by *Melinna palmata* (MC64),
5. Circalittoral mud with *Spisula subtruncata*, *Abra nitida*, *Pitar rudis*, *Acanthocardia paucicostata*, *Nephthys hombergii* and *Mytilus galloprovincialis* beds (MC644),
6. Circalittoral mixed sediments with varied infauna and mussel beds of *Mytilus galloprovincialis* (MC241).

All sampling points were located inside the Danube Delta—Marine Zone MPA (ROSCI0066).

2.2. Calculating Fishing Pressure

Fishing pressure by beam trawling was calculated by using Vessel Monitoring System (VMS) data (yearly kilometers of each vessel authorized by the National Agency for Fisheries and Aquaculture—NAFA), buffered with the average gear width and aggregated to calculate the swept area by dividing it to the total area of the extended zone of ROSCI0066, adapting the existing Swept Area Ratio (SAR) methodology [31,36], according to the formula:

SAR = Towed gear distance covered (km) × Gear width (km)/Total area investigated (km^2)

Vessel monitoring system (VMS) data were accessed and analyzed to reconstruct the trawling lines of Romanian vessels > 12 m equipped with beam trawls for the period 2015–2022. The development of VMS as a surveillance and law enforcement tool transformed the study of fishing activity and footprints [37], offering total or nearly complete coverage of targeted fleets as well as high-resolution information on the positions of specific fishing vessels [38]. In the case of the Danube Delta—Marine Zone, management authorities can use VMS data to verify if a vessel is in an area where fishing is allowed. VMS data were used to point out the hotspot locations and dynamics of beam trawl fishing activity during the analyzed 8-year period.

In this particular case, only VMS data for vessels fishing with the beam trawl (TBB) targeting the gastropod *R. venosa* were used. As there is no actual fixed width of beam trawl used at the Romanian coast, local ecological knowledge (LEK) [39,40] from fishermen and authorities (NAFA) was used to estimate the average width of the gear used in our calculations (4.2 m). Moreover, in order to make a clear separation between the total number of kilometers recorded by the VMS and the actual trawling operations (contact of the gear with the seabed), local ecological knowledge was also used with the result that 50% of the total distance covered by one vessel was actually used for beam trawling.

2.3. Catch Data

In order to make a correlation between pressure, effort, and the outcome of the beam trawling fishery on the Romanian coast, yearly catch data of *R. venosa* were used for the period 2015–2022 [41].

2.4. Geophysical Investigations

The geophysical studies for habitat mapping in the northern Romanian marine unit, corresponding to ROSCI0066, were carried out with the help of a multibeam echosounder (MBES) and a sidescan sonar (SS). During 2019–2020, 3 cruises were carried out (MN-198, MN-227, MN-229, respectively) with the R/V "Mare Nigrum" for data acquisition in shallow waters between 20 and 40 m water depth (Supplementary Material Table S1). Geophysical data coupled with ground truth sediment and biological samples are widely used for habitat classification [42] and allowed us to characterize a large area in a short time.

Two types of MBES were used to record bathymetric and backscatter data: Norbit iWBMSh, with a frequency range of 200–700 KHz, used both for bathymetry and backscatter data, and Elac 1050D MBES, with 50 KHz transducers, for bathymetry only. In addition, a Klein L3900 sidescan sonar, with 455 KHz transducers, was used for the backscatter data. Both MBES systems have transducers mounted on the vessel's keel. Calibration for roll, heave, pitch, roll and a GPS latency test were performed prior to beginning the geophysical investigations. Two real-time corrections were made to the MBES recordings. Corrections from a Motion Reference Unit (MRU) that determines the motion of the vessel/transducers (heave, roll, pitch, and yaw) are critical for the measurements' precision [43]. These were carried out by either an integrated MRU in the head of the MBES system for Norbit MBES or with an iXBlue Octans III MRU for the Elac system. The second set of corrections are for the speed of sound in the water column and were measured using a Valeport MiniSVP probe. Positioning was executed using a differential Global Navigation Satellite System receiver or a Global Navigation Satellite System receiver with Real Time Kinematic correction.

While bathymetry was used to create a high-precision digital elevation model (DEM) of the seafloor, backscatter data along with sediment/biological samples were used to characterize physical/biological habitats. Multibeam data were processed onboard using the Hypack suite: MBMAX64 for bathymetry processing and Geocoder for backscatter data. Sidescan data were processed with Sidescan Targeting and Mosaicking in the Hypack suite. The sampling points design was established following the bathymetric and the backscatter mosaic maps and was analyzed onboard by an interdisciplinary team of researchers.

2.5. Macrozoobenthos and Sediment Sampling

Sample collecting in the field was performed in the study area from 17 stations (Supplementary Material Table S1), during the same scientific surveys with the R/V "Mare Nigrum" (2019–2020). Single replicates of macrozoobenthic samples were collected using van Veen grabs with grasping areas of 0.125 m^2. Samples were washed with sea water using a 0.5 mm mesh sieve [20,44] and the retained organisms fixed in 4% neutralized formalin seawater solution. Density and biomass (as wet weight) were referred to one square meter (indv.m^{-2}, g.m^{-2}). Bivalves were weighed with shells. The nomenclature of species was checked following the World Register of Marine Species [45].

2.6. Statistical Analysis

The structure of the macrobenthic community was analyzed in terms of species richness (S), Shannon-Wiener diversity (H′), Margalef index (d), total abundance (A), and biomass. Macrobenthic community composition was calculated using similarity percentage analysis (SIMPER) and analysis of similarity (ANOSIM) in PRIMER 7 and PERMANOVA+ software package, version 7.0.17. Multivariate analysis (Bray-Curtis similarity) was performed with fourth square-root transformed data using PRIMER 7 and PERMANOVA+ software package, version 7.0.17. Abundance data (transformed with log (x + 1) function) were used to create a similarity matrix based on the Bray–Curtis similarity index. The matrices were used to perform hierarchical cluster analysis (CLUSTER) and nonmetric multidimensional scaling ordination (MDS), in order to evaluate similarities between samples (grouped by stations). To evaluate the contribution of the species that determined the differences between the groups created by the cluster analysis, the similarity percentages were calculated (SIMPER analysis). We used a one-way analysis of similarity (ANOSIM) to test the null hypothesis of no indices differences among all sampling sites. The statistical coefficient Global R-value highlights variable separations between the sites with R-value between 0 to 1. If the ANOSIM R statistic is close to its maximum range of 1 that shows that there is a clear separation of the habitats.

