Landscape-based approach to identification of shallow seabed habitats. Case study: central sector of the Bulgarian Black Sea coastal zone

ABSTRACT

The study represents an attempt to correlate three popular broad-scale marine benthic habitat classification systems with such developed by the author. The focus is on the diversity of shallow submarine landscapes found within the central sector of the Bulgarian Black Sea coastal zone. The core of the investigation is a landscape-based identification and subsequent classification of the seabed complexes occupying the shallow marine area between cape Kaliakra and cape Emine, Bulgarian Black Sea coastal zone. A GIS-aided synthesis of the submarine landscape units was applied based on available graphic and narrative data about the main components and factors of the seabed environment, e.g. seafloor lithology and geomorphology, bathymetry, intensity of the wave-induced sediment transport, trends in the prevailing geomorphodynamic processes, dominant benthic biota etc. The proposed landscape classification scheme comprises 82 kinds aggregated hierarchically in 7 genera, 4 types and 2 classes. Subsequent step of the research was to correlate the developed classification system with these of the seabed habitats enlisted in Council Directive 92/43/EEC (Habitats Directive), Directive 2008/56/EC (Marine Strategy Framework Directive), and Volume 3 (Natural Habitats) of the Bulgarian Red Data Book. The cited correlation was performed at the lowest taxonomic level (landscape kind) and visualized as GIS-compiled maps of the submarine landscape units and the associated benthic habitat types. Results obtained during the correlation process revealed a good relationship between the principal abiotic landscape properties and the physical characteristics of the seabed habitats.

Key words: marine landscape studies, seabed landscape units, marine habitat mapping and analysis, geographic information systems (GIS)

Introduction

The landscape-based approach in studying the seabed represents an interdisciplinary, complex-based methodology for mapping, analysis and cartographic representation of the benthic environment at a given marine sector. This theoretical concept treating the nature of the seabed as an integrated geosystem, when applied in the organization of available data in a geographic information system (GIS), provides well-structured storage and rapid successive interpretation of all main components and factors that comprise the submarine environment. Nevertheless, while the issues concerning proper integrated coastal zone management and ecosystem-based marine spatial planning remain an open question in Republic of Bulgaria, the overall amount of landscape-oriented studies with focus on the national Black Sea sector remains rather insufficient (Mihova, 1989; 1994; Kotsev & Keremedchiev, 2012; Prodanov et al., 2014; Kotsev, 2015) and largely contrasts with the impressive volume of specialized oceanographic investigations in the field of marine geology, geomorphology, geophysics, ecology, biology etc. accumulated over the years. Even scarcer is the total number of published works concerning benthic habitat mapping in the Bulgarian Black Sea (e.g. Kotsev et al., 2012;
Todorova et al., 2013; 2015; Prodanov et al., 2014 etc.). Hence, the aim of the current article is to identify the habitats within the submarine coastal slope stretching between cape Kaliakra and cape Emine (central sector of the Bulgarian Black Sea coastal zone) by applying a landscape-based approach and thus also elucidating the present-day seabed landscape pattern of the cited sublittoral sector. In this study, the term submarine (or seabed / benthic) landscape refers to a spatially defined portion of the seabed, a geo-ecocomplex that is genetically uniform and consists of homogeneous (or a group of homogeneous) lithologic varieties, landforms and associated benthic biological communities found at particular depth, has definite natural resource potential and is influenced to a certain extent by anthropogenic activity. In addition, with a few exclusions, the author adopts the term benthic (or seabed/submarine) habitat as applied by Todorova et al. (2015) for description of the abiotic seabed environment in a precise location.

**Description of the study area**

The investigated sublittoral sector occupies the portion of the submarine coastal slope stretching between Bolata Cove near cape Kaliakra on north and Cockatrice sandbank near cape Emine on south (Figure 1), having a total planimetric area of approximately 39,720ha and off-the-coastline width varying between 1.9 and 8.3km, while maximum depths reach values of 42m south from cape Emine at the foot of Cockatrice sandbank.

