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Coastal typology based on benthic biotope and community data: The Lithuanian case study

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Abstract

The proposed typology is based on the analysis of the abiotic conditions, benthic biotope and community data obtained in the Lithuanian part of the south-eastern Baltic coastal zone and in the Curonian Lagoon. The classification approach is hierarchical, comprising three main levels: coastal type, benthic biotope and benthic macrofauna community. The core of the classification system is a benthic biotope, which is defined as a distinctive sea bottom area with conventionally uniform physical-chemical environment (salinity, substrate, hydrodynamics, light climate, temperature regime, etc.) and matching biological features. A coastal type is characterized as a biotope complex, i.e. a part of the coastal zone comprising several neighbouring interrelated biotopes. Various coastal types may include identical biotopes, however the combination and spatial distribution of the biotopes in each coastal type is different. Qualitative and quantitative data on benthic communities are used for characterization of relevant benthic biotopes. Possibility to use the existing biotope classification systems (e.g. HELCOM 1998; EUNIS 2004) for coastal typology is discussed.

1 Introduction

Coastal typology is a necessary basement of the coastal zone management and a prerequisite for the evaluation and risk assessment of losses or changes of coastal resources. The scientifically sound coastal typology should be based on detailed information on the distribution, quality and quantity of various physical-geographical and biological features, however, in many cases such information may only be derived from heterogeneous data sets with different quality and longevity of observations.

In our study we suggest to use a notion of biotope in order to integrate variable environmental data (such as salinity, depth, wave exposure, substrate, etc) into an operational constituent to be used for the coastal classification. The term “biotope” was introduced by a German scientist, F. DAHL (1908) as an addition to the concept of ‘biocenosis” twenty years earlier formulated by K. MÖBIUS (2000). Initially it determined the physical-chemical conditions of existence of a biocenosis (“the biotope of a biocenosis”). Further, both biotope and biocenosis were considered as abiotic and biotic parts of an ecosystem, accordingly. This notion (“ecosystem = biotope + biocenosis”) became the classics in German, French, Russian and other “continental” ecological literature (OLENIN & DUCROTOY submitted). The new interpretation of the same term (“biotope = habitat + community”) appeared in the United Kingdom in the early 1990s while elaborating the classification of the natural conservation objects of the coastal zone (HISCOCK 1995; CONNOR et al. 1997) This meaning was used also in the international European environmental normative acts (EUNIS 2004).

For the purpose of this study we define a benthic biotope as a distinctive sea bottom area with conventionally uniform physical-chemical environment (salinity, substrate, hydrodynamics, light climate, temperature regime, etc.) and matching biological features. For illustration of methodology we use data collected in the Lithuanian coastal zone, Baltic Sea.

2 Study area

Open coast

The Lithuanian coastal waters are situated in the south-eastern part of the Baltic Sea and comprise the mesohaline (7-8 ppt) waters of the Baltic Proper and oligohaline-to-freshwater (0-3 ppt) of the Curonian Lagoon (Kuršių marios). Comparative characteristics of the environmental conditions of both aquatic systems are generalized in Table 1.

In the Baltic coastal zone major hydrological features are determined by the interaction between the south-eastern Baltic offshore waters and the runoff of the mostly freshwater Curonian Lagoon. The average temperature of the coastal waters has an annual range of 22 °C, showing a typical boreal seasonal pattern (OLENIN & KLOVAITE 1997 and references therein). In July-August the summer thermocline is formed at the depth of approximately 20-30 m, so almost all the coastal zone is influenced by the warm water above the thermocline. In winter, ice is a normal phenomenon along the shoreline; its width varies from 20-30 m to several hundred meters, with a thickness from 10-15 to 40-50 cm, depending on the severity of the winter.

Table 1. Environmental changes along the salinity and depth gradients from the Curonian Lagoon to the coastal areas of the Baltic Sea, Lithuanian waters.

Area*	Depth range, m	Salinity range, PSU	Temperature range, °C	Main bottom substrate	Wave exposure	Major anthropogenic pressures
			Curonian Lagoon			
Central	1-3	<0.5	0-24	Sand, silt, shell deposits	Moderate	Eutrophication
Northern	1-3	0.0-3.0	0-24	Sand, silt, shell deposits	Weak- moderate	Eutrophication
Klaipeda Strait	5-14	0.5-7.5	0-22	Sand, moraine clay, artificial hard substrates	Weak	Eutrophication, dredging, industrial and municipal wastes
			South-eastern Baltic			
South off Klaipeda	5-30	6.0-8.0	0-20	Sand	Strong-moderate	
North of Klaipeda	5-30	6.0-8.0	0-20	Stones, gravel, sand	Strong-moderate	Outflow of the eutrophied Lagoon's water, Būtingė Oil terminal
Offshore	30-55	7.0-8.8	0-11	Silt	Weak-none	Dredge spoil dumping

The permanent influence of winds, waves and water currents produces a hydrodynamically very active environment resulting in no oxygen deficiency and no oxygen based gradients in the distribution of bottom biota in the coastal area in contrast to the deeper offshore areas. Wave exposure is a very important factor shaping benthic biotopes and bottom communities in the upper part of the underwater slope down to the depth of approx. 20 m (OLENIN et al. 1996; OLENIN 1997A).

According to geomorphological and geological studies (e.g. GUDELIS, JANUKONIS 1977; PUSTELNIKOV 1990; ŽAROMSKIS 1992; GULBINSKAS & TRIMONIS 1999) the Curonian Lagoon alluvium (deposits) and abrasive-erosive processes determine the distribution of bottom sediments in the coastal zone. Accumulation sites alternate with intensively and moderately (Palanga - Būtingė) erosive areas. The mainland sub-marine coastal slope (north off Klaipėda), extending from the shore down to about 30 m is characterised by very diverse bottom types, including glacial deposits (morainic clay), large boulders, gravel and pebbles, course, medium and fine sands (GULBINSKAS & TRIMONIS 1999). The uppermost part of the coastal slope, from 0 to approximately 6 m, is covered by quartz sand, movable during storms. A morainic bench lies beneath the sand stripe, extending down to 25-30 m. The upper boundary of the morainic bench may be found approximately at the depth of 15 m in the vicinity of Būtingė and at the depth of about 4-5 m in front of Palanga. Sandy and stony bottoms alternate each other on a small scale from few to hundred meters, creating the sea bottom patchiness, exceptional for the whole coastal zone of Lithuania.

Along the Curonian Spit the bottom sediments are much more homogenous, with sand prevailing throughout the entire area. In the areas south off Klaipėda, the stony bottoms are found only on the southern border of the Lithuanian Exclusive Economic zone at the depths approx. 40-50 m (BUBINAS & REPECKA 2003).

Curonian Lagoon

The Curonian Lagoon is a large (1584 km^2) (ŽAROMSKIS 1996) coastal water body connected to the south-eastern Baltic Sea by a narrow (0.4-1.1 km) strait (Klaipėda port area). Traditionally the Lagoon is divided into the strait area (Klaipėda Strait), northern, central and southern parts according to the major physiographic features (ŽAROMSKIS 1996). The later part belongs to the Kaliningrad District of Russian Federation, and therefore it is not considered in this study. As a transitory system, the Lagoon has many estuarine attributes; from this point of view its strait area, northern and central parts may be regarded as lower, middle and upper reaches, respectively.