These data were processed with Ocean Data View, version 5.4.0 [46]. The AZTI Marine Biotic Index, AMBI [47], and the multivariate AMBI, M-AMBI [48] were calculated using the freeware program available on www.azti.es (accesed on 21 March 2023). Based on the species list provided in AMBI v6.0, we divided the macrobenthos collected in the study areas into five ecological groups (EG) ranked according to their sensitivity to a progressive gradient of stress (EG I–sensitive, EG II–indifferent, EG III–tolerant, IV second-order opportunistic, and EG V–first-order opportunistic). The percentage of macrozoobenthic species belonging to the different ecological groups was then calculated for each station. AMBI results vary from 0 (high environmental quality) to seven (extremely polluted environment). M-AMBI was then derived based on a factor analysis of AMBI, species richness and H′ [48]. M-AMBI*(n) was calculated as the arithmetic mean of the min-max normalized AMBI, H and S [49]. It was proposed as one of the indicators for assessing the good environmental status (GES) of marine habitats in Romanian marine waters. The threshold values of the AMBI, S, M-AMBI*(n) indices were used according to Teacă et al. (2020) [9]. Therefore, GES for the three habitats was established according to the thresholds of M-AMBI*(n), 0.68—circalittoral mud dominated by *Melinna palmata*, 0.71—circalittoral mud with *Abra nitida*, *Pitar rudis*, *Spisula subtruncata*, *Acanthocardia paucicostata*, *Nephthys hombergii*, and *Mytilus galloprovincialis beds* and 0.60—circalittoral mud and sandy mud with *Upogebia pusilla.*

In this paper, no relevant statistical correlations could be established between the biological, geophysical, and fishing data, as the information extracted were retrieved from several non-targeted projects and research, which did not overlap exactly.

3. Results

3.1. R. venosa Catch Evolution and Fishing Pressure in the Danube Delta—Marine Zone

In the past decade, rapa whelk catches increased sharply all over the Romanian coast, but especially in the northern part, off the Danube Delta, an area targeted by vessels using the beam trawl [50]. If before 2013, when this gear was legalized in Romania [30], *R. venosa* catches barely reached 1 ton, after this turning point they increased to almost 6000 tons in 2016–2018. In 2020, catches started to drop constantly [41] (Supplementary Material Table S2, Figure 2).

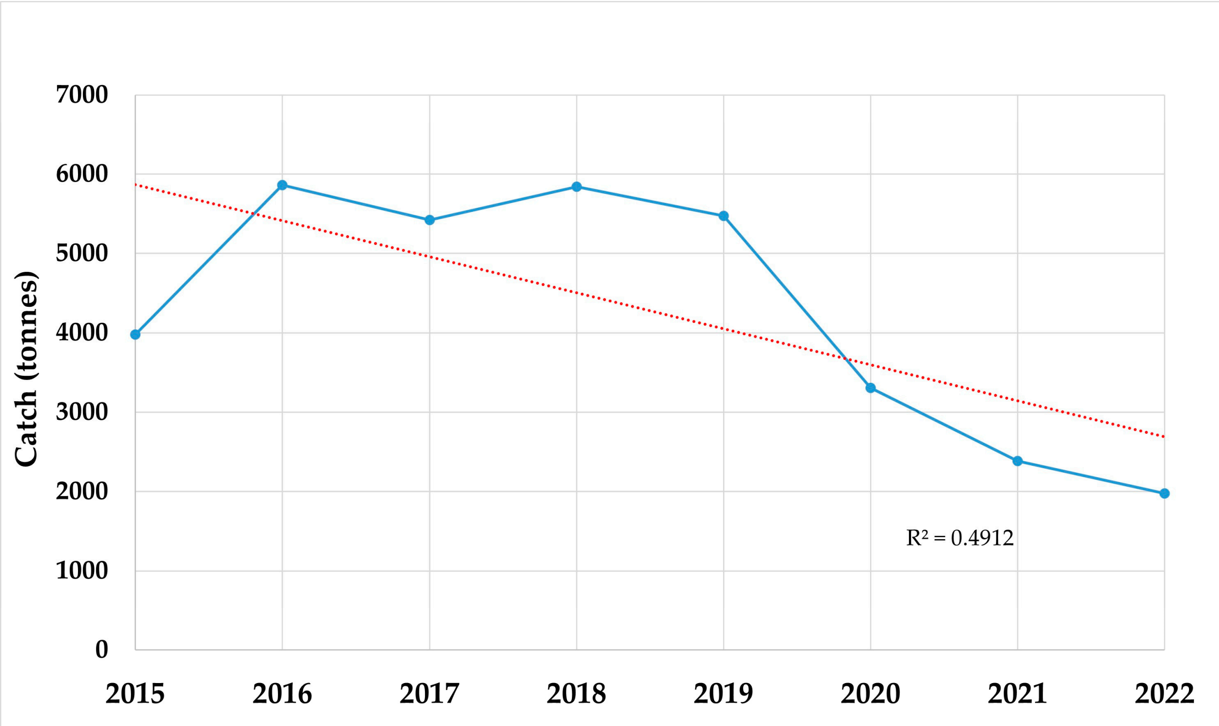

Figure 2. Dynamics of *R. venosa* catches using the beam trawl (TBB) during 2015–2022 in ROSCI0066 (extended zone 20–40 m).