The seabed substrates are presented mainly by loose sediments (e.g. varying in grain size sand, shelly sand, sandy silt and silt), additionally diversified by solid lithologic varieties dominated by sedimentary rocks, namely limestones, sandstones, marls, conglomerates etc. (Peychev, 2004). The benthic relief represents a mosaic of contemporary and relic landforms and is mostly of accumulative or structural-accumulative type, thereby dominated by wave-formed sandy bars, accumulative and structural-accumulative slopes, structural-accumulative terraces, structural depressions, accumulative platforms etc. The seabed topography is additionally diversified by presence of abrasive and some azonal morphologic features, e.g. plantigrade slopes of structural, landslide or landslide-collapse genesis, structural-abrasive terraces, rocky banks, geogenic reefs etc. (Peychev & Dimitrov, 2012). Among the significant features of the submarine environment is the importance of the depth zonality, as well as the central landscape-forming role of the benthic biota. Nevertheless, the spatial occurrence and distribution of the macrobenthic biological communities is in rather strong relation to the abiotic components and factors of the seabed nature, e.g. rock types, grain size of the loose deposits, intensity of the wave-induced sediment transport, hydrodynamic activity, depths and light availability etc. (Todorova et al., 2013). The psammophilous infaunal assemblages are mostly dominated by clams belonging to families *Mesodesmatidae* (Donacilla cornea), *Donaciidae* (Donax trunculus), *Corbulidae* (*Lenthidium mediterraneum*), *Veneridae* (*Chamelea gallina*, *Tellinidae* (*Tellina tenuis*), while the sectors with shelly sand and gravels are populated by bivalves from *Mytilidae* (*Gibbomodiola adriatica*, *Veneridae* (*Gouldia minima*) etc. The deeper seabed areas with sandy silt and silt are inhabited by representatives of *Mactridae* (*Spisula subtruncata*), *Semelidae* (*Abra alba*), *Cardiidae* (*Parvicardium exiguum*) etc., as well as by burrowing thalassinidean shrimps (e.g. *Upogebia pusilla*). The invertebrate macrofauna of the rocky seabed in the mediolittoral and the shallow sublittoral zone is normally dominated by communities of *Mytilid* mussels (*Mytilus galloprovincialis* and *Mytilaster lineatus*) and barnacles (*Balanus improvisus*, *Balanus eburneus* and *Chthamalus stellatus*), gradually turning into monodominant communities of *Mytilus galloprovincialis* with increase of depth (Todorova, 2011a; Todorova & Panayotova, 2011a). Undoubtedly, the most characteristic feature of the deeper submarine sectors are the sublittoral mussel beds of *Mytilus galloprovincialis* on sediments, varying from coarse and shelly sand to sandy silt and silt (Todorova & Panayotova, 2011b). Certain azonal features concerning their spatial occurrence and distribution (and probably strongest dependence on the seabed substrate type) are demonstrated by a few species of rock-boring clams, e.g. *Pholas dactylus* and *Barnea candida* (*Pholadidae*), which populate marls, flysch and solid clays, as well as by *Petricola lithophaga* (*Veneridae*), found exclusively at underwater sectors with limestones or other calcareous-rich lithology (Todorova et al., 2013). Finally, the dominant macroalgal flora is presented mainly by annual communities of green and red algae, as well as by *Cystoseira* sp. at the rocky seabed areas with clean waters, decreased turbidity and improved light availability (Berov et al., 2010; 2012; Todorova & Panayotova, 2011c).
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Materials and Methods

Several graphic and descriptive data sources were used in the process of the GIS-aided submarine spatial analysis for identification and subsequent interpretation of the geo-components forming the study area’s landscape and habitat pattern. These include fine-resolution aerial orthophoto images, ESRI shape files on seabed lithology, bathymetric contours, scanned maps of the seafloor landforms etc., as well as limited narrative and point GIS data concerning the dominant macrobenthic communities.

All graphic data enlisted in Table 1 were integrated, processed and subsequently interpreted in Arc Editor 9.3.1 and Global Mapper 13 GIS software environment (Figure 2). Second step of the analysis was taxonomic grouping of the identified submarine landscape units into hierarchic categories, applying a four-level classification system developed by the author for the central sector of the Bulgarian Black Sea coastal zone (Kotsev, 2014). Main aspects of the cited categorization criteria are summarized in Table 2. Concluding stage of the GIS-aided interpretations was to correlate the developed landscape classification scheme with the seabed habitats enlisted in Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (1992), Directive 2008/56/EC Marine Strategy Framework Directive (Relationship between the initial assessment of marine waters…., 2011), and Volume 3 (Natural Habitats) of the Bulgarian Red Data Book (Todorova, 2011a; b; Todorova & Panayotova, 2011a; b, c, d). The cited correlations were performed at the lowest taxonomic level (landscape kind) and visualized as GIS maps of the submarine landscape units and the associated benthic habitat types, compiled at scale 1:50,000. Criteria used during the correlation process were the principal abiotic properties of the investigated sublittoral sector, e.g. spatial extent and occurrence of the seabed substrates and landforms (Kotsev et al., 2012), bathymetry (Todorova et al., 2015), distribution depths, trends in the prevailing geomorphodynamic processes (abrasion or accumulation) and coastal exposure to wave action. The identified habitat types were additionally verified by consulting distribution maps provided in relevant articles of the Bulgarian Red Data Book.
Table 1. List of the initial data used in the process of the GIS-aided seabed landscape and habitat analysis

