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Hidden Reefs in the Polish Marine Areas: Implications for Conservation Measures and Maritime Spatial Planning

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Abstract

Hard-bottom habitats are among the most structurally complex ecosystems in temperate shelf seas. Identification of reef habitats is fundamental for biodiversity conservation and ecosystem-based marine spatial planning. We used high-resolution seabed mapping combined with field surveys, including benthic sampling, to identify previously undocumented reefs in the Polish part of the Baltic Sea. The newly detected habitat exhibited characteristic hard-substrate morphology and supported diverse benthic assemblages, indicating ecological relevance disproportionate to its spatial extent. The presence of characteristic reef-associated taxa, high biodiversity, and significant natural value of both macrozoobenthic and macroalgal communities were noted. The data presented here not only enrich the existing knowledge on marine habitats but also contribute to the development of more effective environmental conservation strategies for marine ecosystems under international protection. The findings will have direct implications for marine spatial planning and highlight the need to integrate updated habitat data into decision-making processes.

Keywords: reefs (1170); Polish marine areas (PMAs); biodiversity; protected areas; conservation measures

1. Introduction

Hard-bottom habitats are among the most structurally complex ecosystems in temperate shelf seas, supporting disproportionately high biodiversity relative to surrounding soft sediments. The EU Interpretation Manual gives the following definition and clarifications for reefs (code 1170) [1]: "Reefs can be either biogenic concretions or of geogenic origin. They are hard, compact substrata on solid and soft bottoms, which arise from the seafloor in the sublittoral and littoral zones. Reefs may support a zonation of benthic communities of algae and animal species, as well as concretions and corallogenic concretions".

Depth is the key factor shaping reef assemblage structure. Differences in species composition of the reef habitat (1170) among Baltic Sea regions also reflect a strong salinity gradient and local habitat conditions [2].

Most organisms are unable to burrow into hard surfaces, but these provide a stable surface for sessile filter feeders to attach to [3]. In the Baltic Sea, key sessile epifaunal species associated with hard substrates are the blue mussel *Mytilus trossulus*, the barnacle *Amphibalanus improvisus* and the bryozoan *Einhornia crustulenta*. They are accompanied by various species of mobile phytophillous invertebrates, mainly crustaceans (predominantly amphipods and isopods), polychaetes and gastropods [4–7].

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Both artificial and natural hard substrates support particularly rich benthic communities [5,7–11], but studies showed that taxonomic richness is usually significantly higher on boulders than on concrete substrates at the same depth [12–15].

Reefs typically increase structural complexity and provide cryptic habitat that allows settlement of other species and provides refuge from predation, competition, and physical and chemical stresses [16]. This habitat may also provide important food resources for juvenile fish and economically important fish stocks, as well as areas for foraging, refuge, and nursery functions [17].

This habitat type is present in all EU regional sea areas (in twenty-two Member States), in both coastal and offshore locations. In the Polish marine areas (PMAs), reefs have so far been identified at only three locations: the Słupsk Bank Boulder Area, the Rowy Boulder Area, and the Orłowo Reef [18,19]. These are boulder reefs consisting of hard, compact substrates of geogenic origin. A key characteristic is that many reefs are made up of a mosaic of marine communities and habitats rather than being uniform [2,16]. This is illustrated in Annex II of the Nature Restoration Law (NRL), which lists sub-habitats that may be present within some biogenic or geogenic reef types (macroalgal forests—group 2, shellfish beds—group 3, and sponge, coral and coralligenous beds—group 5) using the EUNIS habitat classification as a reference.

Recent habitat mapping in the PMAs [20] identified a part of the seafloor that may qualify as reefs (1170). The study area is located approximately 17 km northwest of Kołobrzeg, measured from its centre. Water depths range from 13 to 24.5 m, and the seabed is characterised by numerous glacial ridges with crests at depths of 13–20 m. The principal geomorphological component of the investigated habitat consists of De Geer moraines (sensu [21–23]), accompanied by isolated kames. These landforms form a complex assemblage of elongated, undulating ridges arranged approximately parallel to one another. Their crests rise 3–4 m above the surrounding seabed and locally exceed 5 m. The moraine crestlines trend predominantly SW–NE. The longest individual ridges exceed 1 km in length and locally attain widths of more than 50 m at their base. The De Geer moraine field continues northward and northwestward beyond the investigated habitat area into deeper water depths exceeding 25 m. The moraines are composed mainly of boulders, gravel, and sand. Boulder accumulations dominate the crest zones of these landforms, with the largest boulders exceeding 2 m in diameter. The surrounding seabed is composed mainly of sandy and sandy-gravel sediments, with isolated boulders and small boulder clusters. This observation motivated targeted biological investigations, carried out in 2025 as part of the project *Development and update of the documentation and management plans for Natura 2000 sites supervised by the Director of the Maritime Office in Szczecin—Part II*: *Special Areas of Conservation* (*PLH*) [24].

The area of interest is partly located within the boundaries of the Special Area of Conservation 'Ostoja na Zatoce Pomorskiej' (PLH990002) and within the Special Protection Area 'Zatoka Pomorska' (PLB990003). Notably, reefs (1170) are not currently listed in the Standard Data Form for PLH990002 [25], highlighting a potential gap in existing habitat records and underscoring the need for more detailed studies to confirm their presence. This gap may affect how reef habitat is considered in future conservation and management efforts, as well as in spatial planning processes, especially since reefs face multiple anthropogenic pressures, including eutrophication, fishing activities, and physical disturbance associated with coastal and offshore development [26].

Despite their ecological importance, the spatial distribution of the reefs remains poorly constrained in many shelf sea regions. Quantitative sampling of epilithic, sessile communities on reefs with complex topography in the subtidal zone over large spatial scales is expensive and severely limited by logistics [27].

The Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (the Habitats Directive, hereafter referred to as HD) [28] obliges Member States to designate and protect natural habitats, including reef habitat (1170), as part of the Natura 2000 network, and to take appropriate steps to avoid deterioration or disturbance that would adversely affect their favourable conservation status. Complementing these obligations, the EU Biodiversity Strategy for 2030 [29], a central pillar of the European Green Deal, sets binding targets to legally protect at least 30% of the EU's sea areas and strictly protect at least a third of its marine protected areas by 2030. The adopted NRL [30] further translates these strategic commitments into binding restoration targets for habitats in unfavourable condition, including marine ecosystems, thereby reinforcing Member State-level legal duties to restore and safeguard biodiverse marine habitats. Adopting the National Plan for the Restoration of Natural Resources as a tool for implementing the NRL will require integrating new data on marine habitats.

Accurate identification of bottom habitats is therefore fundamental for biodiversity conservation and ecosystem-based marine spatial planning.

The objectives of this study were: (1) to develop the criteria for the identification of the reefs (1170) in the PMAs, (2) to identify and characterise previously undocumented reefs (1170), (3) to assess the conservation status of this habitat, and (4) to discuss the implications for marine spatial planning and Natura 2000 site management.

2. Materials and Methods

2.1. The Study Area

The area of investigation is located in the eastern part of the Pomeranian Bay (the Polish part of the Baltic Sea), approximately 17 km from Kołobrzeg. The hard-bottom area is partly located within the Natura 2000 site 'Ostoja na Zatoce Pomorskiej PLH990002'.

As mentioned above, in 2022, as part of the survey, a video inspection using a remotely operated vehicle (ROV) along six 100-metre-long transects was carried out [31].

The ROV was equipped with a camera capable of video recording at a minimum resolution of 480 TVL, with still images extracted from video frames at Full HD 1080i resolution (1920 × 1080 pixels). During video recording, the ROV's navigational data were recorded in real time. In addition, the vehicle was equipped with two laser markers to provide a horizontal scale for the recorded images. The lighting intensity was adjusted to minimize, as far as possible, light reflection from suspended particles.

The video footage was analysed to identify locations where phytobenthos occurred, estimate the percentage cover of the seabed by vegetation, and perform preliminary taxonomic identification of phytobenthos specimens [31].

Additionally, samples of macrophyte, epifauna and accompanying macrozoobenthos communities were collected from two stations: FB_012 (depth of 13.5 m) and FB_014 (depth of 16.7 m) (two replicates per station). An ROV equipped with an underwater sampler (suction pipe with a scraper) was used to collect benthos from the boulders. The samples were frozen. To confirm habitat occurrence in the area, supplementary studies of fouling communities were conducted at nine stations: FB_1–FB_9 (two replicates per station, except one station, FB_10) in 2025 at a greater depth than in 2022 (13 m to 17.2 m) [24]. The number of representative stations and their distribution were determined by specialists and depended on the extent of seabed vegetation cover (min. 10%) and the homogeneity of its structure.

The study area and distribution of sampling stations are presented in the figure and tables below (Figure 1, Tables 1–3).