The mean depth of the Curonian Lagoon is approx. 3.8 m (ŽAROMSKIS 1996). The strait is ca. 11 km long, with artificially deepened water ways down to 14 m depth. In the rest of the study area the eastern side (mainland shore) represents a shallow plain gently sloping westward down to 1-2 m depth, whereas its western side (the Curonian Spit shore) is deeper, on sites reaching the 4 m depth.

Approximately 23 km^3 of freshwater gained in the form of riverine runoff pass the study area annually. More than 40% of this amount is discharged into the sea during spring months, whereas 5 km^3 of incoming seawater are mixed in the Lagoon mostly in autumn months (PUSTELNIKOVAS 1998). Duration and extent of seawater intrusions are coupled with a wind caused rise of water table in the sea. Episodic inflows of the sea water cause irregular rapid (hours-days) salinity fluctuations in the range of 0 - 7 psu in the Strait and to a less extent, in the northern part of the Lagoon (DAUNYS 2001). One-to-two days seawater inflows are most frequent (ŽAROMSKIS 1996) with a residence time of mixed waters within Lagoon not longer than 5 days. The seawater intrusions are mostly restricted to the northern part of the Lagoon, only rarely propagating into its central part for ca. 40 km.

Water temperature dynamics is typical for shallow temperate Lagoons with annual amplitude up to 25-29°C (ŽAROMSKIS 1996). In the Strait it is affected by seawater intrusions and may differ by 1-2 °C from the rest of the Lagoon (GASIŪNAITĖ 2000). The Strait is always ice free, while in the rest of the Lagoon the ice cover is present for 110 days on average (ŽAROMSKIS 1996).

Oxygen concentrations are subject to spatial and temporal (both diurnal and seasonal) variations (JUREVIČIUS 1959). Low concentrations down to 1.8 ml/l were found during the ice cover period in the lower part; local anoxia may take place in summer.

The main bottom sediments in the Lagoon are sand and silt, on sites with shell deposits (mainly of invasive bivalve *Dreissena polymorpha* and native gastropods of the genus *Valvata*). In the Klaipėda strait, the bottom sediments are greatly influenced by constant dredging for the waterway maintenance. The northern part of the Lagoon is acting as a transitory area of sediment transportation, while the central part is most heterogeneous in respect to bottom geomorphology and sediment type. Here, prevailing type is fine sand, on sites mixed with gravel and pebbles, peat and moraine. Muddy bottoms occur in local depressions in the deeper western part of the Lagoon along the Curonian Spit.

Benthic studies in the area and availability of historical data

Studies of benthic macrofauna in the Lithuanian coastal zone of the Baltic Sea were initiated by the Lithuanian government in 1928, when an invited Danish hydrobiologist (Blegvad) took first quantitative samples (presumably with a Petersen type grab) in the northern part of the coastal zone (GASIŪNAS 1963). Unfortunately, neither location of the sampling stations nor the source where the data were published are known.

The macrofauna studies were renewed after the World War II with a research on large-scale distribution patterns of trophic types and zoogeographic complexes in the southern part of the Baltic Sea (LUKSENAS 1967; 1969). However, the Lithuanian coastal zone in these studies was represented by few stations only.

Since 1980's several descriptive studies focused on distribution of selected species and structure of benthic communities were carried out with particular reference to human impacts such as an oil spill (ANDRIUSCTCHENKO et al. 1985; OLENIN 1990) and dredge spoil dumping (OLENIN 1992). Also in 1981 monitoring of the bottom macrofauna in the south-eastern Baltic, including the coastal waters of Lithuania was started using the standard sampling methodology (OLENIN 1987B). Since early 1990's several studies were initiated to classify and map benthic biotopes in the Lithuanian coastal zone (OLENIN et al. 1996; OLENIN 1997C), however this research is still restricted to the areas of highest conservation value in the north off the Curonian Lagoon outlet. The first exhaustive study on the distribution of bottom macrofauna species and communities along the southern Lithuanian coastal zone was only recently carried out (BUBINAS & REPECKA 2003). However, comparative value of published data is relatively low since only few quantitative results are given either on selected species or community level.

Studies on bottom macrofauna in the Curonian Lagoon started in early 1920's with a general focus on diversity and biology of benthic species (SZIDAT 1926; WILLER 1931; LUNDBECK 1935). Later an exhaustive study was carried out in 1950's with a particular reference to diversity and structural characteristics of the main complexes of the bottom macrofauna in the Lagoon (GASIŪNAS 1959). This study is still considered as the most comprehensive inventory of the Curonian Lagoon bottom macrofauna.

Several studies were focused on estimation of acclimated species production (RAZINKOV 1990), evaluation of food sources for commercial fishes (BUBINAS 1983; LAZAUSKIENĖ et al. 1996), accumulation of heavy metals and cytogenetic damage in bottom dwelling animals (JAGMINIENĖ 1995; BARŠIENĖ & BARŠYTĖ 2000). Main structural characteristics of benthic communities and trophic groups were also investigated (ARISTOVA 1965; 1971; BUBINAS 1983; OLENIN 1987A).

Regional biological monitoring program, which started in the Curonian Lagoon in 1980 was aimed to track changes at various levels of biological life. These long-term observations resulted in description of quantitative macrofauna characteristics at 7 monitoring sites (OLENIN 1987A). In 1990's an attempt was made to use the modern functional group approach to understand possible role of macrofauna in the Lagoon's ecosystem (OLENIN 1997B). Later the ecological effect of invasive alien species was summarized by OLENIN & LEPPÄKOSKI (1999).

However, in spite of quite long history of benthic research in the Curonian Lagoon, the role of environmental factors and driving forces in the Lagoon's benthic system is still poorly understood. Even if series of quantitative data exist, they are hardly comparable due to different techniques used in various studies. In most of studies no numeric methods were applied to test relationships between environmental characteristics and structure of the bottom macrofauna, however salinity was frequently suggested to be an important factor for reproduction success and distribution of some benthic species

(GASIŪNAS 1959; BUBINAS 1983; OLENIN 1987A; DAUNYS et al. 2000; DAUNYS 2001). Effect of sediment characteristics (organic carbon, granulometric parameters, depth) was tested in one of the recent works on Lagoon's macrofauna (DAUNYS 2001).

Summarizing published historical material (Table 2) on bottom macrofauna in the Lithuanian waters it can be concluded, that species diversity is rather well described. For the Curonian Lagoon the most comprehensive inventory on species diversity is still based on data collected in 1954-57 (GASIŪNAS 1959), while for the coastal zone of the Baltic Sea the material is spread between different scientific publications, reports and unpublished material. Only few publications contain lists of species and quantitative information on the community level. Use of historical data is also difficult due to different (or not specified) sampling methods and different (or unknown) procedures of sample sorting (onboard immediately after sampling or as fixed material under microscope in a on land laboratory; weight determination method).

On another hand, various indices describing diversity and/or evenness patterns were not popular in earlier studies. Therefore, generally quantitative information of high comparative value is not available for tracing historical changes in macrofauna neither in the Curonian Lagoon nor in the coastal zone of the Baltic Sea. The only material which could be used for quantitative analysis of the long-term changes is the monitoring data from few fixed stations in the Lagoon (observations made since 1980) and in the coastal zone (since 1981). Other sources may only support comparative analysis by providing long-term data on selected species/areas and allow verification of comparison results for longer time periods. Data from GASIŪNAS (1959) were used to complete species inventory of the Curonian Lagoon as well as to distinguish between categories of species (rare, common, very common and dominant). Also data on distribution of selected species in the same paper was used for detection of long-term changes in benthic macrofauna in the Lagoon, however no quantitative comparisons were carried out due to reasons mentioned above.