As rapa whelk shifted from invasive species to commercial fisheries targets, more and more Romanian fishermen fitted their vessels with specialized gears (beam trawls). As such, a remarkable increment in fishing effort (expressed by the number of vessels and beam trawls used) was noted after 2013: from only 7 vessels and 14 beam trawls (in 2013) to 38 vessels and 76 beam trawls (in 2019) [41].

The analysis of VMS data (available starting with 2015, when all vessels >12 m were bound to be equipped with satellite communication tools in order to signal their position) revealed that 2017 was the year with the longest distance recorded, reaching up to almost 42,000 km, and the largest swept area during the investigated period (more than 87 km^2). The years 2018, 2019, and 2021, respectively, also recorded intense fishing activity in the Danube Delta—Marine Zone, with significant distances covered and areas swept, respectively, while the last year analyzed (2022) showed a decrease (Supplementary Material Table S2, Figure 3).

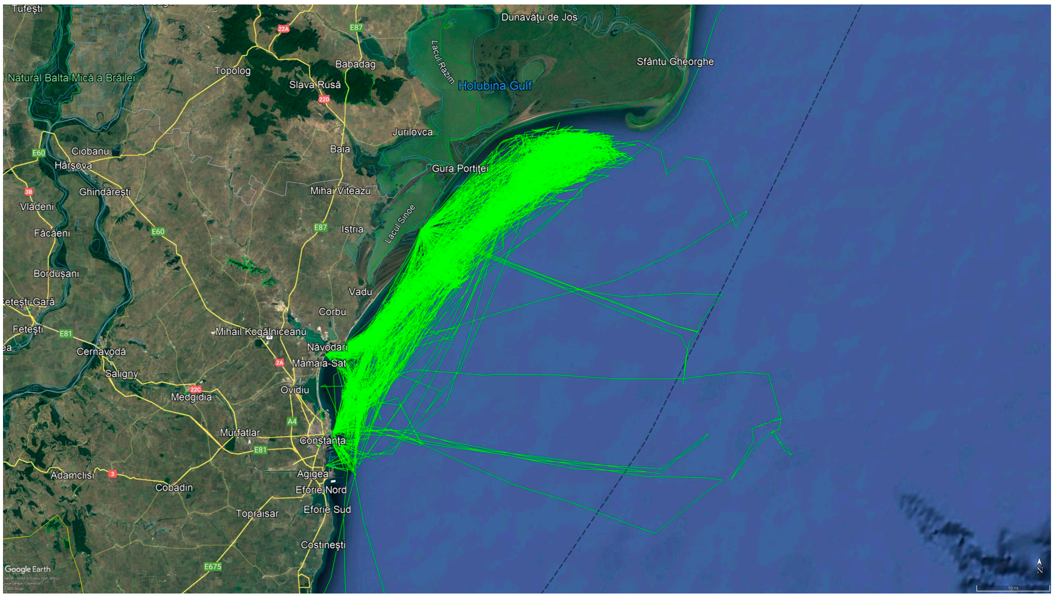

Figure 3. VMS lines for rapa whelk fishing in the Danube Delta—Marine Zone for the peak beam trawling year (2017).

As such, fishing pressure by beam trawling in the Danube Delta—Marine Zone was highest in 2017, when a SAR value of 0.041 was recorded. The lowest SAR values were calculated at the beginning (2015) and the end (2022) of the study period (SAR = 0.009). Moreover, a low SAR was registered in 2020 (SAR = 0.012), most probably due to COVID-19 restrictions (Supplementary Material Table S2, Figure 4).

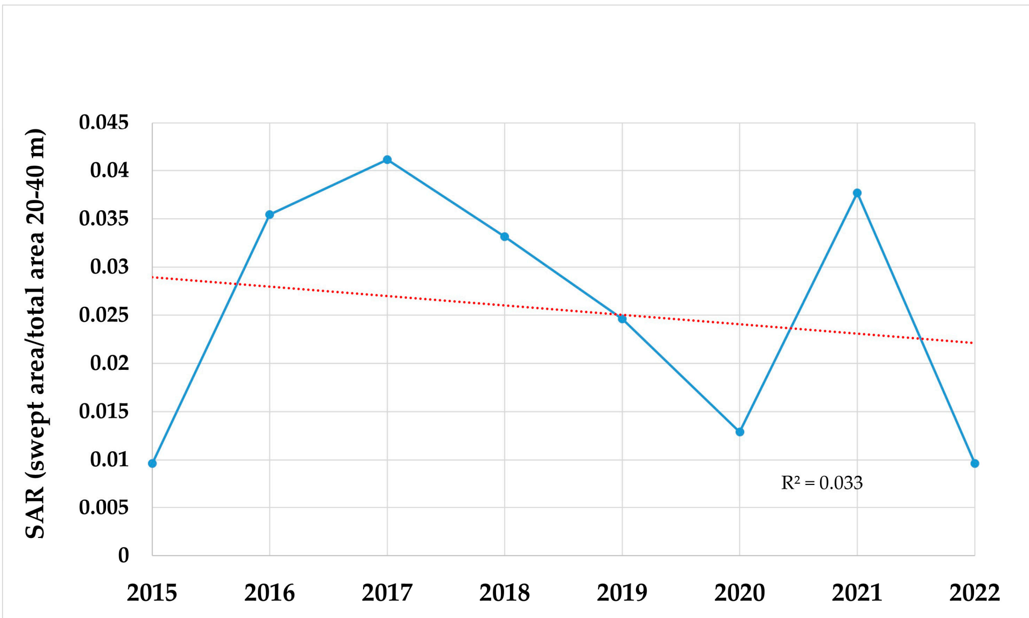

Figure 4. Fishing pressure by beam trawling (SAR) evolution in ROSCI0066 (extended zone 20–40 m) (2015–2022).

According to VMS data, most of the fishing operations were concentrated between the 20 and 30 m isobaths in a soft bottom area covered by circalittoral mud (Figures 1 and 3), thus with a significant probability of affecting the unique mussel bed habitats, which start clustering at these water depths.