<table>
<thead>
<tr>
<th>Name of the initial data set/source/hard-copy map</th>
<th>Data format</th>
<th>Spatial resolution/minimum mapping unit/map scale</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial orthophoto images covering the coastal zone between cape Kaliakra and cape Emine</td>
<td>tiff (raster)</td>
<td>0.5m</td>
<td><a href="http://gis.mrrb.government.bg/MRRB">http://gis.mrrb.government.bg/MRRB</a></td>
</tr>
<tr>
<td>Seabed lithology of the submarine coastal slope between cape Kaliakra and cape Emine</td>
<td>ESRI shape file (vector)</td>
<td>1:5,000</td>
<td>Department “Coastal zone dynamics” at IO-BAS</td>
</tr>
<tr>
<td>Bathymetric contours</td>
<td>ESRI shape file (vector)</td>
<td>2m</td>
<td>Department “Coastal zone dynamics” at IO-BAS</td>
</tr>
<tr>
<td>Point data on dominant macrobenthic biological communities</td>
<td>ESRI shape file (vector)</td>
<td>N/A</td>
<td>Department “Biology and ecology of the sea” at IO-BAS</td>
</tr>
<tr>
<td>Seabed morphologic and geomorphodynamic maps of the submarine coastal slope between cape Kaliakra and cape Emine</td>
<td>tiff (raster)</td>
<td>1:10,000</td>
<td>Keremedchiev, 2013 (personal archive)</td>
</tr>
<tr>
<td>Maps with point distribution of seabed habitat types of nature conservation interest</td>
<td>tiff (raster)</td>
<td>N/A</td>
<td>Online version of Bulgarian Red Data Book, Vol 3 (Natural Habitats), 2011</td>
</tr>
<tr>
<td>Locations of aquaculture installations &amp; stationary pound nets along the central sector of the Bulgarian Black Sea coastal zone</td>
<td>Excel tables</td>
<td>N/A</td>
<td><a href="http://www.iara.government.bg">www.iara.government.bg</a></td>
</tr>
</tbody>
</table>

Figure 2. Simplified flowchart of the GIS procedures carried out in Arc Editor 9.3.1 and Global Mapper 13 software environment.
Table 2. Main features of the applied landscape hierarchic categorization criteria (Kotsev, 2014)

<table>
<thead>
<tr>
<th>Hierarchic category</th>
<th>Conditionally natural submarine landscapes</th>
<th>Anthropogenic submarine landscapes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landscape class</td>
<td>Macrogemorphologic criteria (macro-relief of the seabed, e.g. <em>Landscapes of the submarine coastal slope</em>)</td>
<td>Introduced for better hierarchic correlation with the classification scheme of the conditionally natural submarine landscapes; one single class, namely <em>Anthropogenic submarine landscapes</em></td>
</tr>
<tr>
<td>Landscape type</td>
<td>Intensity of the wave-induced sediment transport and intensity of the geomorphodynamic processes within the submarine coastal slope</td>
<td>Level of alteration of the seabed complex (e.g. <em>Landscapes with significant to complete transformation of the natural complex</em>)</td>
</tr>
<tr>
<td>Landscape genus</td>
<td>Trends in the geomorphodynamic processes (e.g. abrasion or accumulation) and distribution depths of the landscape units</td>
<td>Trends in the geomorphodynamic processes (e.g. abrasion or accumulation) as a result of the anthropogenic intervention (often irreversible), or used as a category heading for a group of entirely artificial seabed elements</td>
</tr>
<tr>
<td>Landscape kind</td>
<td>An underwater complex formed by relatively uniform seabed landforms, sublittoral substrate types and associated dominant macrobenthic biological communities, found at particular depths and constructing altogether the submarine landscape’s vertical structure</td>
<td>Indication of the particular anthropogenic landscape kinds that often coincide with given marine use categories, e.g. <em>port areas, navigable canals, stationary pound nets</em> etc.</td>
</tr>
</tbody>
</table>

Results

*Present-day seabed landscape diversity of the study area.*

The submarine landscape diversity of the investigated sublittoral region consists of 82 kinds united in 7 genera, 4 types and 2 classes. Detailed list concerning the hierarchic categories comprising the proposed classification system is provided as Appendix 1. Figure 3 illustrates a map example of the landscape units within the submarine coastal slope in front of Kamchia Depression.