Table 2. Summary of information on previous studies in the Curonian Lagoon and the Lithuanian coastal zone of the Baltic Sea.

Reference	Period of studies	Methods used	Applicability for coastal typology
Gasiūnas 1959	1954-1957	Ekman-Berdge (0.0225 m^2) and Petersen (0.025 m^2) grabs, sediment core (0.01 m^2)	Inventory of species diversity, biomass/abundance of selected species, description of macrofauna complexes. Sampling methodology as well as details of sample proceeding are not given, therefore study is limited for comparative analysis based abundance and biomass values.
Luksenas 1967	1964-1966	Okean type grab (0.1 m^2), drag, mysid trawl	Distribution of bottom macrofauna that belong to different zoogeographic regions in the southern and south-eastern parts of the Baltic Sea
Luksenas 1969	1964-1966	Okean type grab (0.1 m^2), drag, mysid trawl	Distribution of bottom macrofauna that belong to different trophic types in the southern and south-eastern parts of the Baltic Sea
Aristova 1965	not indicated	Reference to unavailable sources	Description and distribution of bottom communities in the Curonian Lagoon
Aristova 1971	not indicated	Reference to unavailable sources	Description and distribution of *Dreissena polymorpha* community
Bubinas 1983	1978-80	Grab type not given	Description of bottom macrofauna in selected stations of the northern part of Curonian Lagoon
Olenin 1987a	1980-1984	Petersen type grab (0.025 m^2)	Description of benthic communities at 11 monitoring stations; species lists, mean values of abundance and biomass
Olenin, 1990	1981-83	Van-Veen, Okean, dredge	Results from "Globe Assimi" oil spill environmental impact assessment.
Olenin,	1994	Van-Veen grab (0.1 m^2);	Classification and description of benthic com-

Reference	Period of studies	Methods used	Applicability for coastal typology
Chubarova, 1994		SCUBA diving	munities in the northern part of Lithuanian coastal zone
Olenin et al. 1997	1993-1996	Van-Veen grab (0.1 m^2); SCUBA diving	Classification, description and mapping of benthic biotopes in the northern part of Lithuanian coastal zone
Bubinas et al. 1998		Van-Veen grab (0.1 m^2)	Distribution of bottom macrofauna, quantitative characteristics of selected species
Daunys 2001	1980-2001	Petersen type grab (0.025 m^2); Van-Veen grab (0.1 m^2); sediment core	Description of benthic communities including littoral part, statistical analysis of relationships between bottom macrofauna and environmental variables
Bubinas, Repecka 2003	1998-1999	Van-Veen grab (0.1 m^2)	Description of bottom macrofauna with notes on benthic communities in the southern part of Lithuanian coastal zone; descriptive analysis of relationships between sediment granulometry and macrofauna
Olenin et al. 2004	2002-2003	Veen grab (0.1 m^2); SCUBA diving	Description of biodiversity; classification, description and mapping of benthic biotopes in the northern part of the Lithuanian coastal zone.

3 Materials and methods

Collection of benthic data

Data on benthic macrofauna was collected in period from 1980 to 2003. Investigations were performed in the framework of biological monitoring programs, various environmental impact assessments and benthic biotope mapping surveys. In total 420 and 188 samples were taken in the Curonian Lagoon and in the coastal zone of the Baltic Sea respectively. The material was collected using Petersen and Van-Veen grabs, hand operated corers and SCUBA diving methods. All samples washed through a 0.5 mm mesh sieve, preserved with 4 % formalin and treated in a land laboratory according to HELCOM recommendations (1988).

Bottom macrofauna was identified to species level where practicable; such groups as oligochaets, chironomides were identified to appropriate higher taxonomic layer (class, family). Biomass was determined as formalin wet weight (g/m^2). Species which formed more than 40% of total macrozoobenthos biomass were considered dominants. Occurrence in 40% of samples was selected as a conventional threshold to distinguish constant species in a community. Detailed description of the methods used is given in the previous publications (OLENIN 1987A; 1987B; 1992; 1997A; 1997B; 1997C; DAUNYS & OLENIN 1999; DAUNYS 2001).

SCUBA diving observations and remote underwater video survey

SCUBA divers estimated visible geomorphological and biological features of benthic biotopes such as: sediment type and its heterogeneity, bottom vegetation, blue mussel and barnacle colonies, biogenic tubes, holes and animal crawling tracks on the soft sediment, using a semi-quantitative 5-grade scale for the assessment. For standardized descriptions, the divers used a weighed, 10 m long transect line. The SCUBA diver observations were performed at the depths from 3 to 18 m during 1993, 1996, 1997, 1999, 2002 and 2003 field seasons in the northern part of the open Lithuanian coast and in the area of the Klaipėda port breakwaters.

A remote video survey of the sea bottom was performed using various types of underwater video cameras during the same field seasons as SCUBA diving in the northern and southern parts of the open coast. A camera was hauled down from the ship (or a boat) to the bottom. The ship was drifting approximately 100 to 150 m. The analysis of video material included registration of same geomorphological and biological features as in case of SCUBA diving. Detailed description of the methods used is given in the previous publications (OLENIN et al. 1996; OLENIN 1997C). SCUBA diving observations and video surveys were not performed in the Curonian Lagoon because of a very low visibility (usually < 0.5 m).

Identification of benthic biotopes

Identification of the biotopes was based on both physical and biological features. The physical features included: type and uniformity of substrate (sand, gravel, stones or mixture of stones and sand, etc.), depth (as proxy for light availability for plants and comparative strength of wave action), presence of sandy ripples, etc. The biological features used for biotope discrimination comprised: character of coverage of the red algae *Furcellaria lumbricalis*, blue mussel *Mytilus edulis*, barnacle *Balanus improvisus*; presence of mobile nectobenthic species, such as mysids and burrowing amphipods *Bathyporeia*, infaunal bivalves *Mya arenaria* and *Macoma baltica*, as well as visible biogenic signals (empty shells, traces of crawling bottom animals, siphon and burrow openings, etc.).

The procedure of biotope identification included several steps. The first step was the analysis of all information available and preliminary identification of the biotope type for each sampling station. In large extent, that preliminary identification was based on the previous knowledge of the area (OLENIN et al. 1996; OLENIN 1997A; 1997B; DAUNYS & OLENIN 1999; DAUNYS 2001). Then the similar stations were grouped according to the biotope type defined. Specific abiotic and biotic features, which distinguish one group of stations from another, were defined and the level of heterogeneity was evaluated. In case of high heterogeneity, the quantitative biological data were examined using the cluster analysis and/or ordination procedures in order to determine “exceptions” (or “internal groups”) within a given group of stations. Those “internal groups” were additionally analyzed in order to find more specific abiotic or biotic features, distinguishing them from each other. This procedure was aimed to identify the benthic biotopes as objectively as possible.

After preliminary identification and subsequent valuation of the biotope type, the sampling stations were plotted on the geological maps available for the Curonian Lagoon (GULBINSKAS et al. 2003) and for the coastal zone (GULBINSKAS et al. unpublished). The biotope type at each station was compared with the geological map readings and specified by available video and SCUBA diver observation materials (specification using video and SCUBA diving materials was possible only for the northern part of the open coast). The final step was the expert evaluation and extrapolation of the biotope type on the adjacent areas (less covered by the sampling stations).