3.2. Backscatter Data

Benthic trawling gears dragged on the seafloor disturb bottom sediments, changing their acoustic signature. The backscatter of acoustic beams from an MBES or SS, which is a reflection of the acoustic signal back to the transducers, depends on the nature of the sediments. In this way, we can detect the different acoustic signatures of sediments which on a backscatter mosaic appear with a different color. Traces of bottom trawlers have been detected in many places on the seabed. On the backscatter mosaic these marks appear as long stripes of a different color, 3–6 m wide and 5–10 m apart (Figure 5). Sampling points were taken both in the area affected by benthic trawling and in the area where we did not detect traces of trawlers, in order to be able to compare our findings.

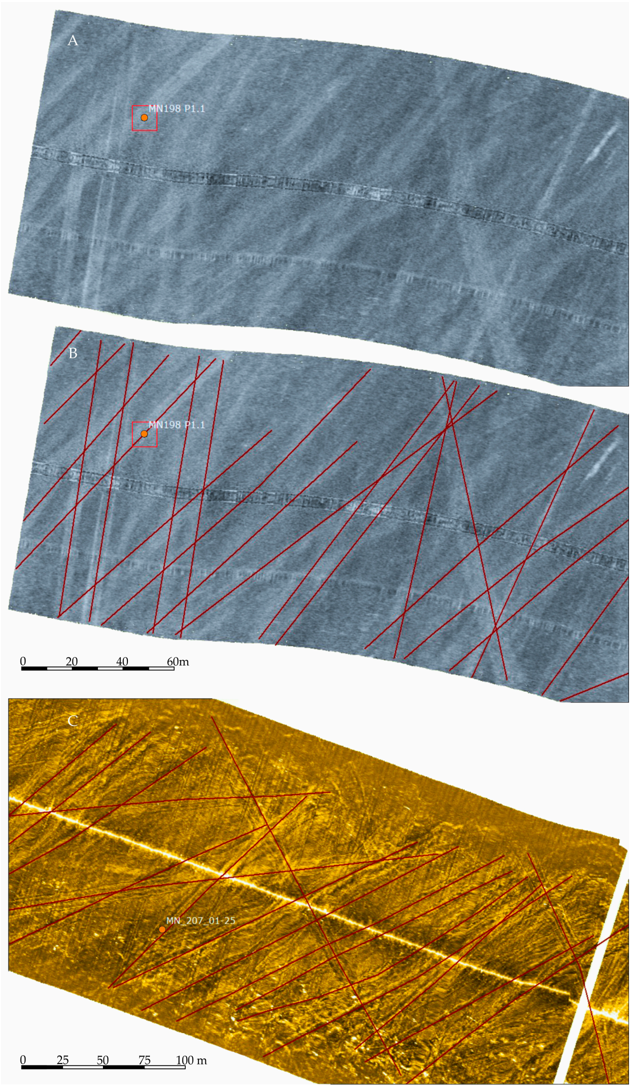

Figure 5. (**A**,**B**)—backscatter image from Norbit IWBMSh MBES with beam/benthic trawler marks on the seabed (MN198 P1.1 point at position 44°22′17.0949″ N/28°49′01.7364″ E and 20.1 m water depth). (**B**)—Trawling tracks are marked with red lines. The lighter shades of gray in these images represent coarser sediments than those from the surrounding area, while finer sediments on the seafloor have been relocated by the trawl nets. Beneath the fine muddy sediments is a thicker layer of mixed sediment (sandy mud, muddy sand, or sand). (**C**)—Backscatter image with beam/benthic trawler marks on the seabed as they appear on Klein L3900 sidescan sonar (MN_207_01–25 point at position 44°37′33.4828″ N/29°15′16.2523″ E and 27.7 m water depth). Trawling tracks are marked with red lines.

3.3. Macrozoobenthos Diversity and Habitats Type

Over the course of the three-year study period, 58 taxa in total were identified from the study region (Supplementary Material Table S3). These taxa belong to 16 major taxonomic groups, as follows: Cnidaria (4), Platyhelminthes (2), Nemertea (3), Polychaeta (19), Gastropoda (3), Bivalvia (12), Phoronida (1), Cirripedia (1), Amphipoda (6), Cumacea (1) and Decapoda (4). Polychaetes and bivalves made up 53% of the total diversity, followed by crustaceans and the other groups. Out of the species collected, two [*Pitar rudis* (Poli, 1795) and *Liocarcinus navigator* (Herbst, 1794)] are currently listed in the Order No. 488/2020 regarding the approval of the list of endangered marine species of the Romanian Black Sea coast in order to protect and conserve them [51]. Dominant species included deposit-feeding oligochaetes and polychaetes (*Melinna palmata*, *Heteromastus filiformis*), suspension-feeding mollusks (*Abra nitida*, *Spisula subtruncata*, *Pitar rudis*) and small crustaceans (*Microdeutopus versiculatus*, *Perioculodes longimanus*, *Iphinoe elisae*).

The higher species richness (25–30) was observed in the stations MN209/VIII-25 and MN207/06-40 and lower (11) in MN207/02-25, MN207/03-20, and MN207/03-25 (Supplementary Material Table S1). Margalef's index (d) varied from 1.23 to 3.09 with an average value of 2.01. The Shannon index (H′) also ranged from 0.70 to 2.13 with an average value of 1.59 (Supplementary Material Table S1). All three diversity indices showed a decline in diversity in areas with traces of trawling identified by geophysical methods (Supplementary Material Table S1 and Figure 6).

As in the case of diversity, the values of abundance (indv.m^{-2}) and biomass (g.m^{-2}) varied from one station to another, a fact illustrated by the similarity indices of the analyzed populations and the dendrogram of the ordering of these stations according to the degree of similarity of macrozoobenthic populations (Figures 6 and 7). The abundance of macrozoobenthic populations varied from 1048 indv.m^{-2} to 11,824 indv.m^{-2} with an average value of 3254 indv.m^{-2}, and the biomass from 11.2 g.m^{-2} to 1191 g.m^{-2} (Supplementary Material Table S1). The spatial distribution of the abundances showed that the highest density was recorded in the SW area of ROSCI0066, namely in the station where no traces of trawling were highlighted (Figure 6).