The seabed landscape pattern is ubiquitously dominated by accumulative and structural-accumulative complexes, found in the weakly active and inactive (in geomorphodynamic sense) zones, distributed at depths greater than 10m. The submarine anthropogenic landscape units are concentrated exclusively within the relatively shallow near-shore areas contiguous to the recreational, harbor and port zones in front of the coastal towns of Kavarna, Balchik, Varna, Byala and Obzor, as well as at the coastline sections with hydrotechnical structures present, occupying approximately 7.2% of the investigated sublittoral sector (Figure 4).

Seabed habitats of the study area and correlations with the identified landscape complexes

The identified habitat types can be united in six large groups based on their lithologic characteristics and distribution depths, namely mediolittoral sands, mediolittoral rocks and reefs, shallow sublittoral sands, shallow sublittoral mud, shallow sublittoral rocks and reefs and shelf sublittoral rocks and reefs. The sixth category is normally differentiated at depths greater than 30m (Todorova et al., 2015). Apart from rocky seabed sectors, the last two habitat types (shallow sublittoral rocks and reefs and shelf sublittoral rocks and reefs) also include areas with mussel beds on sediments, which, despite being representative examples of accumulative submarine landscapes, in terms of habitat mapping are classified as biogenic reefs (Todorova & Panayotova, 2011b; Todorova et al., 2013). The criteria for delineation of the marine mediolittoral (or pseudolittoral) zone are discussed by Mokiyevski (1960) and applied in practice by Todorova et al. (2013). According to the authors, since the Black Sea is a non-tidal basin, the spatial extent of the mediolittoral overlaps with the surf zone, demarcated by the wave-breaking zone from the marine side and the swash zone from...
the terrestrial side, having an average aqueous width of 9.3 m at sandy sectors and 121 m at rocky types of coast. Due to the regional peculiarities of several natural and anthropogenic factors (e.g. coastal lithology, topography, bathymetry, coastal exposure, hydrodynamics, presence of hydro-technical structures etc.), the mean width of the Bulgarian Black Sea mediolittoral zone varies greatly in latitudinal direction. Hence, its proper delineation dictates the necessity of further finer-scale bathymetric investigations (preferably at scale 1:5,000 or better) in order to separate the corresponding habitats from those pertaining to the shallow sublittoral zone.

The results obtained clearly demonstrate that the studied sector is dominated by habitats of the shallow sublittoral mud (14,081.4 ha or 35.45% of the study area) and such of the shallow sublittoral sands (12,987.9 ha or 32.70% of the study area), which is in agreement with the geologic and geomorphologic setup of the submarine sector, whose pattern is characterized by ubiquitous presence of accumulative and structural-accumulative seabed complexes. Detailed list of the performed habitat correlations on taxonomic level submarine landscape kind are provided in Table 3, together with data on absolute and relative spatial coverage of the identified habitat types.

Figure 5 represents an example map of the identified habitats within the submarine coastal slope in front of Kamchia Depression.

![Figure 3. Map example of the seabed landscape units identified within the submarine coastal slope in front of Kamchia Depression.](image-url)
Discussion

Results of the study confirm previously published works that the landscape pattern of the shallow seabed sector stretching between capes Kaliakra and Emine is dominated by accumulative and structural-accumulative complexes with loose sublittoral substrates (e.g. Mihova, 1989; Peychev, 2004; Peychev & Dimitrov, 2012 etc.). These are formed typically in the weakly active and inactive in geomorphodynamic sense sectors of the submarine coastal slope, which is in agreement with the general geologic and geomorphologic setup of the area. Correct interpretations of the seabed lithologic pattern and landforms are recognized as crucial fundamentals of submarine landscape and habitat mapping (e.g. Mortensen et al., 2009; Thorsnes et al., 2009; Todorova et al., 2015 etc.). Nevertheless, further, much finer-scale mapping procedures and subsequent thorough interpretations of the seabed environment are required in order to produce more reliable data sets concerning the seabed terrain, lithology and depths. Among other advantages, this would make possible the correct delineation of the mediolittoral zone and may also facilitate the demarcation of the lower boundary of the submarine coastal slope, thereby optimizing the identification of the corresponding underwater landscapes and habitats. Nevertheless, the proposed landscape-based approach represents and innovative method for studying the benthic environment.