Definition of a coastal type

The proposed typology is based on the analysis of the abiotic conditions and studies on benthic biotope and communities performed both in the Baltic Sea coastal zone and in the Curonian Lagoon (OLENIN et al. 1996; OLENIN 1997A; 1997B; DAUNYS & OLENIN 1999; DAUNYS 2001). The classification approach is hierarchical, comprising three main levels: 1) coastal type, 2) benthic biotope and 3) benthic community.

Definition of a benthic biotope was used in earlier studies (OLENIN et al. 1996; OLENIN 1997C); it corresponds to the notion used for the benthic biotope classification in Great Britain and Ireland: “the physical habitat with its biological community, i.e. the combination of physical environment (habitat) and its distinctive assemblage of conspicuous species” (CONNOR et al. 1997A; 1997B; MARLIN 2004). Benthic macrofauna communities were identified by the names of the biomass dominant species (e.g., *Macoma baltica, Dreissena polymorpha*) in accordance to the benthic ecology tradition (PETERSEN 1911-1918 cit. by NESIS 1977). Due to high heterogeneity of substrate and presence of microhabitats more than one benthic macrofauna communities may be found in most of the biotopes; in such cases we identified the main, most characteristic communities and additional ones.

A coastal type is defined as a biotope complex, i.e. a part of the coastal zone comprising several neighbouring interrelated biotopes. Identical biotopes (e.g. biotope of mobile sands, stony bottoms with macrophytes, soft sandy bottoms with infauna, etc.) may be integrated in various combinations into different coastal types. Therefore, the coastal typology should be based on the analysis of composition and spatial distribution of the biotopes, comprising the biotope complexes within a certain geographical location.

4 Results

4.1 Classification of the coastal types

A general scheme of the classification procedure is shown in Figure 1. At the first step two principally different types of aquatic environment were distinguished: 1) marine, the open Baltic Sea coast, and 2) estuarine (transitional), the Curonian Lagoon.

At the second step two coastal types were identified for the open coast of the Baltic Sea: 1) the area to the north of the Curonian Lagoon outlet, and 2) the southern coastal area. Due to prevailing northern direction of currents, the first area is much more influenced by the freshwater outflow than the second one. Both areas also differ in terms of their geomorphology and origin: the southern area stretches along the Curonian Spit, which evolved as a large alluvial deposit form, with sand being the prevailing type of the bottom sediments. In opposite, the great variety in bottom substrate in the northern area is formed due to an underwater extension of the morainic mainland coast (GUDELIS 1998).

At the third step, the assemblage of benthic biotopes was defined for each coastal type, taking into account the nature of substrate (soft or hard bottoms), depth range and light climate (within or below the euphotic zone). In fact, the classification of biotopes included several intermediate steps which are not shown in Figure 1 for the purpose of simplicity. For instance within the biotope "Stony bottoms in aphotic zone" one may distinguish few lower level biotopes such as "Boulders with dense colonies of blue mussel *Mytilus edulis* and barnacle *Balanus improvisus*"; "Gravel and pebble patches with polychaetes *Nereis diversicolor* and *Marenzelleria viridis*" and, "Sand patches with bivalve *Macoma baltica* and *Marenzelleria viridis* between stones".

In total, seven main benthic biotopes were distinguished for the open coast: five for the northern and two for the southern area (Table 2). According to the geological data, the later area is much more monotonous in terms of the bottom substrates. However, further research may reveal other biotopes in this part of the coastal zone, since yet it was not studied in such details as the northern one.

Finally, the forth step included identification of the main and co-occurring benthic communities which are represented for a given biotope (Table 2).

Table 3. Coastal types, biotopes and characteristic benthic communities of the south-eastern Baltic coastal zone.

Coastal type	Biotope	Abbreviation	Communities*				
			Mac. balt.	***Mya aren.***	***Mar. vir.***	***Bal. imp.***	***Myt. edul.***
Northern coastal area	Mobile sand	NOC.MSD	+				
	Soft bottom	NOC.SFT	++	+	+		
	Mixed bottom	NOC.MIX	+		+	+	+
	Stony bottom in the euphotic zone	NOC.STE				+	++
	Stony bottom in the aphotic zone	NOC.STA				+	++
Southern coastal area	Mobile sand	SOC.MSD	+?				
	Soft bottom	SOC.SFT	++	+			

Mac. balt. – Macoma baltica, Mya aren. – Mya arenaria, Mar. vir. – Marenzelleria viridis, Bal. imp. – Balanus improvisus, Myt. edul. – Mytilus edulis;
++ - main community of the given biotope, + - additional community, ? – status unknown

The same procedure was applied for classification of the Curonian Lagoon. Here, three coastal types were distinguished based on the peculiarities of the salinity regime: 1) Klaipėda Strait, most influenced by the sea water inflows and showing the highest range of salinity fluctuations; 2) the northern part of the Lagoon less exposed to the salinity changes; and 3) the freshwater area in front of the River Nemunas delta in the central part of the Lagoon. At the third step, the assemblage of characteristic benthic biotopes was defined for each coastal type. In total, six main benthic biotopes were distinguished; and at the forth step the characteristic benthic communities were identified (Table 3).

Table 4. Coastal types, biotopes and characteristic benthic communities of the Curonian Lagoon.

Coastal type	Biotope	Abbreviation	Communities*					
			N. div.	***M. vir.***	***V. pisc.***	***U. tum.***	***D. pol.***	***Ol.+Ch.***
Central part of the Lagoon (Delta area)	Muddy bottoms in the central part of the Lagoon	DEL.MUD					++	+
	Sandy bottoms in the central part of the Lagoon	DEL.SND					+	++
Northern part of the Lagoon	Muddy bottoms in the northern part of the Lagoon	LAG.MUD			+		+	++
	Sandy bottoms in the northern part of the Lagoon	LAG.SND		+		++	+	+
Klaipėda Strait	Muddy bottoms in Klaipėda Strait	STR.MUD	+	+				++
	Mixed bottoms in Klaipėda Strait	STR.MIX	++	+				+

**N. div. – Nereis diversicolor, M. vir. – Marenzelleria viridis, V. pisc. – Valvata piscinalis, U. tum. – Unio tumidus, D. pol. – Dreissena polymorpha, Ol.+Ch. – Oligochaeta + Chironomidae*; ++ - main community of the given biotope, + - additional community.