Based on the presence of ecosystem engineers, their coverage, and the kind of substrate, three benthic habitats were identified. According to the SIMPER analysis, there were 32% to 51% similarities between the macrozoobenthic communities at various locations. All of the sampling stations were classified into three categories that correspond to benthic habitats based on similarity values. The ANOSIM of community structure revealed that the three groups' overall community dissimilarity was greater than 69% (global test; R = 0.63, p = 0.001) (Table 1).

Table 1. Tests for differences between unordered habitat groups (*Pairwise Tests*).

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number ≥ Observed
A, B	0.667	2.9	35	35	1
A, C	0.893	0.1	715	715	1
B, C	0.385	2.2	715	715	16

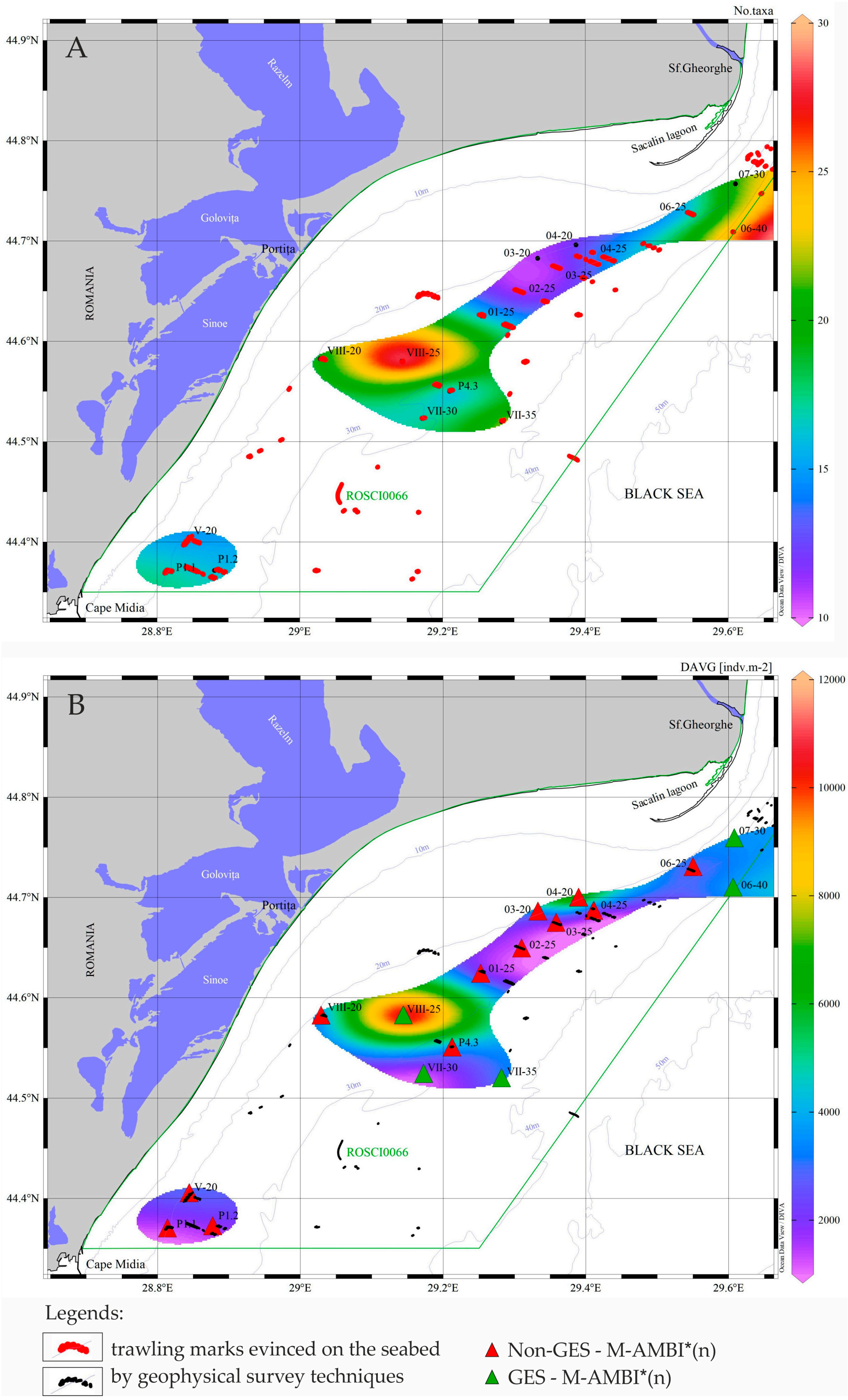

Figure 6. Contour maps showing the variation in the number of macrozoobenthic taxa (**A**), their mean density, M-AMBI*(n) index (**B**) and trawling marks (**A**,**B**) in ROSCI0066, based on samples collected between 2019 and 2020.