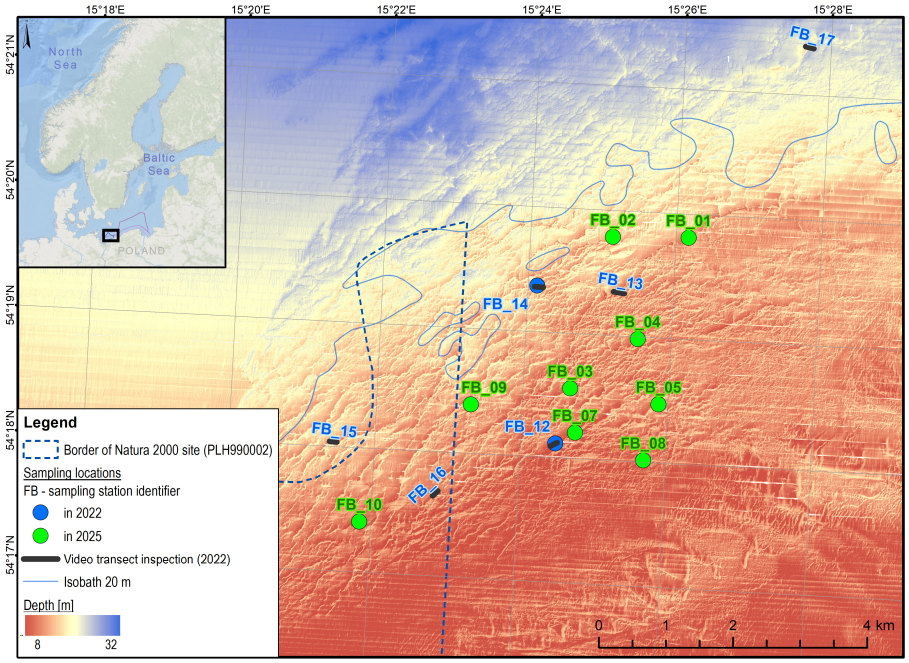


Figure 1. Sampling stations in 2022 and 2025, against the background of the Natura 2000 site 'Ostoja na Zatoce Pomorskiej' (PLH990002), southern Baltic Sea.

Table 1. Geographic coordinates of video transects in 2022.

Transect ID	Geographic Coordinates			
	Start		End	
	Latitude	Longitude	Latitude	Longitude
FB_012	54.30156	15.40701	54.30207	15.40849
FB_013	54.32254	15.41966	54.32239	15.42210
FB_014	54.32268	15.40153	54.32265	15.40355
FB_015	54.30069	15.35645	54.30064	15.35809
FB_016	54.29484	15.38174	54.29416	15.38061
FB_017	54.35627	15.46273	54.35648	15.46082

Table 2. Summary of sampling station information in 2022.

Station ID	Geographic Coordinates		Depth [m]	Secchi Depth [m]	Number of Samples
	Latitude	Longitude			
FB_012	54.30197	15.40812	13.5	6.5	2
FB_014	54.32285	15.40214	16.7	7.0	2

Table 3. Summary of sampling station information in 2025.

Station ID	Geographic Coordinates		Depth [m]	Secchi Depth [m]	Number of Samples
	Latitude	Longitude			
FB_01	54.330255	15.436253	16.6	6	2
FB_02	54.329853	15.418910	17.2	5.5	2
FB_03	54.309392	15.410874	14.0	5	2
FB_04	54.316408	15.425756	15.3	6	2
FB_05	54.307848	15.431269	15.3	5.5	2
FB_07	54.303520	15.412514	13.0	5	2
FB_08	54.300318	15.428435	13.0	4.5	2
FB_09	54.306587	15.388360	15.0	5.5	2
FB_10	54.290217	15.364173	16.0	4.5	1

2.2. Data Acquisition and Analysis

In 2022, the baseline survey included video recordings made with an ROV, as well as sampling with a ROV-mounted device—a scraper designed to collect organisms inhabiting hard substrates over an area of 153.86 cm^2. The seafloor video recordings covered six transects delineated based on bathymetry and sediment maps. The transects were established in areas potentially colonised by phytobenthos, on hard substrates (pebbles, boulders, clay) to a depth of 25 m. Two stations were selected; at each station, two quantitative samples were collected using the scraper.

In September 2025, macroalgae together with the epifauna and phytophillous organisms were collected by a diver at nine stations (from the surfaces of stones and boulders). At each station, two replicates (17 quantitative samples in total) were taken using a DAK frame (20 × 20 cm). Because of poor weather conditions, one sample was collected at station FB_10. The samples were frozen.

Macroalgae samples were subjected to laboratory analysis for taxonomic composition in accordance with the methodological guide for macroalgae research [32]. According to the methods, analyses included taxonomic composition and biomass of individual taxa determined as dry weight in grams per square meter (g DW·m^{-2}).

Epifauna and associated mobile and phytophilous fauna were sampled by selecting animal organisms from macroalgal samples. These samples were subjected to laboratory analysis according to the methods described in the HELCOM guide for the Baltic Sea [33] and the guidelines applied in Polish marine areas for macrozoobenthos studies [34], including qualitative analysis of taxonomic composition, abundance and biomass. The identification was carried out to the lowest possible taxonomic level using a stereomicroscope. Individuals of each taxon were counted (except for organisms forming colonies—the representatives of Hydrozoa). Abundance was expressed as indiv.·m^{-2}. Biomass of individual taxa was expressed as grams of wet weight per square metre (g WW·m^{-2}) with an accuracy of 0.0001 g. Mussel shells were opened or cracked to drain water on the filter paper. Mussels were weighed with shells. For quality assurance, 5% of samples were reanalysed for species composition by another specialist.

The names of identified macroalgal and macrozoobenthic taxa were provided in accordance with the current nomenclature of the World Register of Marine Species (WoRMS).

2.3. Habitat Classification and Extent

Marine communities and typical species on reefs differ by physical structure and location, given that reefs may occur in the intertidal, infralittoral, and circalittoral zones. Key physical factors that characterise communities include: morphology (including roughness and verticality), substrate structure, bathymetry, hydrological conditions, tidal regime, as well as physicochemical characteristics such as transparency, thermal conditions, oxygen levels, salinity and nutrients [16,35,36].

All twenty-two Member States that reported habitat 1170 as present in their jurisdictions provide information on the location and main characteristics of reefs designated as Natura 2000 sites [16]. Since the habitat definitions given in the interpretation manuals of the HD are very general, the interpretation of the habitats can differ somewhat between countries [1,16–18,37].

Stony reefs can be identified with reasonable certainty by focusing on a set of key characteristics to achieve a standardised approach to their classification. Four primary characteristics have been proposed as a starting point: surface area, depth, substrate characteristics, and typical species.

Drawing on available methodological guidance and formal definitions of habitat 1170, criteria were established for its identification and delimitation within Polish marine waters. These criteria are summarised in Table 4.

Table 4. Criteria for the reef identification in the PMAs.

Criteria	
Minimum area [ha]	100 m^2—due to the dynamic nature of the Baltic seabed at this depth and the potential for significant amounts of sand to be displaced, which could result in parts of the habitat being buried
Depth [m]	Up to 25
Substrate type	Boulders and cobbles; surrounded by sand and gravel, with outcrops of cohesive sediments (glacial till, clay, silty clay) in places boulder >256 mm cobble 64–256 mm pebble 4–64 mm
Substrate type—level 3 EUNIS	MA13, MA23, MA33, MA43; MB13; MB23; MB33; MB43; MC13; MC23; MC33; MC43 In an area surrounded by elevations and accumulations of boulders, cobbles and gravel, the following may be present: MA53; MB53; MC53
Diameter of cobbles/boulders	>10% cobbles (or larger particles, i.e., small boulders and/or boulders); forming continuous covers with an area > 100 m^2 [35]
Substrate stability/structural stability	A stable hard-bottom structure not seasonally mobile
Physical structure	A distinct elevation above the surrounding seabed; between the elevations, there may be dense covers of cobbles and boulders, as well as clusters of boulders
Occurrence of typical species—invertebrates	*Amphibalanus improvisus*, *Einhornia crustulenta*, *Mytilus trossulus*, *Gammarus* spp.
Occurrence of typical species—macroalgae	*Furcellaria lumbricalis*, *Ceramium* spp., *Vertebrata fucoides*
Dominance structure based on the biomass/abundance of macrozoobenthos	≥80% of species present are epifaunal species

2.4. Structure of the Reefs in the Pomeranian Bay

Twelve Member States have developed specific methodologies for reefs assessment and monitoring, which also apply to habitat condition reporting under Article 17 [16,38].

To characterize the habitat, a list of potential habitat quality variables (e.g., phytobenthos and zoobenthos indices, community variables, and the presence of typical species) was compiled based on scientific literature, our data, EU guidelines, and expert knowledge. In particular, this study draws on previous experience in monitoring habitat 1170 in Poland and other EU Member States.

The obtained macrozoobenthos and phytobenthos data were analysed for biocenotic indices: constancy index C and dominance index D [39,40]. Additionally, for phytobenthos, the degree of coverage was estimated, and a valuation based on relevant criteria was performed [41]. For the macrozoobenthic taxa, those with high sensitivity were identified [42]. Results obtained from replicates at the stations were averaged. Because the sampling tool and the number of representative stations differed between years, results for some parameters are presented separately.

No specific assessment criteria for non-indigenous species have been developed, as no serious effects (e.g., loss of ecological functions or a decline in habitat-forming species) on habitat structure and functioning in the PMAs have been recorded to date.

2.5. Conservation Status Assessment

In the European Union, the conservation of valuable or threatened habitats, animals and plant species is regulated by the HD. This legal act requires monitoring and reporting the conservation status of selected natural habitats and species within the entire territory of the Member States every six years.

The assessment followed the Polish methodology for the reefs (1170) [18] (Tables 5 and 6).

Table 5. Description of parameters and indices with their components of the reefs (1170) (source: [18]).