Due to insufficient spatial resolution, certain imperfections characterize the geo-data used, which consequently reflected upon the level of confidence of the results obtained, with GIS layers on dominant macrobenthic communities and bathymetry being the weakest components of the submarine landscape and habitat analyses.

As already discussed in the previous sections of the current text, finer-scale bathymetric mapping campaigns are needed in order to produce more reliable data sets concerning the seabed terrain, lithology and depths. Among other advantages, this would make possible the correct delineation of the mediolittoral zone and may also facilitate the demarcation of the lower boundary of the submarine coastal slope, thereby optimizing the identification of the corresponding underwater landscapes and habitats. Nevertheless, the proposed landscape-based approach represents and innovative method for studying the benthic environment.

Figure 4. Relative coverage of the identified submarine landscape genera (as percentage of the studied seabed sector).

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<tbody>
<tr>
<td>1.1 – 1.6, 2.1 – 2.7; 2.9 – 2.10; 2.12 – 2.13; 2.16-2.17</td>
<td>02A2 Littoral sands and muddy sands / 10A4 Sublittoral sands</td>
<td>1140 Mudflats and sand flats not covered by seawater at low tide / 1110 Sandbanks which are slightly covered by sea water all the time</td>
<td>Littoral sediments / Shallow sublittoral sands</td>
<td>2,147.6</td>
<td>5.41</td>
</tr>
<tr>
<td>2.8; 2.11; 2.14; 3.1-3.2; 4.1-4.5; 4.8-4.12; 4.15-4.16; 5.1-5.5; 5.10-5.15; 5.17-5.18</td>
<td>10A4 Sublittoral sands</td>
<td>1110 Sandbanks which are slightly covered by sea water all the time</td>
<td>Shallow sublittoral sands</td>
<td>12,987.9</td>
<td>32.7</td>
</tr>
<tr>
<td>2.15; 4.13; 5.6; 5.16</td>
<td>Not enlisted</td>
<td>Not enlisted</td>
<td>Shallow sublittoral mud</td>
<td>14,081.4</td>
<td>35.45</td>
</tr>
<tr>
<td>4.6-4.7</td>
<td>10A4 Sublittoral sands / 07A3 Infralittoral rocks and other hard substrates</td>
<td>1110 Sandbanks which are slightly covered by sea water all the time / 1170 Reefs</td>
<td>Shallow sublittoral sands / Shallow sublittoral rocks and biogenic reefs</td>
<td>30.3</td>
<td>0.08</td>
</tr>
<tr>
<td>1.12</td>
<td>07A3 Infralittoral rocks and other hard substrates</td>
<td>1170 Reefs</td>
<td>Littoral rocks and biogenic reefs / Shallow sublittoral rocks and biogenic reefs</td>
<td>24.1</td>
<td>0.06</td>
</tr>
<tr>
<td>1.9</td>
<td>01A1 Black mussels and/or barnacle communities on mediolittoral rocks</td>
<td>1170 Reefs</td>
<td>Littoral rocks and biogenic reefs / Shallow sublittoral rocks and biogenic reefs</td>
<td>423.9</td>
<td>1.07</td>
</tr>
<tr>
<td>1.7-1.8; 1.13</td>
<td>01A1 Black mussels and/or barnacle communities on mediolittoral rocks / 08A3 Cystoseira spp. On exposed to waves infralittoral bedrock and boulders</td>
<td>1170 Reefs</td>
<td>Littoral rocks and biogenic reefs / Shallow sublittoral rocks and biogenic reefs</td>
<td>360.3</td>
<td>0.91</td>
</tr>
<tr>
<td>1.10-1.11’</td>
<td>07A3 Infralittoral rocks and other hard substrates / 08A3 Cystoseira spp. On exposed to waves infralittoral bedrock and boulders</td>
<td>1170 Reefs</td>
<td>Littoral rocks and biogenic reefs / Shallow sublittoral rocks and biogenic reefs</td>
<td>735.1</td>
<td>1.85</td>
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<tr>
<td>3.4; 3.6-3.7; 5.19; 5.24</td>
<td>07A3 Infralittoral rocks and other hard substrates / 08A3 Cystoseira spp. On exposed to waves infralittoral bedrock and boulders</td>
<td>1170 Reefs</td>
<td>Shallow sublittoral rocks and biogenic reefs</td>
<td>813.3</td>
<td>2.05</td>
</tr>
<tr>
<td>3.3; 3.5; 5.20-5.21; 5.23</td>
<td>07A3 Infralittoral rocks and other hard substrates</td>
<td>1170 Reefs</td>
<td>Shallow sublittoral rocks and biogenic reefs</td>
<td>490.5</td>
<td>1.23</td>
</tr>
<tr>
<td>4.14</td>
<td>11A4 Sublittoral mussel beds on sediments</td>
<td>1170 Reefs</td>
<td>Shallow sublittoral rocks and biogenic reefs</td>
<td>98.0</td>
<td>0.25</td>
</tr>
<tr>
<td>5.7-5.9</td>
<td>11A4 Sublittoral mussel beds on sediments</td>
<td>1170 Reefs</td>
<td>Shallow sublittoral rocks and biogenic reefs / Shelf sublittoral rocks and biogenic reefs</td>
<td>4,091.0</td>
<td>10.3</td>
</tr>
<tr>
<td>5.22</td>
<td>07A3 Infralittoral rocks and other hard substrates (category partially overlapping, reaching 30m of depth)</td>
<td>1170 Reefs</td>
<td>Shallow sublittoral rocks and biogenic reefs / Shelf sublittoral rocks and biogenic reefs</td>
<td>313.2</td>
<td>0.79</td>
</tr>
</tbody>
</table>
Acknowledgement