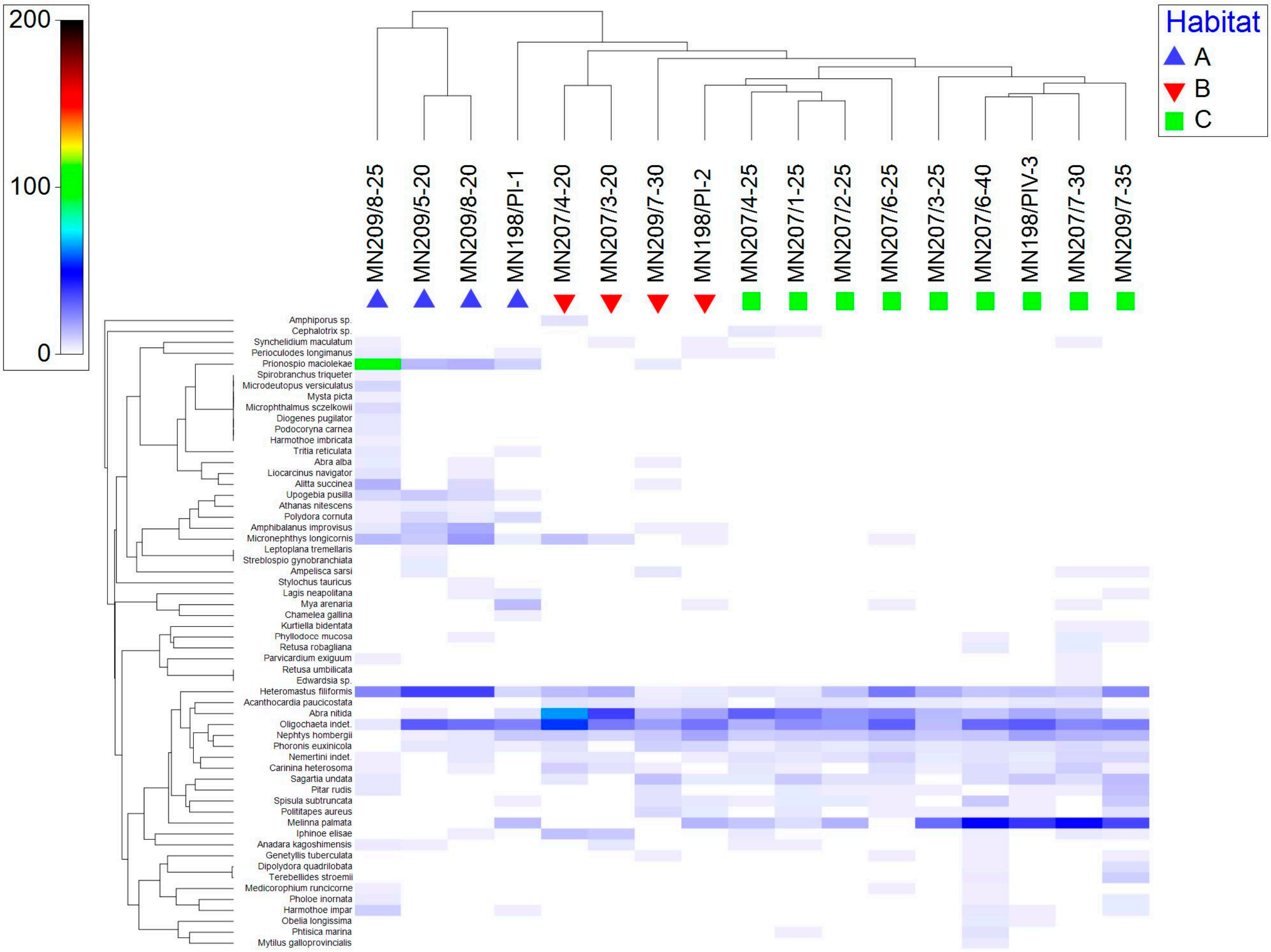

Figure 7. Shade plot of square root transformed abundances for the abundant species. Species clustering based on the index of association. Habitat A—circalittoral mud and sandy mud with *Upogebia pusilla* (up to 30 m depth); habitat B—circalittoral (20–45 m) mud with *Abra nitida*, *Pitar rudis*, *Spisula subtruncata*, *Acanthocardia paucicostata*, *Nephthys hombergii*, and *Mytilus galloprovincialis* beds; habitat C—circalittoral mud dominated by *Melinna palmata*.

The Whitaker index of association-based shade-plot analysis revealed the species with comparable patterns of abundance throughout the samples (Figure 7). Multidimensional scaling (MDS) ordination of macrozoobenthic data readily distinguished the bootstrap-like samples from the three benthic habitats, particularly those from A and B, as assemblage dissimilarity was higher between these two (75%) than between B and C (58.5%).

Habitat A—circalittoral mud and sandy mud with *Upogebia pusilla* accounted for a diversity of 44 taxa and an average density of 4806 indv.m^{-2}, characterized mainly by *U. pusilla*, which reached up to 225 indv.m^{-2} (mean: 56 indv.m^{-2}). Detritivorous annelids (*Heteromastus filiformis*, *Prionospio maciolekae,* and oligochaetes) numerically dominated this habitat (4067 indv.m^{-2}).

Habitat B—circalittoral mud with *Abra nitida*, *Pitar rudis, Spisula subtruncata*, *Acanthocardia paucicostata*, *Nephthys hombergii*, and *Mytilus galloprovincialis* beds was characterized by 26 taxa, among which, besides opportunistic oligochaets and polychaets species (45% of total density), there were *N. hombergii* and *H. filiformis*, typical mollusks association of this habitat dominated, *A. nitida* (1481 indv.m^{-2}), *A. paucicostata* (23 indv.m^{-2}), *Polititapes aureus* (16 indv.m^{-2}), *S. subtruncata* (15 indv.m^{-2}), and *P. rudis* (8 indv.m^{-2}). The mollusks biomass represented 95% of the total.

Habitat C—circalittoral mud dominated by *Melinna palmata*—as a result of hydrodynamics, this habitat covered the largest area in the investigated perimeter. This habitat was characterized by a species richness of 37 taxa that recorded an average density of 2544 indv.m^{-2}, distinguished from habitat B through the dominance of deposit feeder polychaete *M. palmata*, which reached up to 2304 indv.m^{-2} (mean: 930 indv.m^{-2}). The engineering species *M. palmata*, with 37% of the total average density, along with the oligochaete *H. filiformis* and *A. nitida*, with 82%, build characteristic habitats and community associations.

3.4. Ecological Indicators

The AMBI values for all stations were between 1.67 and 4.40, showing that GES was achieved by macrobenthic communities in four stations (23%), but not by communities in 13 sites (77%). According to M-AMBI*(n) scores that ranged from 0.36 to 1.00, the bulk (71%) of the stations that were under investigation were not in GES, and there were few sites that did achieve it (Supplementary Material Table S4 and Figure 6).