Parameter/Indicator	Description of Parameter or Indicator
Area	The area of the habitat within its natural boundaries at individual sites
Specific structure and functions	
Typical macroalgal taxa	Index based on occurrence of typical taxa: *Furcellaria lumbricalis*, *Ceramium* spp., *Vertebrata fucoides*
Typical fouling and phytophillous macrozoobenthos taxa	Index based on occurrence of typical taxa: *Amphibalanus improvisus*, *Einhornia crustulenta*, *Mytilus trossulus*, *Gammarus* spp.
Conservation prospects	An expert forecast for the condition of the habitat for the next 20 years. It takes into account: the current condition of the habitat as a complex of abiotic and biotic features and the processes taking place within it, as well as any identified impacts and anticipated threats that may affect the future condition of the habitat at the studied site. As part of the monitoring work, in addition to examining specific indicators, information is collected on current and future impacts on the habitat, the site conservation method, the protective measures being carried out, as well as their effectiveness

Table 6. Valorisation of parameters and indices of the reefs (1170) (source: [18]).

Parameter/Indicator	Assessment		
	FV **Favourable Status**	**U1** **Unfavourable Inadequate Status**	**U2** **Unfavourable Bad Status**
Area	The area of the habitat is not reduced and it is not anthropogenically fragmented	The area of the habitat shows a slow downward trend compared to earlier studies or literature information, or it is anthropogenically fragmented	The habitat area has a fast downward trend compared to earlier studies or literature information, or it is strongly anthropogenically fragmented
Specific structure and functions			
Typical macroalgal taxa	3 taxa from the list of the typical taxa occur	2 taxa from the list of the typical taxa occur	1 or none of the taxa from the list of the typical taxa occur
Typical fouling and phytophillous macrozoobenthic taxa	4 taxa from the list of the typical taxa occur	3 or 2 taxa from the list of the typical taxa occur	1 or no taxa from the list of the typical taxa occur
Conservation prospects	Conservation prospects for the habitat are good or excellent, no significant impact of threatening factors predicted, the survival of the habitat over the next 20 years is highly probable	Conservation prospects are rated as moderate; threatening factor impact expected	Conservation prospects are rated as poor; observed strong influence of threatening factors; the survival of the habitat in the perspective of 20 years cannot be guaranteed

3. Results

3.1. Habitat Classification and Extent

Based on the criteria in Table 4, the habitat extent was delineated (Figure 2). The assessment results against these criteria are shown in the table below (Table 7).

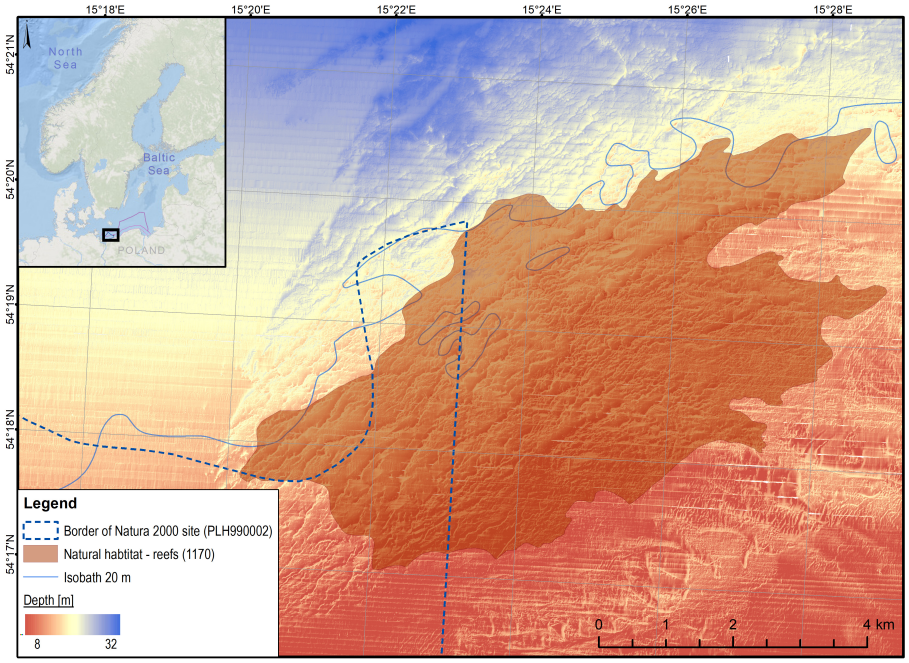


Figure 2. Reefs (1170) extent in the Pomeranian Bay.

Table 7. Fulfilment of the criteria for the reefs (1170) in the study area (source: own study).

Criteria	Fulfilment of the Criteria
Minimum area [ha]	3124.59
Depth [m]	12.6–24.5
Substrate type	Boulders and cobbles; surrounded by sand and gravel, with outcrops of cohesive sediments (glacial till, clay, silty clay) in places
Substrate type—level 3 EUNIS	MB13; MB23; MB33; MB43; MC13; MC23; MC33; MC43 and MA53; MB53; MC53 (surrounding elevations; depth greater than the elevations themselves)
Diameter of cobbles/boulders	>10% cobbles (or larger particles, i.e., small boulders and/or boulders); forming continuous covers with an area > 100 m^2
Substrate stability/structural stability	+
Physical structure	+
Occurrence of typical species—invertebrates *	+
Occurrence of typical species—macroalgae *	+
Dominance structure based on the biomass/abundance of macrozoobenthos	Dominance of epifaunal species in abundance: 92.5% Dominance of epifaunal species in biomass: 99.7%

Note: * See also Sections 3.2 and 3.3.

Habitat 1170 in the Pomeranian Bay (Pomeranian Bay Boulder Area) covers 3124.59 ha (31.24 km^2), of which 553.79 ha (5.53 km^2) lies within the Natura 2000 site PLH990002, representing 17.72%.

3.2. Structure of the Reefs in the Pomeranian Bay

3.2.1. Invertebrates

Within the studied habitat 1170, 35 taxa of macrozoobenthos representing 8 classes have been recorded: Hydrozoa, Polychaeta, Clitellata, Thecostraca, Malacostraca, Arachnida, Gastropoda, Bivalvia and Gymnolaemata, as well as two phyla: Platyhelminthes and Nemertea—in the case of taxa for which the rank of classes does not appear in the taxonomic classification (Table 8).

Table 8. List of macrozoobenthic taxa identified in the study area based on 2022 data [31] from two stations and 2025 data [24] from nine stations.

No.	Taxon/Station	2022 Survey		2025 Survey								
		FB_12	FB_14	FB_01	FB_02	FB_03	FB_04	FB_05	FB_07	FB_08	FB_09	FB_10
	Hydrozoa											
1.	*Gonothyraea loveni*	+		+		+				+		
	Platyhelminthes											
2.	*Procerodes littoralis*										+	
	Nemertea											
3.	Nemertea		+									
	Polychaeta											
4.	*Hediste diversicolor*			+	+	+	+		+	+		
5.	*Pygospio elegans*	+	+	+	+	+	+	+		+		+
	Clitellata											
6.	*Piscicola geometra*						+	+				
	Thecostraca											
7.	***Amphibalanus improvisus*** *		+	+	+	+	+	+	+	+	+	+
	Malacostraca											
8.	*Calliopius laeviusculus*	+		+	+	+	+	+	+	+	+	
9.	*Corophium volutator*	+		+	+	+	+		+		+	
10.	*Crangon crangon*		+									
11.	***Gammarus juvenes*** *	+	+	+	+	+	+	+	+	+	+	+
12.	***Gammarus locusta*** *									+		
13.	***Gammarus salinus*** *	+	+	+	+	+	+	+	+	+	+	+
14.	*Heterotanais oerstedii*	+				+		+	+		+	
15.	*Idotea granulosa*										+	
16.	*Jaera* spp.	+	+	+	+	+	+	+	+	+	+	+
17.	*Melita palmata*	+	+									+
18.	*Microdeutopus gryllotalpa*	+	+	+	+	+	+	+	+	+	+	+
19.	*Mysis mixta*		+			+		+				
20.	*Neomysis integer*			+			+	+			+	+
21.	*Palaemon* juvenes							+			+	
22.	*Palaemon elegans*						+				+	+
23.	*Palaemon longirostris*										+	
24.	*Praunus flexuosus*							+				
25.	*Praunus inermis*			+			+	+			+	+
26.	*Rhithropanopeus harrisii*					+						
	Arachnida											
27.	Hydrachnidia	+		+	+		+	+		+	+	+
	Gastropoda											
28.	*Limapontia capitata*			+								+
29.	*Peringia ulvae*	+		+	+	+	+	+	+	+	+	+
30.	*Theodoxus fluviatilis*			+	+	+	+		+	+	+	
	Bivalvia											
31.	*Cerastoderma glaucum*			+	+	+	+	+	+	+	+	
32.	*Macoma balthica*			+	+	+	+	+		+	+	+
33.	*Mya arenaria*									+		+
34.	***Mytilus trossulus*** *	+	+	+	+	+	+	+	+	+	+	+
	Gymnolaemata											
35.	***Einhornia crustulenta*** *	+	+	+	+	+	+	+	+	+	+	+
Total taxa		14	13	20	16	19	20	20	14	18	22	16
Number of typical taxa		3	4	4	4	4	4	4	4	4	4	4

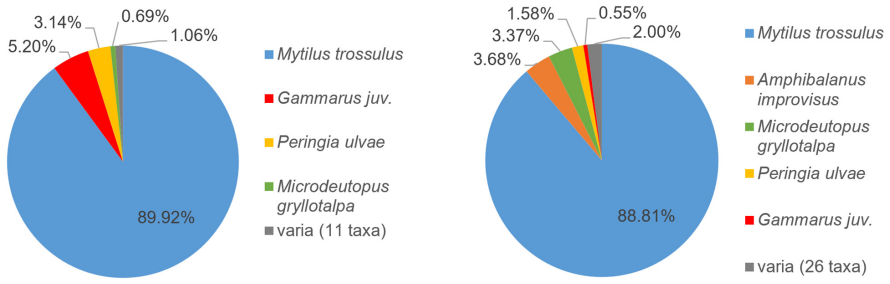
Note: * **Typical taxa** of the epifauna and phytophilous fauna.