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Figure 5. Map example of the benthic habitat types within the submarine coastal slope in front of Kamchia Depression
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References


Appendix 1.
Detailed classification scheme of the identified submarine landscape units

NB: A-B – landscape classes; 1-IV - landscape types; 1-7 - landscape genera; 1.1-7.3 – landscape kinds

A. Landscapes of the submarine coastal slope

1. Landscapes of the geomorphodynamically active zone

1.1. Abrasive landscapes at structural slopes, with coarse sand and infauna dominated by Donacidae, Veneridae etc. clams, developed at depths 3-7m; 1.2. Abrasive landscapes at structural slopes, with medium sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 3-7m; 1.3. Abrasive landscapes at structural slopes, with fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 2-10m; 1.4. Abrasive landscapes at landslide and landslide-collapse plantigrade slopes, with coarse sand and infauna dominated by Donacidae, Veneridae etc. clams and Polychaeta worms, developed at depths 3-7m; 1.5. Abrasive landscapes at landslide and landslide-collapse plantigrade slopes, with medium sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 2-10m; 1.6. Abrasive landscapes at landslide and landslide-collapse plantigrade slopes, with unsorted medium and fine sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 2-10m; 1.7. Abrasive landscapes at landslide-structural-plantigrade slopes of conglomerates overgrown by Mytilidae mussels and Cystoseira brown algae, developed at depths 0-10m; 1.8. Abrasive landscapes at landslide-structural-plantigrade slopes of sandstones overgrown by Mytilidae mussels and Cystoseira brown algae, developed at depths 0-10m; 1.9. Landscapes of the geogenic reefs and rocky banks of sandstones overgrown by Mytilidae mussels and green and red annual algal communities, developed at depths 0-10m; 1.10. Abrasive landscapes at landslide-structural-plantigrade slopes of flysch, with communities of Pholadidae rock-boring clams and overgrown by Cystoseira brown algae, developed at depths 0-10m; 1.11. Abrasive landscapes at landslide-structural-plantigrade slopes of marls, with communities of Pholadidae rock-boring clams and overgrown by Cystoseira brown algae, developed at depths 0-10m; 1.12. Abrasive landscapes at landslide-structural-plantigrade slopes of marls, with communities of Pholadidae rock-boring clams and overgrown by green and red annual algal communities, developed at depths 0-10m; 1.13. Abrasive landscapes at landslide-structural-plantigrade slopes of limestones, with communities of Veneridae rock-boring clams and overgrown by Mytilidae mussels and Cystoseira brown algae, developed at depths 0-10m