4. Discussion

4.1. Shifting Trends in Target Species and Fishing Habits in the Danube Delta—Marine Zone

The rapa whelk, an invasive gastropod that is native to the Far East (Sea of Japan, South China Sea), was originally introduced to the Black Sea between 1930 and 1940 [52,53]. *R. venosa*, a voracious predator with no natural enemies and competitors for food, soon spread throughout the basin and is blamed for destroying native flat oyster beds (*Ostrea edulis*, Linnaeus, 1758) [54,55]. It was first reported on the Romanian coast in 1963 [54]. During the 1960s, *R. venosa* recorded an exponential development, with the population reaching considerably high values [56]. Due to its high fecundity and wide tolerance to salinity, water pollution, and oxygen shortage, the rapa whelk population continued to thrive in the following decades, while other benthic species in the area suffered from deteriorating ecological conditions [30].

Although it is a species considered to have a major negative impact on mussel stocks [8], *R. venosa* has a high commercial value, mainly due to its gastronomic and nutritional qualities [57]. Thus, it became an object of exploitation on an industrial scale for most of the Black Sea riparian countries, being a valuable bioresource. *R. venosa* caught the interest of economic operators in Romania as it can be exploited with smaller expenses than other target valuable species [50].

Until beam trawl fishing was legislated in 2013, rapa whelk specimens were harvested manually, with divers, but with a poor yield and high operational expenses, the maximum catch being achieved in 2012 (588 t). The use, starting from August 2013, of the beam trawl, led to a progressive increase in the amounts of rapa whelk harvested, which were almost 15 times higher in 2017, when the catch represented 98.6% of the total catch made on the Romanian coast [50]. At the beginning of the large-scale exploitation of this species, estimates highlighted a stock value of approximately 17,500 tons, with an annual TAC value of approximately 10,000 t/year [30]. Starting from 2018, rapa whelk catches entered a downward trend, so that in 2020 they decreased by almost 40% compared to the catch in 2019. This was mainly caused by the reduction in the *R. venosa* stock, as well as by the restrictions of the COVID-19 pandemic, which affected both fisheries and the hotels-restaurants-catering (HORECA) industry [41].

Although the intensive fishing of this species functions as a regulator of the stock size on the Romanian coast, there are major concerns regarding the impact of beam trawling on the seabed, even more so in a protected area sheltering sensitive and ecologically valuable habitats.

4.2. Impact of Beam Trawling on Benthic Habitats

Bottom-trawl fishing, in general, and beam trawling, in particular, disturb benthic species and habitats and can reduce ecosystem biomass, production, and diversity [58]. In comparison to communities in locations that are not exploited in this manner or are fished at low levels of effort, benthic communities in extensively fished areas using towed gears typically have lower biomass and productivity [59]. It has been established that intensive trawling typically causes major changes in the composition of the infauna, as well as losses in the infauna and epifauna's biomass [60].

The research carried out in the Danube Delta—Marine Zone shows that the benthic communities, despite the high variability of the natural conditions of the area, are well developed and play an important role in the area's bioeconomy, fully aligned with the purpose for which it was established as a protected area for migratory fishes' populations. In general, overfishing effects, by using any kind of trawling gears and especially in such an environment heavily impacted by a high input of sediments and nutrient enrichment, are difficult to detect, and selected habitats and communities thriving in the area are already adapted to have great ecological resilience for recovery. Still, the natural recovery is limited and depends on non-impacted adjacent healthy benthic communities, which can contribute by the larval dispersion of core engineering species. The analysis of the extent of trawl marks detected on the seabed raises doubts that the recovery can properly take place at the same parameters or change to other statuses/habitats as proven in other human activities on the Romanian coast [18]. The main habitat that confers to the area a unique status is represented by the mussel biogenic reefs on the muddy substrata (soft bottoms). Usually, the *Mytilus* "clumps" are widely distributed in the study area, starting from the infralittoral up to the offshore circalittoral bionomic zone [20,21]. No such biogenic structures were found during the study period, except for a few solitary mussel individuals close to the outer deeper part of the trawling area (Station MN207/6–40) in the habitat of Circalittoral mud dominated by *Melinna palmata*. The low number of taxa also suggests that the habitats are threatened and affected by constant physical disturbance. A number of 26 taxa recorded in the habitat of Circalittoral mud with *Spisula* and *Mytilus* beds is extremely low, basically half of the potential biodiversity which can be supported by the habitat. More recent and denser beam trawl marks (finding also supported by VMS lines—Figure 3) are concentrated in the north-western area of the MPA, which corresponds to the lowest recorded number of taxa. Secondarily, eutrophication is another negative effect of intensive trawling through which water quality decreases in the area due to the excavation of nutrients trapped in the sediments and their relocation in the water mass.

In our investigation, in the areas where intensive trawling was carried out, the community-level indicators of species richness (S), Shannon diversity (H′), total abundance (A), and biomass all decreased. Relevant references consulted showed that under intense trawling conditions the rates for the depletion of biota (density and biomass combined) have been estimated at ~6% per pass of an otter trawl [61]. The efficacy of A as an indicator of trawling impacts in gradient studies has been demonstrated in a number of regions: the Irish Sea [62] and the Mediterranean [63]. Furthermore, total biomass has been shown to persistently decline in highly trawled areas [64], while AMBI and M-AMBI indicators were found to be unresponsive to trawling [65]. Despite this, in our study we observed a decrease in the values of the M-AMBI*(n) index with increasing trawling disturbance. However, we point out that we analyzed the available data from the area in order to obtain a first regional image of the potential impact that *R. venosa* beam trawling may have on benthic habitats. This preliminary screening strongly advocates for an urgent dedicated study inside well-defined polygons, allowing for clear statistical correlations between biological, geophysical, and fisheries data to be made.