During the basic campaign in 2022, including data from only two stations (four samples), a total of 17 macrozoobenthic taxa were found, while in 2025, based on data from nine stations (17 samples), a total of 33 macrozoobenthic taxa were identified. At station

FB_09, located in the central part of the study area, a maximum of 22 macrozoobenthic taxa were identified, indicating high species diversity in the area discussed. While in 2022, only three species typical for the hard bottom were present at one station, studies conducted in 2025 confirmed the absolutely constant presence of four typical species of the fouling and phytophilous fauna at all nine stations examined: the habitat-forming aggregations of the mussel *Mytilus trossulus*, the barnacles *Amphibalanus improvisus* growing on them, and the bryozoan *Einhornia crustulenta*, along with the accompanying gammarids *Gammarus salinus* or *Gammarus locusta* or juvenile gammarids. In addition to the typical taxa, the most common taxa at all stations were the crustaceans *Microdeutopus gryllotalpa*, *Jaera* spp., and the snails *Peringia ulvae*. It is also worth mentioning the species occurring at over 75% of the surveyed stations in 2025: *Calliopius laeviusculus*, *Cerastoderma glaucum*, *Macoma balthica*, *Pygospio elegans*, and *Theodoxus fluviatilis*. The most diverse phylum was Malacostraca, comprising 19 crustaceans, including those that are highly sensitive in the southern Baltic: *C. laeviusculus*, *Jaera* spp., *Heterotanais oerstedii*, *Idotea* spp., and *Melita palmata* [42].

The average macrozoobenthos abundance in the Pomeranian Bay Boulder Area, based on 2022 data, was 82,851 ± 3516 indiv.·m^{-2}, while taking into account the diversity of station locations within a larger area in 2025, the average abundance in the studied region was 44,367 ± 18,965 indiv.·m^{-2}. The maximum abundance reached 84,900 indiv.·m^{-2}, which was related to high numbers of mussels, barnacles, and crustaceans *Microdeutopus gryllotalpa* and *Melita palmata* at station FB_10, located in the southernmost part of the study area at a depth of 16 m.

The macrozoobenthos dominance structure in the Pomeranian Bay in 2022 and 2025 was characterised by a similar composition of dominant species, although their relative contributions varied slightly between the two years (Figure 3). However, it can be assumed that targeted studies covering a larger bottom area in 2025 indicate the actual shares of the dominants. The mussel *M. trossulus* had the predominant share in abundance (88.81%). The next most abundant species was the barnacle *A. improvisus*, accounting for 3.68%. Also noteworthy in this community were the crustacean *M. gryllotalpa* with a share of 3.37%, the snail *P. ulvae* (1.58%), and juvenile gammarids (0.55%). Taxa whose share in the macrozoobenthos population structure did not exceed 0.5% were included in the 'varia' group and constituted a total of 2.00% (26 taxa).

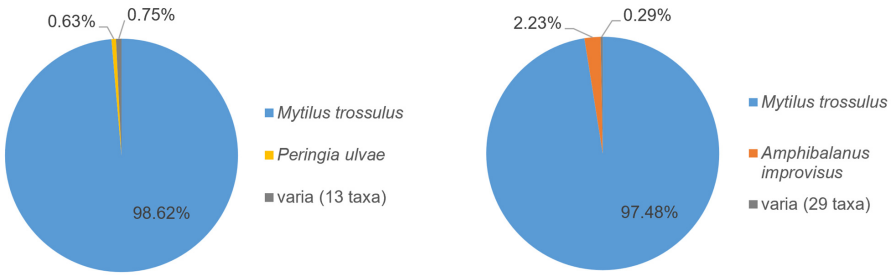


(**a**) (**b**)

Figure 3. Dominance structure of the total macrozoobenthos abundance in the study area in 2022 (**a**) and 2025 (**b**).

The average macrozoobenthos biomass in the Pomeranian Bay Boulder Area, based on 2022 data, was 525.38 ± 170.21 g WW·m^{-2}, but taking into account the 2025 data from nine stations in the Pomeranian Bay boulder bottom, the biomass of this community was 1508.29 ± 964.30 g WW·m^{-2}. Similarly, the maximum macrozoobenthos biomass was recorded at station FB_10, reaching 3736.95 g WW·m^{-2}. This was due to the high biomass of mussels.

In the biomass dominance structure, the mussel *M. trossulus* remained clearly dominant, with shares of 98.62% and 97.48% in 2022 and 2025, respectively (Figure 4). While in 2022 the snail *P. ulvae* had a small share (0.63%), in 2025 the barnacle *A. improvisus* growing on mussel shells stood out among the other taxa in terms of biomass, with a small share of 2.23%. Taxa with a share in the macrozoobenthos biomass structure lower than 0.5% were included in the 'varia' group.



(**a**) (**b**)

Figure 4. Dominance structure of the total macrozoobenthos biomass in the study area in 2022 (**a**) and 2025 (**b**).

In the identified region of the Pomeranian Bay, boulders were overgrown by dense aggregations of the mussel *M. trossulus*, with a maximum shell length of up to 5 cm, although the most numerous individuals were those not exceeding 5 mm in length. The mussel clearly dominated the identified macrozoobenthos communities, both in terms of abundance and biomass. Based on 2025 data, the mean abundance of mussels in this region was 39,401 ± 16,509 indiv.·m^{-2}, while the mean biomass was 1470 ± 917 g WW·m^{-2}.

3.2.2. Macroalgae

The study revealed the presence of 15 macroalgal taxa belonging to brown algae (6 taxa) and red algae (9 taxa). In addition to rare species such as *Desmarestia viris* and *Coccotylus truncatus*, protected species such as *Furcellaria lumbricalis* and *Ceramium* sp. were also found. Three red algae species typical of habitat 1170 were also recorded (Table 9). The most common species occurring at each station was the habitat-forming species *Vertebrata fucoides*. In addition, the group of absolutely constant taxa (present at over 75% of the surveyed stations) included *Pylaiella littoralis*, *Sphacelaria cirrosa*, *Rhodomela confervoides*, and *C. truncatus*. The number of taxa identified at all stations ranged from 2 to 11. Only two taxa were recorded at station FB_10, which was characterised by low bottom cover (Table 9) and its location at the edge of the habitat range.

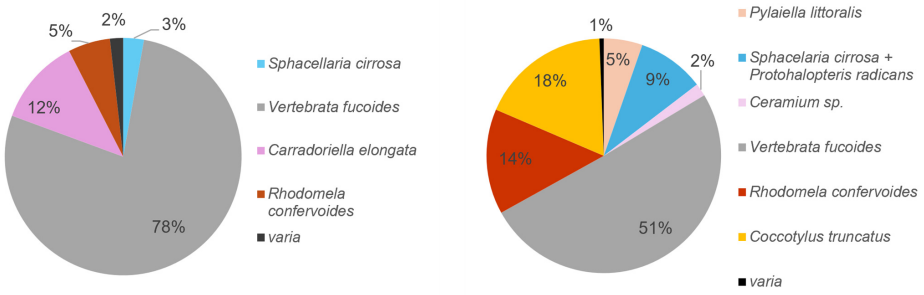
In the 2022 and 2025 studies, the dominant species in terms of biomass was *V. fucoides*, occurring at each station, with dominance index D reaching 78 and 51% in 2022 and 2025, respectively. Other biomass subdominants were red algae such as *Carradoriella elongata* (2022—12%) and, in 2025, *R. confervoides* (14%) and *C. truncatus* (18%). The share of other taxa in the biomass did not exceed 10% (Figure 5).

The degree of macroalgal bottom cover is a subjective assessment. Vegetation coverage is closely related to the substrate type. On sandy bottoms, rooted plants show patchy vegetation. On hard bottoms, cover depends not on rock and boulder density but on their ability to be covered by plants. Boulders are not covered over their entire surface, but usually only on the top. The mussels *Mytilus trossulus* are also often covered with macroalgae. As reported by the diver and supplemented by video documentation, the degree of hard-bottom overgrowth within the station was estimated. The values are included in Table 10.

Table 9. List of phytobenthos taxa identified in the study area based on 2022 data [31] at two stations and 2025 data at nine stations [24].

Taxon/Station	2022 Survey		2025 Survey									Frequency [%]
	FB_012	FB_014	FB_01	FB_02	FB_03	FB_04	FB_05	FB_07	FB_08	FB_09	FB_10	
Brown algae												
Elachista fucicola			+	+	+		+	+	+	+		63
Pylaiella littoralis	+		+		+	+	+	+	+	+	+	81
Stictyosiphon tortilis						+						9
Sphacelaria cirrosa	+	+	+	+	+	+	+	+		+		81
Protohalopteris radicans			+	+		+	+	+	+	+		63
Desmarestia viridis		+	+				+		+			36
Red algae												
Gaillona rosea			+			+		+				27
***Ceramium* sp.** *			+	+	+	+	+	+	+	+		72
Ceramium tenuicorne *	+											9
Carradoriella elongata	+						+					18
Vertebrata fucoides *	+	+	+	+	+	+	+	+	+	+	+	100
Rhodomela confervoides	+		+	+	+	+	+	+	+	+		81
Rhodomelaceae						+						9
Coccotylus truncatus		+	+	+	+	+	+	+	+	+		81
Furcellaria lumbricalis *	+	+	+	+				+				45
Number of taxa	7	5	11	8	7	10	10	10	8	8	2	

Note: * **Typical taxa**.