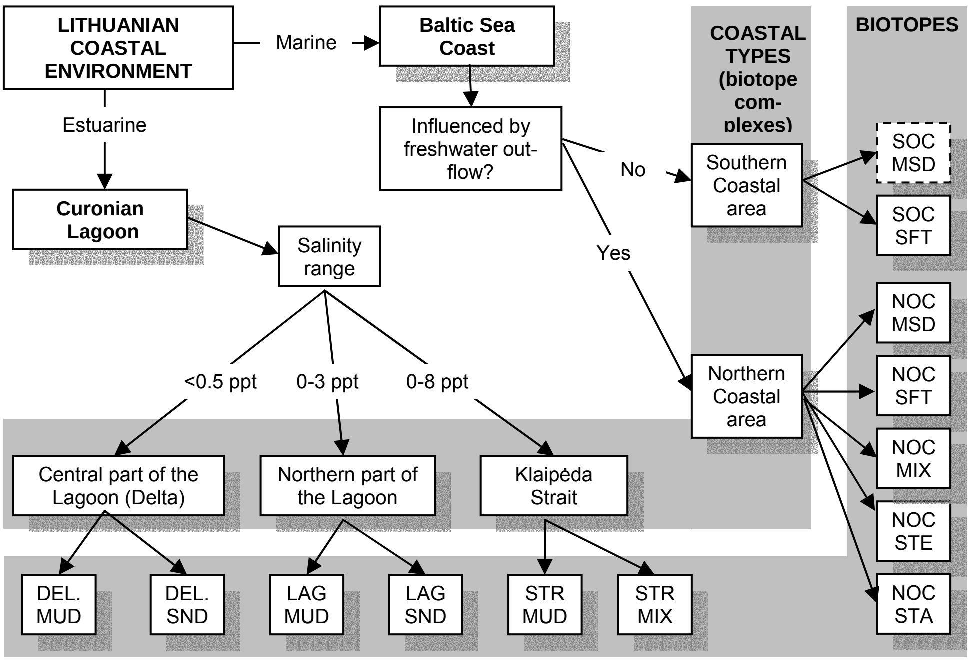

Figure 1. Typology of the Lithuanian coastal benthic environment based on benthic biotopes and biotope complexes. Abbreviations: DEL – delta, LAG – Lagoon, STR – strait, SOC – southern coast, NOC – northern coast; MUD – mud, SND – sand, STE – stones in euphotic zone, STA – stones in aphotic zone, MSD – mobile sands, SFT – soft bottoms, MIX – mixed (stones, gravel and sand) bottoms. See text for explanation.

4.2 Characterization of coastal types and benthic biotopes

Biotopes of the northern open coast type

The general scheme showing distribution of the coastal types and main benthic biotopes in the Lithuanian part of the Baltic Sea and in the Curonian Lagoon is shown in Figure 2. The northern coastal type stretches from the Curonian Lagoon outlet to the Latvian border (approx. coordinates: N 56°03', N 55°43', E 21°03', N 20°03'). This area is characterized by the most diverse bottom substrates and the highest patchiness of the bottom in the entire Lithuanian coastal zone. Brief description of the main benthic biotopes is given below.

The mobile sand biotope (NOC.MSD in Fig. 1) occupies the uppermost sublittoral from the shore line to approximately 6 m depth, where sands are permanently transferred due to wave and current action. This biotope forms a narrow band along the entire shore line. Instability of the substrate prevents formation of established benthic communities. Species diversity is low: only 8 species were found (3 species per sample). These species are either burrowing infaunal (*Marenzelleria viridis, Pygospio elegans, Macoma baltica*) or actively swimming nectobenthic (*Bathyporeia pilosa, Crangon crangon*) forms adapted to the active hydrodynamic conditions of the exposed sandy coast. No macrophytes occur on such bottoms. The total community biomass ranges from 3 to 93 (mean 33±9) g/m^2. Abundance is much lower than in other sandy bottom biotopes laying beneath the wave exposure zone: 70-3900 (2200±530) ind./m^2. No macrophyte species were found in this biotope during SCUBA diving and remote underwater video surveys in 1993-2003.

Soft bottom biotopes (NOC.SFT in Fig. 1) include "Sand banks in the middle sublittoral with bivalves *Macoma baltica* and *Mya arenaria*" and "Fine sand in the lower sublittoral (20-30 m) with bivalve *Macoma baltica* and isopod *Saduria entomon*". Both biotopes are rather similar in their physical and biological features with no clear boundaries due to variety of transitional forms.

The first biotope typically occupies a wide (up to 6 km) band within the depth range from 5 to ca. 15 m along the shore in Butinge area (close to Latvian border); it shrinks to few fragments within large stony fields near Palanga. The benthic community comprises about 20 species (6 species per sample) with the biomass dominant bivalve *M. baltica* and total biomass ranging from 0,5 to 123 (37±7) g/m^2 and abundance - 850 - 48530 (22684 ± 2900) ind./m^2. The most characteristic species (occurrence > 60%) are typical coastal infaunal dwellers: polychaetes *M. viridis, Nereis diversicolor* and *P. elegans,* bivalves *M. baltica* and *M. arenaria,* crustacean *C. volutator*. Due to numerous juvenile forms, the abundance of benthic macrofauna is 4-10 times higher than in other sandy bottom biotopes. Due heterogeneity of environment the structure of benthic communities is also rather variable: on sites, the dominant bivalve *M. baltica* is shifted by the polychaetes *M. viridis* and *N. diversicolor.* Although the light penetration is sufficient in the upper part of the biotope, no macrophytes occur there.

Another soft bottom biotope is mostly characteristic for the Klaipėda – Palanga area. It may be found also in a form of rather wide (hundred meters) sandy bottom inclinations among the stony fields in lower sublittoral (ca. 20 m depth) in Palanga area. The environment in this biotope is less heterogeneous and more stable comparing to the sandy bottoms in middle and upper sublittoral. The distinctive biological feature is presence of the isopod *S. entomon,* which does not occur on sands in the upper sections of sublittoral and on stony bottoms. In opposite, some shallow sandy coast dwellers, such as *M. arenaria* are absent in this biotope. The most characteristic species (occurrence > 60%) are: the bivalve *M. baltica,* polychaetes *N. diversicolor, Marenzelleria viridis, P. elegans* and the isopod *Saduria entomon*. The total number of species found is 12 (7±1 per sample in average). The biomass and abundance are less variable than in other sandy bottom biotopes: 17 – 48 (28 ± 10) g/m^2 and 1340 ± 11280 (5390 ± 3010) ind./m^2.