4.3. Management Perspectives

The assessment of the sustainability of beam trawling's impact on benthic species is a crucial part of an ecosystem-based approach to fisheries management (EAFM), as bottom-dwelling species contribute to the benthic-pelagic coupling (i.e., the flow of organic matter from the water column to the seabed), are habitat engineers, and are a significant source of food for demersal fish [58]. Fishery management strategies that incorporate limitations on fishing effort and gears over time and space are essential tools for addressing this issue [59]. Temporal and/or spatial closures have been indicated as approaches to mitigate overfishing-related disturbances and to promote biodiversity recovery and ecosystem restoration [66].

The EAFM calls for managers to take the environmental effects of fishing into account in management plans [67]. However, the associated management measures may displace fishing activity. The consequences of this could be evaluated using information on the distribution of recovery rates of various benthic habitats. As a result, MPA management plans that limit beam trawling to more resilient areas and maintain permanently unfished patches within these areas should minimize the effects of MBCG fishing efforts on seabed habitats. The speed of habitat recovery can be increased by keeping patches of nearby habitats unfished [68].

Other significant biological benefits, such as the prevention of habitat degradation that invariably follows the use of MBCG such as beam trawls, can result from fishery management systems that regulate the use of certain types of fishing gears, in addition to the obvious benefits for targeted species (deep sea mussel beds, in the case of ROSCI0066).

It is crucial to bear in mind that trawling has a greater negative impact on benthic species in areas that have not yet experienced it than it does in areas that have. The severity of the impact will also depend on how frequently and intensely natural disturbances occur [58]. Consequently, management measures that displace trawling effort from existing fishing grounds can have significant effects on benthic communities [69], the magnitude of these effects being determined by trawling frequency, and the frequency and intensity of natural disturbance. The preservation of sensitive benthic habitats is one of many management objectives for which area closures have been proposed [69]. It is known that rotational management and area closures enable benthic fauna to recover from the effects of fishing [70].

Even though the deep-sea mussel beds are included in an MPA under national and European legislation (Danube Delta—Marine Zone ROSCI0066), they are not currently protected from beam trawling, as this type of fishing is banned only at depths below 20 m (near the coast), while most of the beam trawling activity overlaps with deep-sea mussel beds in the 25–30 m bathymetric zone. The revised Management Plan of the Danube Delta Biosphere Reserve (currently under appropriate assessment by the Romanian Environmental Agency) advocates for establishing certain Fisheries Restricted Areas (FRAs) beyond the 20 m isobath. The restrictions consider both temporal and spatial bans within the Danube Delta—Marine Zone, by alternating defined areas undergoing fishing with biological recovery polygons. The selection of these areas should be completed only after performing dedicated studies to assess the impact of beam trawling on the seabed in ROSCI0066, with a particular focus on circalittoral muds with *M. galloprovincialis*.

5. Conclusions

Our study is the first carried out on the Romanian coast of the Black Sea, which investigates the potential effects of beam trawl fishing on benthic communities in a marine protected area. Beam trawling has developed extensively in the past 10 years in Romanian waters, particularly in the northern area covered by soft bottoms, corresponding to the marine zone of the Danube Delta Biosphere Reserve.

By analyzing the available beam trawl catch dynamics information (for the target species *R. venosa*), VMS data, geophysical investigations, and macrozoobenthos sampling, we performed a preliminary assessment of the actual impact of physical disturbance on soft bottoms. Our research shows that beam trawling activities can cause changes in the benthic habitat structure. As such, mussel biogenic reefs on soft substrata (the so-called mussel "clumps"), unique in this region, were basically absent from the samples collected during the study period. Moreover, the low number of benthic taxa identified also suggests that the habitats here may be threatened by constant physical disturbance. More recent and denser beam trawl marks (finding also supported by VMS lines clustering) are concentrated in the northern area of the MPA, which corresponds to the lowest recorded number of taxa. Additionally, the benthic community species richness (S), Shannon diversity index (H′), total abundance (A), and biomass declined with increasing trawling disturbance, as well as the values of the M-AMBI*(n) index. Based on the M-AMBI*(n) scores, most of the area investigated was in non-GES, suggesting that beam trawling may impact the substrate in the area.

In order to allow the recovery of the affected benthic habitats, an ecosystem-based management approach is proposed, by establishing certain Fisheries Restricted Areas (FRAs) beyond the 20 m isobath, considering both temporal and spatial bans within the Danube Delta—Marine Zone, by alternating defined areas undergoing fishing with biological recovery polygons. These particular FRAs should be designated only after performing thorough dedicated investigations and before-after comparative studies of the impact of beam trawling on the seabed in ROSCI0066, with a particular focus on circalittoral muds with *M. galloprovincialis*.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15122241/s1, Table S1: Sampling locations; Table S2: Summary of catch data and beam trawling fishing pressure in the study area (2015–2022); Table S3: List of macrozoobenthic taxa found in the study area; Table S4: Ecological quality assessment of circalittoral habitats using M-AMBI*(n) index [the threshold value of the M-AMBI*(n) index was used according to Teacă et al. (2020), [9]].

Author Contributions: Conceptualization, M.N., V.N., A.T. and T.B.; methodology, M.N., V.N., A.T. and A.P.; software, A.T. and A.P.; validation M.N. and A.T.; investigation, M.N., V.N., A.T., A.P. and T.B.; writing—original draft preparation, M.N., V.N., A.T., A.P. and T.B.; writing—review and editing, M.N. and T.B.; supervision, V.N. and A.T.; funding acquisition, T.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Romanian Ministry of Research, Innovation, and Digitization in the framework of the national NUCLEU Programs, projects: PN 23300202 and PN 23230301, POIM project "Revision of the Danube Delta Biosphere Reserve Management Plan and Regulation", SMIS Code 123322, contract number 253/18.06.2019, the Program Development of the National R&D system—AMBI AQUA—no. 23PFE, and the European Union's Horizon 2020 BRIDGE-BS project under grant agreement no. 101000240, and the DOORS project under grant agreement no. 101000518.

Data Availability Statement: Not applicable.

Acknowledgments: Our sincere thanks to Selma Menabit and Ana Bianca Pavel for the preprocessing of macrozoobenthic samples. Likewise, we thank the reviewers for their valuable comments.

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

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