(**a**) (**b**)

Figure 5. Dominance structure of the total macroalgal biomass in the study area in 2022 (**a**) and 2025 (**b**).

Table 10. Phytobenthos coverage in the study area in 2022 and 2025 (source: own study).

2022 Survey		2025 Survey	
Transect	**Phytobenthos Coverage [%]**	**Station**	**Phytobenthos Coverage [%]**
FB_12	50	FB_01	40
FB_13	50	FB_02	30
FB_14	50	FB_03	30
FB_15	10	FB_04	60
FB_16	40	FB_05	60
FB_17	0	FB_07	90
—	—	FB_08	50
—	—	FB_09	30
—	—	FB_10	10

The area was assessed based on phytobenthos data collected at 11 stations (2022—two stations, 2025—nine stations). The valuation method includes four criteria, i.e., occurrence, presence of rare and protected species, and analysis of the dominance of species considered eutrophication indicators [41]. According to the methodology, a score was assigned to each criterion at each station. The total score of 78 was averaged for the area (11 stations) and classified as 3—high natural value (Table 11).

Table 11. Analysis of criteria for the natural valuation of phytobenthos in the study area (source: own study).

Criterion No.	Name of Criterion	Fulfilment of the Criterion	Score
CI	Occurrence of phytobenthos (as single specimens or communities)	Yes, phytobenthos, as communities, occurred at each station	11
CII	Occurrence of phytobenthos communities	Yes, phytobenthos coverage exceeds 30% at 10 of the 11 stations	10
CIII	Presence of rare, protected species	Protected (*Furcellaria lumbicalis*, *Ceramium* spp.) and rare species (*Desmarestia viridis*, *Coccotylus truncatus*, *Protohalopteris radicans*, *Rhodomela confervoides*, *Sphacelaria* sp.) were present at 10 of the 11 stations, in numbers from 3 to 6	47 (1 score for each rare/protected species)
CIV	Lack of dominance in biomass of species regarded as eutrophication indicators	Yes, *Pylaiella littoralis* was not dominant in biomass	10
	Total Score		**78**

3.3. Conservation Status Assessment

Conservation status assessment is presented in the table below (Table 12).

Table 12. Assessment of the conservation status of reefs in the Pomeranian Bay (source: own study).

Parameter/Indicator	Indicator Value	Assessment
Area	3124.59 ha	FV
Specific structure and functions		**FV**
Typical macroalgal taxa	3	FV
Typical fouling and phytophillous macrozoobenthic taxa	4	FV
Conservation prospects	Description below the table	U1
Overall status		**U1**

3.3.1. Area

Based on the proposed criteria for habitat identification (classification), the area of reefs (1170) in the Pomeranian Bay was determined (Figure 2) with a value of 3124.59 ha. The status was expert-assessed as favourable (FV).

3.3.2. Specific Structure and Functions

A total of 14 macroalgal taxa were identified in 2025, with red algae being the most numerous group. Three typical macroalgal taxa were recorded: *F. lumbricalis*, *Ceramium* sp., *V. fucoides*. Similar results were obtained in 2022. Based on this indicator, the status was assessed as favourable (FV).

In the macrozoobenthos samples, 35 taxa were identified, with Malacostraca being the most represented class (19 taxa). Except for one station examined in 2022, four typical fouling and phytophillous taxa were recorded at all other stations: *A. improvisus*, *E. crustulenta*, *M. trossulus*, and amphipods *Gammarus* spp. The status is favourable (FV).

In summary, both macroalgal and epifaunal/phytophilus fauna studies confirmed the presence of the taxa characteristic of the reefs. Consequently, the 'Structure and function' parameter was assessed as favourable (FV).

3.3.3. Conservation Prospects

The assessment of the habitat's conservation prospects considered both existing and potential threats. It was based on the available knowledge, including Polish legal acts, and supported by evidence from the scientific literature.

In accordance with the Maritime Spatial Plan of the Polish Internal Sea Waters, Territorial Sea and Exclusive Economic Zone (hereinafter referred to as MSP) [43], an area designated for future development (basin POM.08.P) has been established at the location of habitat 1170 in the Pomeranian Bay (Figure 6). This means preserving maritime areas in a condition that enables the determination of any possible basic function for these areas in the future to serve the interests and needs of future generations. In detail, ten permitted functions have been identified for the basin. Most importantly, within the boundaries of the reefs, sub-basin 08.201.I has been designated for laying and maintaining the linear elements of technical infrastructure—external connection infrastructure for the offshore wind farms (a public purpose investment). At 2 km from the PLH990002 site and the boundary of habitat 1170, the MSP designates an area for offshore wind energy development (basin POM.14.E).

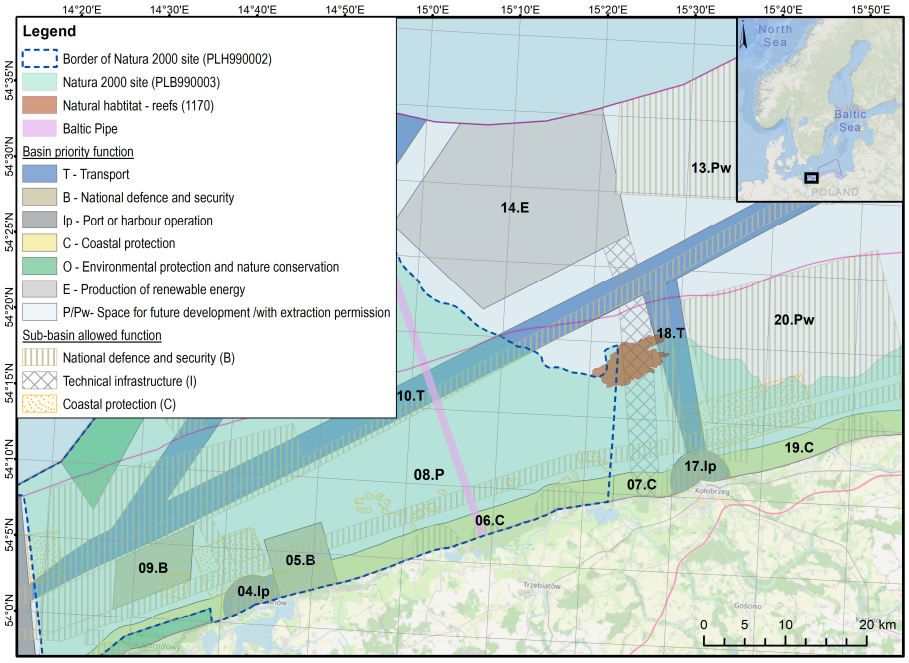


Figure 6. Reefs (1170) in the Pomeranian Bay against the background of the basin designated in the Maritime Spatial Plan of the Polish Internal Sea Waters, Territorial Sea and Exclusive Economic Zone [43] (source: own study based on SIPAM).

The technical infrastructure between the planned offshore wind farms and the land, crossing habitat 1170, may result in a range of adverse impacts on the benthic communities inhabiting this area. Before burying power cables in the seabed—typically along several cable routes—pre-installation works are carried out, consisting of clearing the seabed of stones and boulders. This process is most often conducted using a specialist plough and/or grab. The plough, towed behind a vessel along the cable route, displaces boulders located on the seabed outside the cable-laying corridor. A similar effect is achieved using a grab, whereby boulders are relocated in the vicinity of the investment area, beyond the seabed section intended for cable installation [44,45]. Regardless of the method used, these activities may fragment the habitat and destroy natural reef structures, including epifaunal communities, as well as alter their functional structure. At a subsequent stage, seabed works during cable installation may result in seabed disturbance, increased suspended

sediment concentrations in the water column, sediment deposition, and the release of contaminants from sediments into the water column [46–52].

All of these impacts are likely to cause primarily physical (mechanical) damage to benthic flora and fauna communities or—depending on the sensitivity of particular benthic species—increased mortality associated with impaired respiration, inhibited feeding processes, or exposure to contaminants released from sediments (e.g., toxic chemical compounds, heavy metals) [53]. The loss of a habitat-forming species, e.g., *F. lumbricalis*, *M. trossulus* in reef habitats, causes significant changes in the community structure, biodiversity, biomass, and productivity of the habitat [11,54,55].

A small part of the reefs is located within area POM.18.T—the sea basin established to secure the connection between the port in Kołobrzeg and the main transit routes, and used for coastal and passenger shipping as well as commercial shipping to a lesser extent. The shipping lane in this area does not require dredging; the potential risk is associated with emergencies such as oil spills. Oil spills in the Baltic Sea do not typically result in documented destruction of habitat 1170; however, scientific evidence shows that petroleum contamination can significantly impair key reef-forming components, including macroalgae and mussel populations, leading to reduced photosynthetic activity, physiological stress, and destabilisation of biogenic reef structures, which collectively may result in local degradation of reef habitat functioning [56,57].