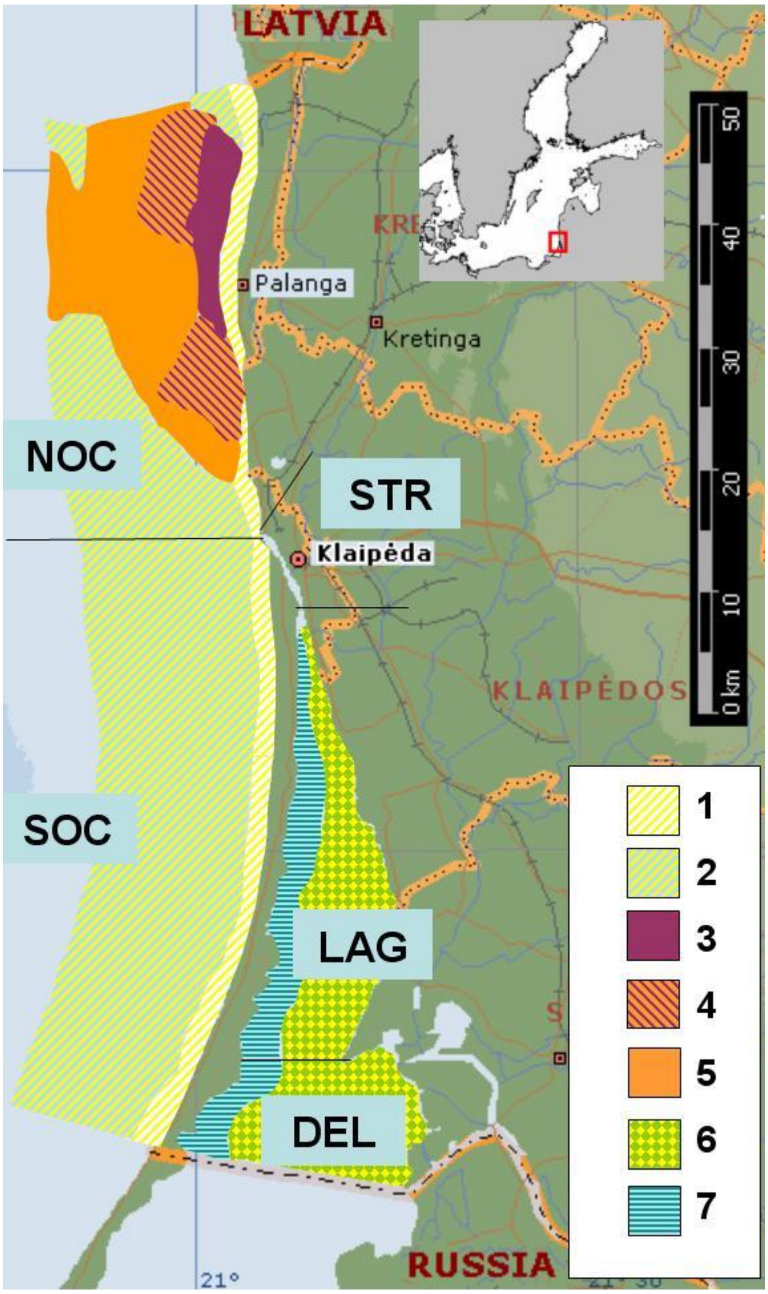

Figure 2. Scheme showing location of the coastal types and main benthic biotopes in the Lithuanian waters of the Baltic Sea and the Curonian Lagoon. Open coast biotopes: 1 - mobile sand, 2 - soft bottoms, 3 - stony bottoms in the euphotic zone, 4 - stony bottoms in the aphotic zone, 5 - mixed bottoms. Curonian Lagoon biotopes: 6 - sandy bottoms, 2 – muddy bottoms.

Stony bottom biotopes within the euphotic zone (NOC.STE in Fig. 1) include "Boulder reefs with red algae *Furcellaria lumbricalis"* and "Stony and gravel bottoms with red algae *Furcellaria lumbricalis*". The first biotope is characterised by fields of densely packed stones and large boulders with very little or no sand and gravel parches. This biotope is found in front of Palanga, where it occupies a small area (ca. 1 km^2) within the depth range 5 to 10 m. This is the only place in the entire Lithuanian coastal zone where the red algae *F. lumbricalis* may form dense colonies and successfully compete for space with the blue mussels and barnacles due to favorable lithodynamic and geomorphological conditions within the euphotic zone (BUCAS et al. in prep.). The biomass of *Furcellaria* may be as high as 4 kg/m^2. In opposite, the blue mussel biomass is 5-6 times less in this biotope than in the similar habitats beneath the euphotic zone. *F. lumbricalis* is the only habitat forming perennial algae at the Lithuanian coast; the dense colonies of this red algae create microhabitats for diverse macrofauna, especially for phytophagous *Idothea baltica* and nectobenthic species such as gammarids and mysids. The species richness is comparatively high: 14±1 species per sample (31 species in total). The most characteristic species are: *Mytilus edulis, Balanus improvisus, Fabricia sabella, Nereis diversicolor, Hydrobia sp., Gammarus salinus* and *Jaera albifrons*. The total benthic community biomass varies from 187 to 1429 (663 ± 135) g/m^2 and abundance - 1100 – 81275 (16860 ± 6420) ind./m^2.

In another biotope, stony and gravel bottoms are still suitable for *F. lumbricalis* due to favourable light conditions. However, high hydrodynamic activity facilitates the abrasive effect of sand and gravel, and therefore there are many spots on boulders with no attached plants or animals. In general, the stones which are elevated to less than ca. 20 cm above the bottom are not covered by any attached fauna or flora. The most characteristic forms are: *M. edulis, B. improvisus, Bathyporeia pilosa, Fabricia sabella, Gammarus salinus, C. volutator* and oligochaetes. The total benthic community biomass varies from 47 to 5735 (2 488 ± 286) g/m^2 and abundance - 1900 – 37750 (17473 ± 1561) ind./m^2. Areas occupied by this biotope are found within the depth range 5-16 m near Karkle (10-15 km north off Klaipėda) and in Palanga area.

<u>Stony bottom biotope in the aphotic zone</u> (NOC. STA in Fig. 1) includes fields of densely packed stones and large boulders nearly entirely covered by colonies of blue mussels *M. edulis* and barnacles *B. improvisus* represent features which are usually typical for reefs. This biotope occupies the area off Palanga in the depth range of ca. 15-20 m, where the abrasive effect of sand and gravel is low. This biotope displays the most favourable environment for epifaunal species: their total biomass, ranging from 3515 to 5530 (4500±208) g/m^2, is the highest at the Lithuanian coast. Abundance varies within 15375 – 33 850 (25747 ± 2261) ind./m^2. The blue mussel constitutes about 90 and *B. improvisus* 5% of total biomass, the role of other species is insignificant. Besides these two species other characteristic invertebrates are: *Jaera albifrons*, *N. diversicolor*, *Gammarus zaddachi* and *G. salinus*. Variability of the biomass of blue mussels between samples is considerably lower than in other stony bottom biotopes. On the upper edge of the biotope (ca. 15 m) single specimens of macroalgal species, such as *Coccotylus truncatus* tolerant to low light conditions may be found.

<u>Biotopes of mixed bottoms</u> (NOC.MIX in Fig. 1) comprise stony and gravel fields with blue mussel *M. edulis* and barnacle *B. improvisus* as the most conspicuous biological features. These heterogeneous biotopes are the most typical for the entire northern coastal area within approximately 5 to 25 m depth range. Here stony areas and large boulders alternate with patches and stripes of sand, gravel, pebbles and moraine on a scale of meters - tens of meters. Species composition and dominant species of macrofauna also varies depending on the character of the bottom sediments. The blue mussels and barnacles form dense colonies on boulders and stones, attracting associated fauna. The species diversity here is higher than at the adjoining sandy or gravel locations. Besides *M. edulis* and *B. improvisus*, other characteristic species are: *N. diversicolor*, *Gammarus salinus*, *Jaera albifrons* and *Corophium volutator*. The total benthic community biomass varies from 22 to 6060 (1950 ±280) g/m^2 and abundance - 390 – 97210 (16250 ± 2490) ind./m^2. Bottom macroflora is represented by very rare single specimens of some tolerant species.

The patches of <u>gravel</u> and pebbles are mostly inhabited by polychaetes *N. diversicolor* and *M. viridis*. The larger pebbles are still suitable for *B. improvisus* and *M. edulis*, however both species do not form dense colonies and the total species richness is lower than on boulders (6±1 per sample). Gravel and pebbles are not suitable for typical infaunal sandy bottom dwellers such as *M. arenaria*, *C. volutator* and *P. elegans*. The variation in quantitative parameters is very high, from no macrofauna in some pebble patches to rather high values: 0 –310 (64± 34) g/m^2 and 0 – 4350 (1290± 450) ind./m^2.

Sandy patches between stones are occupied by the benthic community dominated by *M. baltica* and *M. viridis* with other characteristic forms such as oligochaetes, *N. diversicolor* and *Hydrobia sp*. In contrast to the typical sandy bottom biotopes the biomass is 3-5 times less here, but the species richness is similar (7±2 species per sample). On sites, the gastropod *Theodoxus fluviatilis* may be found, which is rare in the other parts of the coastal zone within the stony bottoms. The total benthic community biomass varies from 3 to 15 (7,8 ± 3,6) g/m^2 and abundance - 650 – 8160 ind./m^2.