2. Accumulative (incl. structural-accumulative) landscapes at depths 0-10m and rarely reaching 15m:

2.1. Accumulative forebeach landscapes, with unsorted coarse and medium sand and infauna dominated by Mesodesmatidae, Donacidae etc. clams and Polychaeta worms, developed at depths 0-7m; 2.2. Accumulative forebeach landscapes, with medium sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 3-7m; 2.3. Accumulative forebeach landscapes, with fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 0-7m; 2.4. Accumulative landscapes at wave-formed bars, with medium sand and infauna dominated by Mesodesmatidae, Donacidae etc. clams and Polychaeta worms, developed at depths 0-7m; 2.5. Accumulative landscapes at wave-formed bars, with coarse sand and infauna dominated by Donacidae, Veneridae etc. clams and Polychaeta worms, developed at depths 3-7m; 2.6. Accumulative landscapes at wave-formed bars, with medium sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 3-7m; 2.7. Accumulative landscapes at wave-formed bars, with fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 0-10m; 2.8. Accumulative landscapes at wave-formed bars, with sandy silt and burrows of...
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thalassinidean shrimps or infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 7-10m; 2.9. Accumulative landscapes at contemporary submarine terraces, with unsorted coarse and medium sand and infauna dominated by Mesodesmatidae, Donacidae etc. clams and Polychaeta worms, developed at depths 0-7m; 2.10. Accumulative landscapes at contemporary submarine terraces, with fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 3-7m; 2.11. Slope-accumulative landscapes, with coarse sand and infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 10-15m; 2.12. Slope-accumulative landscapes, with medium sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 3-7m; 2.13. Slope-accumulative landscapes, with fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 0-15m; 2.14. Slope-accumulative landscapes, with sandy silt and burrows of thalassinidean shrimps or infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 7-10m; 2.15. Slope-accumulative landscapes, with silt and infauna dominated by Veneridae, Mactridae, Semelidae, Cardiidae etc. clams, developed at depths 10-15m; 2.16. Geostucturally formed accumulative landscapes, with coarse sand and infauna dominated by Mesodesmatidae, Donacidae etc. clams and Polychaeta worms, developed at depths 0-7m; 2.17. Geostucturally formed accumulative landscapes, with fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 0-15m

II. Landscapes of the weakly active zone

3. Abrasive (incl. structural-abrasive) landscapes at depths 5-15m and rarely reaching 20m:

3.1. Abrasive landscapes at structural terraces, with medium sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 5-10m; 3.2. Abrasive landscapes at structural terraces, with unsorted medium and fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 5-10m; 3.3. Landscapes of the geogenic reefs and rocky banks of sandstones overgrown by Mytilidae mussels and green and red annual algal communities, developed at depths 5-10m; 3.4. Landscapes of the geogenic reefs and rocky banks of sandstones overgrown by Mytilidae mussels and Cystoseira brown algae, developed at depths 8-15m; 3.5. Landscapes of the rocky banks of sandstones overgrown by Mytilidae mussels, sponges, hydrozoans etc., developed at depths 10-20m; 3.6. Landscapes of the geogenic reefs and rocky banks of flysch, with communities of Pholadidae rock-boring clams and overgrown by Cystoseira brown algae, developed at depths 5-15m; 3.7. Landscapes of the rocky banks of marls, with communities of Pholadidae rock-boring clams and overgrown by Cystoseira brown algae, developed at depths 5-15m

4. Accumulative (incl. structural-accumulative) landscapes at depths 5-20m and rarely reaching 30m:

4.1. Landscapes of the sand bars of medium sand with infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 10-12m; 4.2. Landscapes of the sand bars of sandy silt with burrows of thalassinidean shrimps or infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 10-12m; 4.3. Landscapes of the structural bars of coarse sand with infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 10-20m; 4.4. Geostucturally formed slope-accumulative landscapes, with coarse sand and infauna dominated by Donacidae, Veneridae, Tellinidae etc. clams, developed at depths 7-15m; 4.5. Geostucturally formed slope-accumulative landscapes, with coarse sand partially covered by blocks, boulders and shells overgrown by Mytilidae mussels, green and red annual algal communities and infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 5-7m; 4.6. Geostucturally formed slope-accumulative landscapes, with medium sand partially covered by blocks, boulders and shells overgrown by Mytilidae mussels, green and red annual algal communities and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 8-12m; 4.7. Geostucturally formed slope-accumulative landscapes, with medium (rarely heterogeneous) sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 5-15m; 4.8. Geostucturally formed slope-accumulative landscapes, with medium (rarely heterogeneous) sand and infauna dominated by Donacidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 8-15m; 4.9. Geostucturally formed slope-accumulative landscapes, with unsorted medium and fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 8-15m; 4.10. Geostucturally formed slope-accumulative landscapes, with fine sand and infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 15-20m; 4.11. Geostucturally formed slope-accumulative landscapes, with fine sand and infauna dominated by Mytilidae, Veneridae, Tellinidae etc. bivalves, developed at depths 20-30m; 4.12. Geostucturally formed slope-accumulative landscapes, with sandy silt and burrows of thalassinidean shrimps or infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 10-20m; 4.13. Geostucturally formed slope-accumulative landscapes, with silt and infauna dominated by Veneridae, Mactridae, Semelidae, Cardiidae etc. clams and Polychaeta worms, developed at depths 10-15m; 4.14. Geostucturally formed slope-accumulative landscapes, with unsorted sand and epifaunal mussel beds of Mytilus galloprovincialis, developed at depths 15-25m; 4.15. Accumulative...
III. Landscapes of the inactive deep-water zone