Pursuant to the Act of 19 December 2014 on marine fisheries [58], the described area is used for fishing purposes and fishing vessel routes to other areas pass through it. Bottom trawling disturbs benthic faunal communities, but its effects on sediment suspension and seabed biogeochemistry are less well described [59–61]. Bottom fishing affects benthic carbon cycling by displacing bottom-dwelling organisms, altering sediment structures, and leading to the impairment of biogeochemical processes. Trawl-induced mortality of benthic organisms can simplify benthic communities and lead to a loss in functional diversity [62]. Pursuant to the Regulation of 21 August 2019 [63], bottom trawling is prohibited within the coastal zone up to six nautical miles, but the reefs described in this study are located in deeper waters, outside this prohibition. Analysis of AIS vessel tracking data from 2019–2025, including identification of vessel movements characteristic of bottom trawling operations, revealed limited fishing activity within the investigated area. Analysed routes also indicated that fishing vessels generally avoided the area, providing no evidence of significant bottom trawling pressure (own study based on AIS data analysis). In addition, within the Natura 2000 PLH990002 (only part of the 1170 habitat), a ban on the use of static nets applies due to harbour porpoise (*Phocoena phocoena*) protection requirements during the period from 1 November to 31 January, as established under Regulation (UE) 2022/303 [64]. Based on the available data, fisheries are therefore not considered a significant current pressure or threat in the area.

Climate change represents an additional long-term stressor that may affect the extent, condition, and resilience of the reef habitat 1170 [19]; however, rising temperatures, altered salinity regimes and increased nutrient loads are expected to interact, producing complex non-linear responses in macroalgal communities [65]. It is often suggested that climate change will favour invasions by non-indigenous species worldwide [66]. Zoobenthic communities are likewise affected by environmental parameters projected to change under climate, i.e., temperature, salinity, pH and oxygen, as well as benthic–pelagic coupling. However, the effects are not unidirectional, and several processes may amplify or counteract the possible changes. The magnitude of the future salinity decline is unclear, and other factors, such as decreasing ice cover and changes in future wind conditions (of which no consensus exists), may also affect nutrient and oxygen dynamics of the Baltic Sea [67].

Similarly to sandbanks, reefs are also affected by eutrophication and pollution, which impact the macrofauna community [68]. The assessment of pressure-specific human activities is challenging because human activities have simultaneous individual and combined impacts on marine habitats [26]. Human-induced pressures showed highly variable effects across reef habitats, with no consistent significant impacts detected at the habitat scale, largely due to high between-study variability. Among the pressures such as nutrient input, non-native species, and wind farms, the invasive round goby had the most consistent negative effect, significantly reducing reef area, while nutrient input and offshore wind farms showed mixed and highly variable impacts. More significant impacts emerged in the species-specific biotopes (*Fucus vesiculosus*, *F. lumbricalis*, and *M. trossulus*) associated with reefs. The species-specific analysis showed that offshore wind farms (OWF) had a positive impact on mussel biotope and a negative impact on algae-based biotope (causing areal loss for macroalgae). Round goby reduced the area of mussel and *Fucus* biotope; similar information on *Furcellaria* biotope is unavailable [26].

External environmental pressures strongly influence the ecological condition and functioning of protected stony reefs, indicating that formal protection could be insufficient to ensure their long-term stability [69].

Based on the conditions described above, habitat 1170 at the site in the Pomeranian Bay may deteriorate. For this reason, future reef monitoring should address potential changes in the extent and condition of the habitat in relation to major anthropogenic and environmental pressures, including eutrophication, fishing activities, physical disturbances, non-native species, and climate-related changes. Such an integrated approach would enable assessment of reef communities and their ecological functioning in the context of cumulative pressures and provide a more robust basis for adaptive conservation and management.

4. Discussion

4.1. Habitat Extent

There are three other sites representing reefs within the PMAs: one in Gdańsk Bay and two in the open sea (Figure 7) [18,19]. The Orłowo Reef (Natura 2000 site PLH220105) is the smallest, covering approximately 1 km^2 and with depths ranging from 1 to 8 m. It is a mosaic of bottom types—sandy patches with seagrass beds of *Zostera marina* occurring between boulders [19,70]. The best-known site is the Słupsk Bank Boulder Area (Natura 2000 site PLC990001), with an area of over 143 km^2 and depths ranging from 8 to 20 m [19,71]. The Rowy Boulder Area, located in the coastal zone (2–18 m), covers an area of 8.8 km^2 [19,72]. Part of this site lies within the boundaries of the Słowiński National Park and Natura 2000 site PLH220023.

Unlike the previously documented Polish reef sites, the newly identified area is neither a readily accessible coastal abrasion platform, such as those at Rowy and Orłowo, nor a long-recognised offshore feature, such as the Słupsk Bank. The Rowy and Orłowo Boulder Areas occur adjacent to, or at the foot of, coastal cliffs in areas rich in coarse-grained glacial and fluvioglacial deposits. The Słupsk Bank, the shallowest area of the Baltic Proper, has long been recognised as a seabird foraging ground and as an area of diverse seabed topography, described in detail in 2020 [71]. In contrast, the area had not previously been recognised as a reef habitat.

The study area was therefore not selected from a set of candidate sites; rather, it was identified and described for the first time through analysis of high-resolution bathymetric and sonar data, supported by environmental surveys [20]. These data enabled the recognition of an extensive offshore area as a newly proposed example of habitat type 1170.

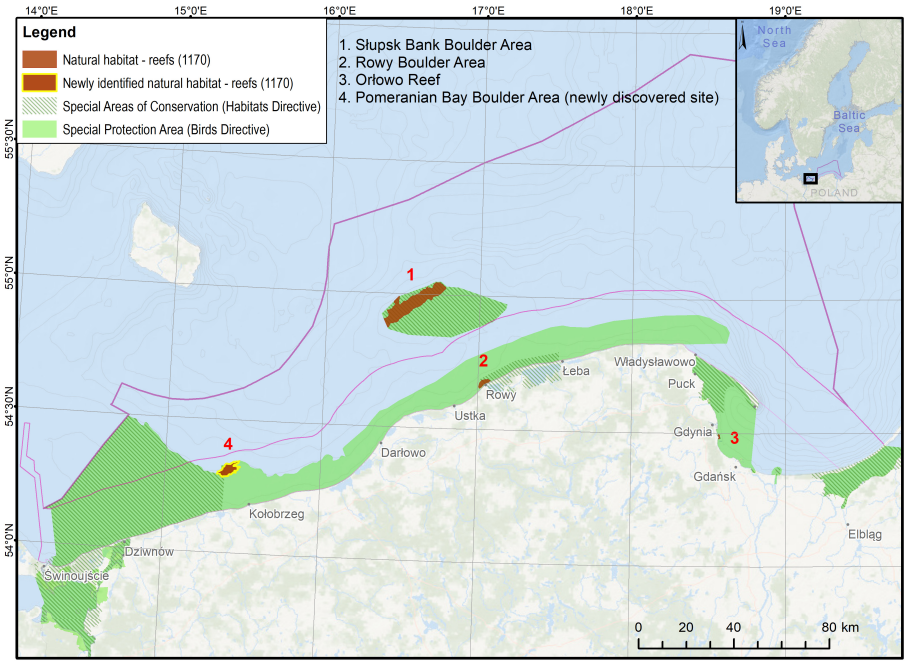


Figure 7. Reefs (1170) distribution in the PMAs.

A key limitation in habitat mapping across the Baltic Sea is the limited availability and accessibility of sufficiently detailed data on seabed-surface characteristics, particularly bathymetric and sonar data. Until recently, the resolution of the available datasets was insufficient for comprehensive habitat characterisation in this area, which partly explains why it had not been identified as meeting the criteria for habitat type 1170. The newly acquired high-resolution data revealed complex seabed topography at depths of up to 25 m, with numerous exposed boulders and gravel deposits that satisfy the geomorphological criteria for this habitat type.

For comparison, in the whole Estonian marine area (northern Baltic Sea), reefs had the widest distribution area—1704 km^2 based on the 1 × 1 km grid [11].

4.2. Structure of the Reefs in the Pomeranian Bay

The existing definitions of reefs differ between EU Member States surrounding the North Sea and Baltic Sea not only due to the type of substrate: biogenic reef (e.g., blue mussel reef) and non-biogenic reef (rocky, boulder or cobble reef), but also show striking variation in the number of parameters even in the case of a single reef type [11,73]. Comparing the reefs in the Pomeranian Boulder Area is reasonable with other reefs in this Baltic Sea region, especially with the Słupsk Boulder Area and Rowy Boulder Area, since they are located in open waters.

Boulder reefs can be considered as biological hot-spots for macroalgae and benthic animals. This structurally complex habitat serves as the base of the food web and supports expectations of significant positive impacts on local oxygen dynamics, sediment conditions and water quality. Areas dominated by such reefs are expected to be active sites for carbon and nutrient recycling [74]. Abundance and biomass of macroalgae and the fouling and phytophilous taxa of macrozoobenthos are controlled by the availability of suitable substrate, light, temperature, salinity and physical exposure. Among macrozoobenthos, *M. trossulus* aggregations are widely known to be habitat-forming species of epifauna playing a very important role in the ecosystem. These filter-feeding and long-living mussels serve as a natural biofilter, especially in polluted and eutrophic waters, contributing to their purification. By absorbing suspended solids from the water column, they alter

environmental conditions and help reduce the increased trophic state of the water body [75]. Habitat-forming species, due to their ability to achieve high biomass values and cover large areas of substrate, constitute a place of growth and existence for diverse accompanying fauna, phytophilous organisms, provide shelter for many species of crustaceans and fish, and provide a food source for benthophages [73].