Biotopes of the southern open coast type

The southern coastal type is situated along the Curonian Spit (approx. coordinates: N 55°43', N 55°16', E 21°04', N 20°40').

The mobile sand biotope (SOC.SFT in Fig. 1) was defined by the analogy with the same biotope in the northern coastal area. Its existence may be confirmed by geological maps and geomorphological studies (GUDELIS & JANUKONIS 1977; PUSTELNIKOV 1990; ŽAROMSKIS 1992; GULBINSKAS & TRIMONIS 1999). Although only preliminary observations of benthic environment have been performed in that biotope, it may be assumed that species composition, abundance and biomass should be similar to those found in the northern area.

The soft bottom biotope (SOC.SFT in Fig. 1) in the southern coastal area occupies the largest area in the Lithuanian coastal zone, stretching along the entire Curonian Spit within the depth range from ca. 10 to 30 m. The bottom substrate is much more monotonous than in the same biotope in the northern area. The main community is that of bivalve *Macoma baltica;* other characteristic benthic macrofauna forms are: *Pygospio elegans, Nereis diversicolor, Marenzelleria viridis, Mya arenaria*, *Cerastoderma lamarcki* and oligochaetes. The total biomass varies within 5 – 314 g/m^2, the total abundance within 800-30000 ind./m^2. *M. baltica* is the biomass dominant species constituting 40- 90% of total community biomass; while *M. arenaria* is might be dominant in front of Nida at the depths of about 15 m.

Biotopes of the central part of the Curonian Lagoon

The central part of the Lagoon (approx. coordinates: N 56°20', N 55°15', E 21°17', N 20°58') situated in front of the Nemunas delta area is strongly influenced by the river outflow. Two main biotopes were identified preliminary for this part of the Lagoon: one with mud as prevailing bottom substrate and another with fine sand. Both biotopes alternate each other on the scale of hundred meters. The muddy bottom biotope (DEL.MUD in Fig. 1) is, in great extent, "created" by the zebra mussel *Dreissena polymorpha,* which invaded the Curonian Lagoon approximately two hundred years ago (OLENIN et al. 1999). Shell deposits and clusters of living mussels cover the largest part of the delta area, their distribution well coincide with that of mud. The later is formed in spite of the active hydrodynamic regime caused by the outflow current of Nemunas and comparatively high wave exposure. *D. polymorpha,* as a very effective seston feeder, deposits suspended material from the water column in form of faeces and pseudofaeces. Besides, the shell deposits and clusters of living mussels trap suspended particles contributing to formation of biogenic mud within and around the shell deposits. Due to habitat engineering activity of *D. polymorpha*, community of co-occurring species is rich in species number (up to 29 per sample, and about 50 in total). The total biomass (up to 11 kg/m^2) and abundance (up to 100000 ind./m^2) are the highest in the entire Curonian Lagoon.

The biotope of sandy bottoms (mainly fine sand and aleurite) in the central part of the Lagoon (DEL.SND in Fig. 1) is occupied by the community of "Oligochaeta + Chironomidae", which is the most widespread in the Curonian Lagoon (OLENIN 1987A; 1988) and the most variable in structure (DAUNYS 2001). Approximately half of the species recorded in the Lagoon were present in that community, however none of them was constant. The species number varied from 2 to 16 per sample, and total biomass – from 10 to 40 g/m^2. Fine sand was mixed with mud on sites situated close to local organic pollution sources (Nida, Juodkrantė, etc.). In such places only oligochaetes and chironomids were found in benthic samples.

Biotopes of the northern part of the Curonian Lagoon

The northern part of the Lagoon (approx. coordinates N 55°38', N 56°20', E 21°15', N 21°04') is under the influence of both the Nemunas outflow and episodic inflows of sea water. Preliminary two groups of biotopes are distinguished in that area: one in the large eastern shallow (depth < 1,5 m) flat area with fine sand as prevailing bottom substrate and another one in the deeper (1,5 <depth< 4 m) western area along the Curonian Spit.

The sandy bottom biotope on the eastern side LAG.SND in Fig. 1) of the Lagoon may be sub-divided into variety of lower level biotopes: fine sands with macrophytes; sand with large native unionids (*Unio tumidus* as the most characteristic species); fine sand and silt with oligochaets and chironomids as well as biotopes with alien invasive species *Dreissena polymorpha, Marenzelleria viridis* and Ponto-Caspian amphipods of genus *Chaetogammarus* and *Pontogammarus*. The later one is present in a very narrow (<20 m) uppermost part of the underwater slope (depth <0,5 m) and may be distinguished only during the warm period of the year when the dense communities of Ponto-Caspian gammarids are developed (DAUNYS & OLENIN 1999). All other biotopes alternate each other on the scale of tens – hundreds meters. Invasive benthic macrofauna constitutes an important part of the biotope forming species, on sites contributing up to 95% of total community biomass. Even in locations where the unionids are predominant species approximately 65 % of them are fouled by the zebra mussels. In general, benthic environment in that part of the Lagoon is essentially changed by the invasive species (OLENIN & LEPPÄKOSKI 1999).

The main community in the muddy bottom biotope (LAG.MUD in Fig. 1) is "Oligochaeta + Chironomidae", which, in general, is the same as in the central part of the Lagoon. Comparatively large part of the muddy bottoms is covered by shell deposits formed mainly by *Valvata* species with admixture of *Bithynia spp., Radix spp., D. polymorpha, Potamopyrgus antipodarum* and *Theodoxus fluviatilis.* Presence of *Valvata* shell deposits with large number of other species is characteristic feature of the muddy bottoms in this area, in opposite to the central part of the Lagoon where *D. polymorpha* is predominant species. On sites, clusters of living zebra mussels also may be found in that part of the area which is less exposed to the saline water inflows (close to the central part of the Lagoon).

Biotopes of the Klaipėda Strait

Benthic environment in the Klaipėda Strait (approx. coordinates N 55°43', N 55°38', E 21°08', N 21°05') is characterized by the most changeable conditions due to natural factors: rapid salinity fluctuations, changes in water hydrochemistry and shifts in temperature regime caused by alternate movements of limnic and marine water masses. On another hand, the area is exposed to the highest anthropogenic pressure for the entire coastal region caused by dredging operations, organic and chemical pollution from industrial and municipal waste waters and ships, hydrotechnical construction, etc. There is a clear difference between muddy biotopes situated in the eastern (harbour) part of the Strait and those on the western side, more flashed by running waters.

Mixed bottoms in Klaipėda Strait (STR.MIX in Fig. 1). The western side of the Strait is characterised by the great variety of bottom substrates: fine and coarse sands, gravel and pebble bottoms, moraine - clay and stones, patches of mud as well as artificial substrates, such as concrete embankments, submerged wood, etc. The array of relevant benthic communities is also very broad, on sites such dominants may be found as: *Nereis diversicolor, Marenzelleria viridis,* oligochaets and chironomids, *Balanus improvisus, Cordylophora caspia, Mya arenaria, Macoma baltica, Mytilus edulis.* The most widespread are the *Nereis diversicolor* and Oligochaeta + Chironomidae communities. The number of species, abundance and biomass vary within large limits and are subject to rapid changes. Due to active hydrodynamic and absence of large inlets the area is not exposed to oxygen deficiency and due to that is inhabited by rather diverse benthic fauna which is able to withstand rapid environmental fluctuations and essential anthropogenic pressure.