5. Accumulative (incl. structural-accumulative) landscapes at depths 10-30m and rarely reaching 42m:

5.1. Slope-accumulative and platform-accumulative landscapes with unsorted coarse and fine sand and infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 15-20m; 5.2. Slope-accumulative and platform-accumulative landscapes, with medium sand and infauna dominated by Donaciidae, Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 10-15m; 5.3. Slope-accumulative and platform-accumulative landscapes, with fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 10-15m; 5.4. Slope-accumulative and platform-accumulative landscapes, with unsorted shelly sand and infauna dominated by Mytilidae, Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 20-42m; 5.5. Slope-accumulative and platform-accumulative landscapes, with sandy silt and burrows of thalassinidean shrimps or infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 20-30m; 5.6. Slope-accumulative and platform-accumulative landscapes, with silt and infauna dominated by Veneridae, Mactridae, Semelidae, Cardiidae etc. clams and Polychaeta worms, developed at depths 10-30m; 5.7. Slope-accumulative and platform-accumulative landscapes, with unsorted sand and epifaunal mussel beds of Mytilus galloprovincialis, developed at depths 20-42m; 5.8. Slope-accumulative and platform-accumulative landscapes, with sandy silt and epifaunal mussel beds of Mytilus galloprovincialis, developed at depths 20-42m; 5.9. Slope-accumulative and platform-accumulative landscapes, with silt and epifaunal mussel beds of Mytilus galloprovincialis, developed at depths 12-42m; 5.10. Geostructurally formed accumulative landscapes at structural terraces, with coarse sand and infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 12-20m; 5.11. Geostructurally formed accumulative landscapes at structural terraces, with unsorted shelly sand and infauna dominated by Mytilidae, Veneridae, Tellinidae etc. bivalves, developed at depths 20-25m; 5.12. Geostructurally formed accumulative landscapes at structural slopes and structural depressions, with unsorted coarse and medium sand and infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 12-20m; 5.13. Geostructurally formed accumulative landscapes at structural slopes and structural depressions, with unsorted medium and fine sand and infauna dominated by Corbulidae, Veneridae, Tellinidae, Arcidae etc. clams, developed at depths 12-15m; 5.14. Geostructurally formed accumulative landscapes at structural slopes and structural depressions, with unsorted shelly sand and infauna dominated by Mytilidae, Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 20-25m; 5.15. Geostructurally formed accumulative landscapes at structural slopes and structural depressions, with sandy silt and burrows of thalassinidean shrimps or infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 13-20m; 5.16. Geostructurally formed accumulative landscapes at structural slopes and structural depressions, with silt and infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 12-20m; 5.17. Landscapes of the structural bars, with coarse sand and infauna dominated by Veneridae, Tellinidae etc. clams and Polychaeta worms, developed at depths 12-20m; 5.18. Landscapes of the structural bars, with sandy silt and burrows of thalassinidean shrimps or infauna dominated by Veneridae, Tellinidae etc. clams, developed at depths 12-20m; 5.19. Landscapes of the rocky banks of conglomerates overgrown by Mytilidae mussels and Cystoseira brown algae, developed at depths 10-15m; 5.20. Landscapes of the rocky banks of sandstones overgrown by Mytilidae mussels and green and red annual algal communities, developed at depths 10-12m; 5.21. Landscapes of the geogenic reefs and rocky banks of sandstones overgrown by Mytilidae mussels, sponges, hydrozoans etc., developed at depths 12-20m; 5.22. Landscapes of the rocky banks of sandstones with epifaunal mussel beds of Mytilus galloprovincialis, developed at depths 22-42m; 5.23. Landscapes of the rocky banks of flysch, with communities of Pholadidae rock-boring clams developed at depth 10-20m; 5.24. Landscapes of the rocky banks of marls, with communities of Pholadidae rock-boring clams and Cystoseira brown algae, developed at depth 10-12m

B. Class anthropogenic submarine landscapes

IV. Landscapes with significant to full modification of the seabed substrates and the associated macrobenthic biological communities

6. Accumulative anthropogenic landscapes:

6.1. Accumulative landscapes in the wave-shadow zone near hydrotechnical structures; 6.2. Port and harbor areas

7. Landscapes with significant to complete transformation of the natural complex:

7.1. Navigable canals; 7.2. Stationary pound nets; 7.3. Aquaculture installations

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