Habitat quality in the Pomeranian Boulder Area was discussed based on taxonomic structure, community dominance structure, and the presence of typical and sensitive taxa in the macroalgal and macrozoobenthic communities. The results for biodiversity and the quantitative structure of the Pomeranian Boulder Area in terms of macrozoobenthos stand out compared to other reefs in the open zone of the Polish Marine Areas. The diverse flora and fauna of the Pomeranian Boulder Area contribute to the biodiversity and productivity of this part of the Baltic Sea. Single-sample collection at station FB_10 does not appear to limit the study results, as the biological diversity of the reefs in the Pomeranian Bay was higher than in habitat 1170 of the Słupsk Bank, an area previously considered to have the most compact and largest boulder area in PMAs. The total number of macrozoobenthic taxa identified in the Pomeranian Bay at all stations was 33 taxa in comparison to the Słupsk Bank Boulder Area, where 22 taxa were identified in the 2019 inventory study [71]. In addition, the results of monitoring in the Słupsk Bank Boulder Area in 2021, when a total of 20 macrozoobenthic taxa were identified [76], indicate lower biodiversity than on the newly classified reefs in the Pomeranian Bay. Also, the maximum number of taxa at a single station in the Pomeranian reef was much higher (22 taxa) than in the Słupsk reef (15 taxa) [71].

It is ecologically relevant and reasonable to assign high priority to typical species in the context of habitat quality, which, in the case of macrozoobenthos, are habitat-forming species such as *M. trossulus*. They have mainly been used to assess the habitat structure and function within the framework of the HD. Four typical species of epifauna and phytophilous organisms of habitat 1170 were identified in the Słupsk Bank Boulder Area and the Pomeranian Bay Boulder Area, with *G. locusta* also identified in the Pomeranian Bay in addition to *G. salinus*.

The Pomeranian Boulder Area meets the criterion for a dominant macrozoobenthos structure based on reef biomass and abundance, which is considerably higher than 80%. The average macrozoobenthos abundance results in this study were slightly higher than those recorded in the Słupsk Bank Boulder Area in 2019 (42,131 $\pm$ 52,482 indiv.·m^{-2}) [71], but lower than those recorded during the monitoring of the Słupsk Bank Boulder Area in 2021 (67,640 $\pm$ 33,314 indiv.·m^{-2}) [76]. The average biomass in the Pomeranian Bay Boulder Area was only slightly lower compared to the results of this parameter in the Słupsk Bank Boulder Area for 2019 (1729.62 $\pm$ 1739.43 g WW·m^{-2}) [71] and higher than the average biomass of the fouling and phytophilous fauna of the Słupsk Bank reef (1231.84 $\pm$ 580.03 g WW·m^{-2}) obtained during the 2021 monitoring survey [76]. Additionally, the number of taxa and macrozoobenthos abundance and biomass in the Pomeranian Bay Boulder Area were significantly higher than at the Rowy site, which, however, represents a much shallower coastal water body with a depth not exceeding 10 m [76].

The quantitative structure of *M. trossulus* aggregations exceeds the mean abundance and biomass of mussels observed in the Słupsk Bank Boulder Area in 2007 [77]. Among all stations examined on the hard bottom of the Pomeranian Bay, the maximum abundance (73,175 indiv.·m^{-2}) and biomass (3574.79 g WW·m^{-2}) of mussels were observed at station FB_10, which is located in the southwestern part of the study area. Considering these parameters for the Słupsk Bank Boulder Area [77], the values are comparable, slightly lower for abundance and slightly higher in the case of biomass.

Among the assessment criteria applied to the reef habitat type (1170) for the mussel zone in Estonia, the presence of at least one highly sensitive zoobenthic taxon determines a good quality value in the partial assessment of the reef [11]. In this study, as many as five phytophilous crustacean taxa were identified that are highly sensitive in the southern Baltic Sea and further contribute to the high ecological value of the Pomeranian Bay reef.

The Pomeranian Boulder Area is characterised by high macroalgal diversity. The study revealed the presence of 15 macroalgal taxa belonging to the brown algae (six taxa) and red algae (nine taxa), including protected taxa such as *F. lumbricalis* and *Ceramium* spp.

The other two habitat 1170 sites (Słupsk Bank Boulder Area, Rowy Boulder Area), located in open water, are characterised by lower diversity. Since 2020, 6 to 12 taxa have been recorded within the Słupsk Bank Boulder Area, primarily red algae, including typical taxa—*Ceramium* sp., *F. lumbicalis* and *V. fucoides*. Similar species composition and frequency were recorded in the Rowy Boulder Area—6 to 10 taxa. The boulder area located closest to the site under consideration, within the coastal zone of the Wolin National Park (WPN), is characterised by relatively low species diversity, with only 4–7 species identified. Because of the shallower depths within WPN, green algae have also been recorded, accounting for a significant proportion of the frequency [71,76,78]. This group of algae was not detected during studies in the Pomeranian Bay in 2022 and 2025.

In the Pomeranian Bay Boulder Area, the species with the highest biomass—found at every station—was *V. fudoides* (7.065 $\pm$ 5.508 g DW·m^{-2}). This red algae was also a dominant species in terms of biomass in the Rowy Boulder Area (for example, in 2021: 11.476 $\pm$ 13.396 g DW·m^{-2}) [76,78]. However, the protected species—*F. lumbricalis*, which clearly dominates biomass in the Słupsk Bank Boulder Area (for example, in 2021: 19.391 $\pm$ 24.731 g DW·m^{-2}) [71,76], i.e., at its main occurrence site, was recorded in the study area in very small quantities—below 1 g DW·m^{-2}. In the Rowy Boulder Area, this red algae achieved a lower biomass in 2021: 2.669 $\pm$ 8.204 g DW·m^{-2}.

Red algae *F. lumbricalis*, along with *V. fucoides* and the mussel *M. trossulus*, are valuable habitat-forming species found in the Słupsk Bank Boulder Area, as well as in the newly discovered Pomeranian Bay Boulder Area. Through various attachment methods, habitat-forming macroalgal species can colonise not only stones and boulders but also other plants or benthic invertebrates, such as *M. trossulus*, creating plant-animal communities that enhance the biological diversity and productivity of the water body [77].

Data collected at 11 stations were used for the natural valuation of the boulder area based on phytobenthos, which was assessed using four criteria [41]. The assessment showed that the boulder area is valuable (high class of natural values) due to the presence of macroalgal communities with five rare and two protected species (Table 11). The same assessment conducted for the Rowy Boulder Area indicated a medium class [41].

4.3. Conservation Status Assessment

In accordance with the provisions of Article 17 of the HD, the UE Member States are required to submit to the European Commission (EC), every six years, a report on the implementation of the provisions of the Directive. Part of this reporting obligation consists of reports on the conservation status of natural habitats, plant and animal species, excluding birds, of Community interest. In 2025, Poland submitted to the European Commission, for the fourth time, a report covering 2019–2024 on the conservation status of habitats, including habitat type 1170. The conservation status of the reefs in the PMAs was assessed as FV (Favourable) across all assessed parameters, including area, structure and functions, and future prospects [79]. However, this assessment did not include the newly identified reefs (Pomeranian Bay Boulder Area). A similar conservation status of the reefs was

reported in Estonia (Favourable), whereas the conservation status in Denmark and Sweden was assessed as Unfavourable-Bad (U2).

4.4. General Conservation Strategy

Maritime spatial management encompasses both socio-economic aspects (including resource allocation and exploitation, investment processes, and transport) and environmental aspects (including decisions regarding areas of high environmental value and those under legal protection) [80]. In recent years, spatial planning has become a key element of management [81–83]. Maritime spatial plans (MSPs) and marine protected areas (MPAs) are establishing two distinct area-based management processes that are often conflated. While MPA planning is crucial for biodiversity conservation and localised sustainable use, it cannot bring the benefits that larger-scale MSP can deliver [84]. The Polish MSP also poses a potential threat to the newly identified habitat, as indicated in the assessment of its conservation prospects.

Described in this paper, a compact rocky-bottom habitat, hosting rare representatives of macroalgae and characterised by high taxonomic diversity, is of considerable importance due to its habitat-forming and trophic functions. Given the scarcity of habitat 1170 in Polish marine waters, it is therefore essential to develop an adequate and targeted conservation strategy for its protection.

MPAs are widely recognised as essential tools for maintaining marine biodiversity, enhancing ecosystem resilience, and supporting human well-being. However, their effectiveness varies greatly because of substantial differences in protection levels and implementation stages across sites [85]. MPAs may be established through a sequence of stages: (i) proposed/committed by a governing or other organising body; (ii) designated by law or other authoritative rulemaking; (iii) implemented with activated regulations; and (iv) actively managed with ongoing monitoring and adaptive management [84]. In addition, MPAs differ in their level of protection: (i) fully protected—no impact from extractive or destructive activities; (ii) highly protected—minimal impact; (iii) lightly protected—moderate impact; and (iv) minimally protected—high total impact, although still an MPA by IUCN criteria [84]. Consequently, only a small fraction of global marine areas meet the criteria of strict protection under international biodiversity strategies [86]. Less than 1% of Polish marine waters meet the criteria for strict protection.