Muddy bottoms in Klaipėda Strait (STR.MUD in Fig.1) comprise inlets on the eastern side of the Strait belonging to the port area. The main bottom sediment is black mud on sites with admixture of sand and gravel, containing also human litter. The sediments are polluted with organic material, heavy metals and oil products. Only most tolerant species may survive in this heavily disturbed biotope: oligochaetes and chironomids as the main forms, while *Nereis diversicolor* and *Marenzelleria viridis* may be found in comparatively less polluted locations. In the most polluted sites benthic macrofauna is absent.

5 Discussion

The notion of biotope is being more and more widely used in aquatic and terrestrial environmental research (OLENIN & DUCROTOY submitted). For instance, the Internet search system for scientific literature SCIRUS (www.scirus.com) recently (October 2004) indicated 246 links to research papers in which the terms "biotope" and "benthic" were used, 51 journal articles for the combination "biotope" and "landscape planning", 52 for "biotope" and "indicator species", 213 for "biotope" and "biodiversity".

Our study shows that the biotope is a convenient unit which may be used for the coastal typology. We identified five coastal types, one of them being heavily impacted by human activity (Klaipeda Strait), and four comparatively less disturbed: two areas belonging to the transitional waters (the Central and Northern parts of the Curonian Lagoon) and two belonging to the coastal waters (the Southern and Northern parts of the Lithuanian coast). All these types clearly differ in terms of composition and distribution of benthic biotopes. Thus, by our opinion, the coastal type, defined as a biotope complex, may be efficiently used for the purposes of the coastal typology within the Water Framework Directive. There are several arguments to support such point of view.

First of all, the biotope integrates several, if not all, obligatory and optional factors listed in the relevant WFD recommendations (GUIDANCE DOCUMENT 2003). The biotope classification procedure takes into account the tidal range, salinity, depth, current velocity, wave exposure, turbidity, etc. (Fig. 3).

Furthermore, it includes such a necessary step as the analysis of matching between physical and biological features used to characterize the biotopes. The next step, following the creation of the biotope classification system and its use for coastal mapping, includes identification of coastal types as the complexes of interrelated neighboring biotopes. This step gives the coastal typology a solid natural background and provides it with essential ecological relevance.

Yet another argument to use biotopes for the coastal typology is that there are already several national and international biotope classification systems developed for the coastal zones of Europe. For instance, in the United Kingdom, the marine biotope classification was published by the Joint Nature Conservation Committee (CONNOR et al. 1997A; 1997B). This classification was developed as a contribution to BioMar, a project part-funded by the EU's Life programme. In France, the Zones Nationales d'Intérêt Scientifique, Faunistique et Floristique (ZNIEFF) have been created for the Atlantic and Mediterranean coasts (DAUVIN et al. 1996). A regional international classification of coastal biotopes and their complexes was developed for the Baltic Sea (HELCOM 1998). Later, the above mentioned and several other classifications were unified in the European Nature Information System (EUNIS 2004). The later is the product of the European Topic Centre for Nature Protection and Biodiversity (ETC/NPB in Paris), which was created for the European Environment Agency (EEA) and the European Environmental Information Observation Network (EIONET). We believe that use of the EUNIS approach may give productive results for the coastal typology, not only on a local (Lithuanian) and regional (Baltic) but also on the EU scale.

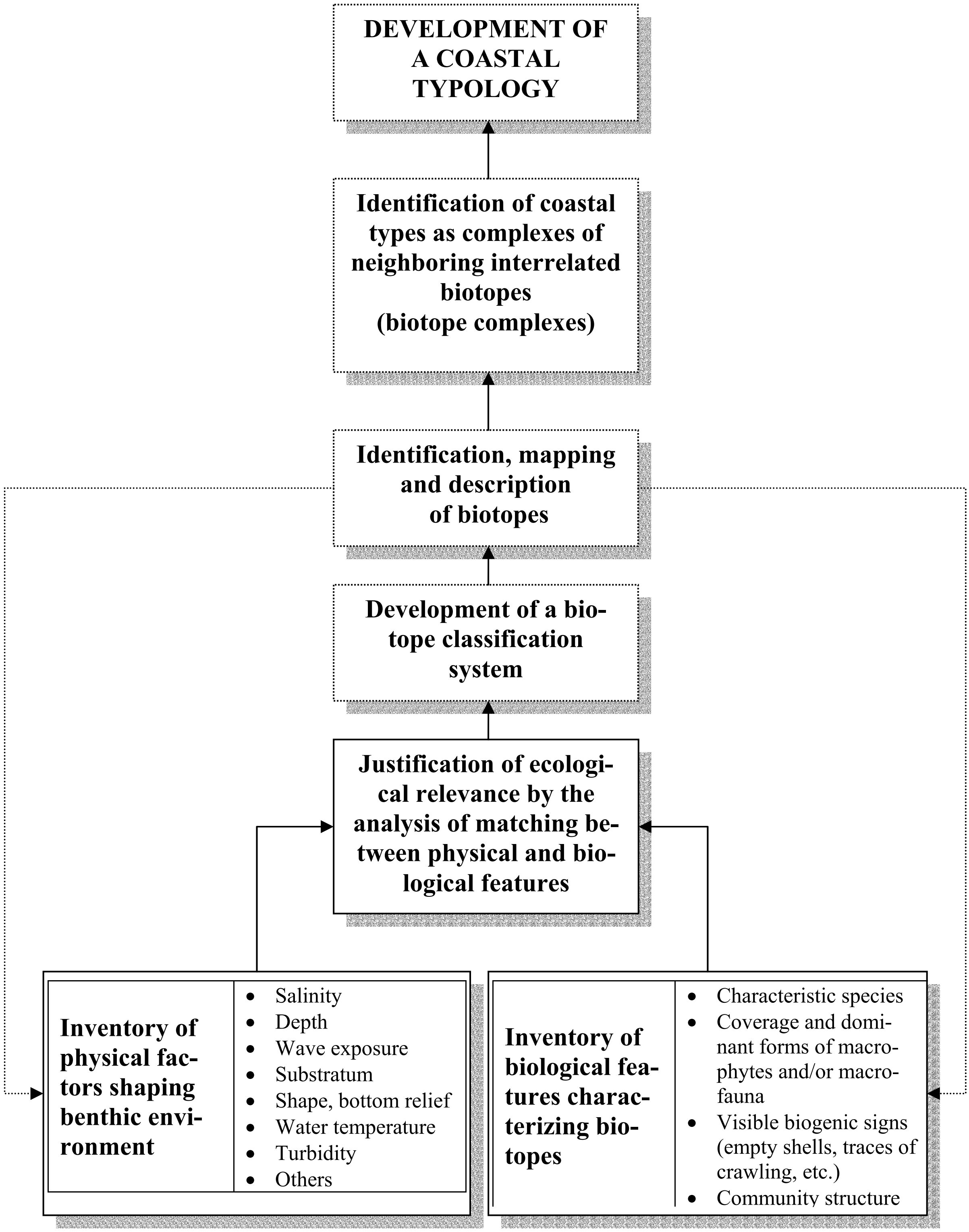

Figure 3. Generalized scheme showing the benthic biotope classification procedure and its relevance to the coastal typology

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