In this context, the newly identified occurrence of habitat 1170 highlights a clear mismatch between ecological value and formal conservation design. As indicated in this paper, only part of the newly discovered reefs falls within the marine protected area—Special Area of Conservation PLH990002, which was not originally designated for reef protection. That is why the habitat is not explicitly included in the Standard Data Form. A potential response would be to revise the SDF, followed by adjusting the site boundaries to extend the Natura 2000 site. A similar procedure was previously applied to the Ławica Słupska site (PLH990001), where, while preparing a conservation plan for this area, it was discovered that the reef habitats extend beyond the originally designated boundaries [71]. The administrative process proved lengthy (until 2023) [87].

A substantial proportion of MPAs globally fall into categories of partial or minimal protection, where ongoing human activities significantly reduce their conservation effectiveness compared to fully protected no-take reserves [85,86]. This issue is also relevant in the Polish context, where experience in establishing fully protected underwater nature reserves is limited, despite a few terrestrial reserves with marine components. In contrast, neighbouring countries such as Germany have implemented more strictly protected marine conservation areas in the Baltic and North Sea, including zones with restricted bottom-contact fishing in ecologically sensitive habitats [88]. These areas are characterised

by substantial spatial extent—the largest protected area in the German Baltic Sea is the Pomeranian Bay/Rønne Bank nature conservation area (NCA), measuring 2092 km^2 (with reefs covering an area of 163 km^2). The smallest area (in the German EEZ of the North Sea) is the Borkum Reef Ground NCA, measuring around 625 km^2. Reefs in this site cover approximately 23 km^2. Both NCAs are Special Areas of Conservation (SAC) under the EU Habitats Directive. Numerous studies indicate that larger, well-enforced and highly protected MPAs generally conserve biodiversity, maintain ecological processes and enhance ecosystem resilience more effectively than small or weakly protected areas [89]. The recommended size for HELCOM MPAs is >30 km^2 [90].

Taking into account the characteristics of the habitat 1170 discovered in the Pomeranian Bay (despite its relatively small size), the definition of a nature reserve in the Polish Nature Conservation Act, as well as its role in the Polish legal system of nature conservation, it seems that initiating a procedure for designating a nature reserve is an idea worth considering. In particular, criteria such as representation of crucial habitats and species, adequacy, and representativity [91] are well met in the case of the reefs in the Pomeranian Bay. This site comprises ecologically significant structures within the southern Baltic Sea, supporting a diverse assemblage of benthic organisms and fulfilling important ecological functions. The structural role of reefs as shelters for mobile species such as fish and crustaceans and as spawning grounds should not be overlooked [35]. For successful spring- and autumn-spawning of herring, the availability of suitable substrate (various aquatic plants, stones and boulders or sand and gravel) is crucial [92]. Model studies conducted to develop the maritime spatial plan for PMAs indicate that the area of habitat 1170 in the Pomeranian Bay may be optimal for herring reproduction, especially in autumn (unpublished data). Field verification of the modelling results would be necessary. Similarly, the assessment of the area's importance for seabirds requires further scrutiny. While the reefs meet key ecological criteria for conservation prioritisation, their long-term effectiveness depends on integration into a coherent and well-managed protection framework.

Effective marine biodiversity conservation depends not only on the establishment of protected areas but also on the implementation of clear and enforceable management measures that reduce human pressures. Therefore, regardless of the approach public authorities adopt, it will be essential to approve and implement documents that set out the conditions for management and conservation. MPAs alone are not sufficient to address the full range of cumulative impacts affecting marine ecosystems [84]. For example, MPAs do not per se provide shelter from fishing activities, either recreational or commercial [90]. In 2024, the EU adopted conservation measures to strengthen environmental protection in five Natura 2000 sites in the German Exclusive Economic Zone (EEZ) of the Baltic Sea. The initiative, put forward by Germany and agreed by all Baltic EU countries, prohibits fishing with mobile bottom-contacting gear in the Fehmarnbelt, Kadetrinne and Pommersche Bucht mit Oderbank and the entire sites of the Westliche Rönnebank and Adlergrund. The measures will protect sensitive seabed habitats, such as sandbanks and reefs, and will contribute to reversing the unfavourable environmental status of species and biotopes [93]. Similar formal restrictions should be considered for the newly identified habitat 1170 to maintain its favourable conservation status.

Furthermore, achieving meaningful protection requires an ecosystem-based approach that integrates marine spatial planning with cross-sectoral management of cumulative impacts [94]. As mentioned above, MSP is not intended to substitute for MPA planning or promote economic growth at the expense of biodiversity, ecosystem health, and collective human well-being. Both processes should be mutually synergistic, and ideally work in parallel and be further integrated [84]. Therefore, during the planned revision of the spatial development plan for PMAs, carried out in accordance with the Act on Maritime Areas

of the Republic of Poland and Maritime Administration [95], it is extremely important to take into account new environmental circumstances. I It is recommended to reclassify the function in the area of habitat 1170 from 'future development' to 'environmental protection and nature conservation'. In addition, the feasibility of alternative routing for offshore infrastructure (cables) should be assessed. In line with the precautionary principle, such investments should be planned in a way that minimises impacts on the ecological integrity of this newly identified reef habitat.

5. Conclusions

The actual distribution of reef habitats in PMAs remains uncertain. Bottom sonar surveys, visual surveys, and subsequent detailed biological studies in the zone up to 25 m in the southeastern part of the Pomeranian Bay allowed for identifying a valuable hard-bottom habitat in an area previously classified as coarse-grained or mixed sediments. Our study confirmed that the hard-bottom substrate in the Pomeranian Bay fulfils the criteria for reefs (code 1170 under Annex I of the HD). The characteristic reef-associated taxa were recorded, indicating high biodiversity and significant ecological value for both macrozoobenthic and macroalgal communities.

The newly identified reef is distinguished by its extensive and highly heterogeneous seabed topography, occurring relatively close to the coast and at comparatively shallow depths. De Geer moraines and kames form elongated ridges that create a mosaic of distinctive microhabitats rarely encountered in the Polish sector of the Baltic Sea. A comparable habitat configuration has been documented only at the Słupsk Bank Boulder Area. The reef extends across a transitional zone between coastal and offshore environments at depths of 12.6–24.5 m, and this combination of geomorphological complexity, spatial extent, and depth range may promote the development of distinctive biological assemblages.

Macrozoobenthos abundance and biomass in the Pomeranian Bay Boulder Area were comparable to those recorded at the largest reef in the PMAs, the Słupsk Bank Boulder Area [71]. Although both reefs are located in the infralittoral zone, with an accumulation of boulders and cobbles surrounded by sand and gravel, and with a similar depth range of up to 25 m, with a predominance of up to 20 m, the species diversity based on macrozoobenthos was much higher in the Pomeranian Bay Boulder Area than in the Słupsk Bank Boulder Area. Additionally, the occurrence of macroalgal communities with protected and rare species, as well as six highly sensitive macrozoobenthic taxa, in the Pomeranian Bay boulder field indicates the high value of this habitat. The high mussel biomass per unit seabed area in the identified site may be an important link in the trophic chain of this part of the Baltic Sea, especially as a significant food component for fish and seabirds, including long-tailed ducks and velvet scoters wintering in the Baltic.

We recommend further research, which goes beyond the scope of our study. In particular, investigations are needed to improve our understanding of the habitat's role as a fish spawning ground and its importance for birds. The potential impacts of non-native species should also be monitored. Long-term monitoring should consider both the condition of reef-forming communities and the main environmental pressures acting on them.

Given the scarcity of habitat 1170 in Polish marine waters, targeted and effective conservation measures are required to ensure its protection. Importantly, only part of the identified reef structures lies within the existing Natura 2000 site, suggesting that current protection boundaries do not fully reflect this habitat distribution. This may justify reassessing the boundaries or designating an additional strictly protected area (marine reserve). The results may also help evaluate progress towards national restoration and

conservation targets, including the implementation of biodiversity recovery objectives (30% protection and 10% strict protection targets).

The current maritime spatial plan does not adequately account for the actual distribution of reef habitats. The findings have direct implications for marine spatial planning and highlight the need to integrate updated habitat data into decision-making processes.

High-resolution bathymetric data form the basis for precise habitat identification and mapping. Currently, comprehensive high-resolution bathymetric coverage is not available for the whole southern Baltic Sea. Based solely on general bathymetric data (e.g., navigational charts), the reliable identification of habitat 1170 is not possible. Therefore, systematic acquisition of high-resolution bathymetric data at depths of up to approximately 30 m is strongly recommended to identify and map this habitat type. Such habitats may occur either as extensive seabed areas or as isolated patches/elevations with a surface area only slightly exceeding 100 m^2.

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Abbreviations

The following abbreviations are used in this manuscript:

AIS	Automatic Identification System used by vessel traffic services
EEZ	Exclusive Economic Zone
EU	European Union
FV	Favourable status
g WW	Grams of wet weight
g DW	Grams of dry weight
HD	Habitat Directive
IUCN	International Union for Conservation of Nature
MPAs	Marine protected areas
MSP	The Maritime Spatial Plan of the Polish Internal Sea Waters, Territorial Sea and Exclusive Economic Zone

NCA	Nature conservation area
NRL	Nature Restoration Law
OWF	Offshore wind farm
PMAs	Polish marine areas
ROV	Remotely operated vehicle
SAC	Special Areas of Conservation
SDF	Standard Data Form
U1	Unfavourable inadequate status
U2	Unfavourable bad status
WoRMS	World Register of Marine Species
WPN	Wolin National Park

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