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Marine landscape mapping of the south-eastern part of the Baltic Sea (Russian sector)

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Abstract Five different kinds of broad-scale characterizations of the marine environment were used for marine bottom landscape mapping. In addition to three "primary" environmental parameters of the BALANCE project – sediment types, available light and near-bottom water salinity two more were also taken into account: near-bottom temperature and ice cover. Combination of these parameters allows for distinguishing 21 types of marine bottom landscapes. The dominant landscape type is located far beyond the surface photic zone and not influenced by the ice-cover. It is characterized by mud sediment type, salinity of 11–18 psu and deep low variable relatively cold near bottom waters (4–8 ^{o}C) with ulterior seasonal variability. The most perspective marine landscape, from the point of view of nature conservation zones, is small area located in the Curonian Spit marine nearshore zone where bottom sediments are represented by the relict lagoon hard clays partly covered by sands. These clays are unique bottom oasis where the numbers of benthic organism species sharply increase in contrast to almost lifeless adjacent extensive sand areas.

Keywords *• marine landscape • abiotic approach • spatial planning • relict lagoon clays • the south-eastern Baltic Sea*

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INTRODUCTION

An improved insight of the many competing uses of the sea requires more precise information and understanding of maritime activities and the impact they have on the surrounding environment. The benthic marine landscapes are the most relevant characterization of the marine environment for achieving a sustainable management of the marine environment as it does reflect broad-scale species assemblages.

After Al-Hamdani and Reker (2007), the ecologically relevant marine landscape maps could then be applied as an ecological parameter for broad-scale marine spatial planning, thus contributing to knowledge-based management of our marine environment and the long-term goal of achieving a sustainable development within the marine regions. These maps will provide a better understanding of the extent and distribution of the physical entities of sea for end users and improve the representativity of the Marine Protected Areas (MPAs). The availability of a broad-scale ecologically relevant map can fix up sea use planners with an opportunity to incorporate an ecosystem-based approach when making regional scale planning decisions, taking a layer with the natural values into account, and thus help in an assessment of the potential impact of human activities. Marine landscape maps provides a baseline study of the complexity within a region giving field surveyors a planning tool for areas with limited information and may be used with regard to maritime safety issues. These issues make an indirect ecological input for a region showing the amount and distribution of broad-scale ecological subjects and thus provide a basis for sensitivity mapping of areas considered as emergency harbours in case of shipping accidents. Marine landscape mapping is in accordance with HELCOM Baltic Sea Action Plan aimed to apply an ecosystem-based approach to the management of the Baltic Sea.

The BALANCE project (2005–2007) was based on transnational and cross-sectoral co-operation with participants from nine countries surrounding the Baltic Sea as well as Norway, and was partially financed by the European Union through the BSR INTERREG IIIB programme (Al-Hamdani *et al.* 2007; Al-Hamdani, Reker 2007). The overall objective of the BALANCE was to enhance awareness on applying broad-scale ecologically relevant maps for informed marine spatial planning. The mapping of the marine landscapes in the Baltic Sea follows to some extent the approach, developed for UK waters (Vincent *et al*. 2004, Connor *et al.* 2007). The maps present the BALANCE efforts to produce a tool for implementing an ecosystem-based approach to Baltic Sea management keeping the long-term goal of sustainable development in sight. These marine landscape maps should thus be seen as the first transnational attempt to develop broad-scale coherent ecologically relevant maps for the Baltic Sea. The experiences which were made during this process presented in order to provide guidance for future marine spatial planning.

In the Russian sector of the south-eastern Baltic Sea (Fig. 1) the only A. Blazhchishin's attempt to landscape mapping is known (Blazhchishin 1992). He summarized sedimentological and relief data and composed conceptual scheme of marine bottom landscapes. In view of nominal participation of Russian scientists in the BALANCE project, marine data on Russian parts of the Baltic were incomplete and unsatisfactory. The aim of this paper is identifying and mapping seabed features of the Russian sector in the south-eastern part of the Baltic Sea using the BALANCE approach. A first attempt to solve this problem was undertaken by Sivkov *et al.* (2014). Their results are improved and developed in this work.

MATERIAL AND METHODS

The approach to marine landscape mapping is based on the use of available physical, chemical and hydrographic data to prepare ecologically meaningful viewpoint for areas with little or no biological information. It is basically a broad-scale mapping approach based on presenting geophysical and hydrographical data in thematic GIS layers from which "marine landscapes" can be derived. In order to limit the number of possible landscapes, the thematic layers are typically presented in a limited number of categories reflecting shifts in major ecological parameters.

Ecologically relevant entities of the Baltic Sea bed were identified in the BALANCE using "primary" environmental parameters which all have an influence upon the benthic distribution of species assemblages (Al-Hamdani, Reker 2007). The primary environmental parameters included sediments, available light and salinity. Not all data sets were used in the final analysis due to the following reasons. The "secondary" environmental parameters were considered in the BALANCE, but these were judged to be either more relevant for detailed habitat mapping e.g. water temperature, wave exposure. Entire regional parameter as ice cover, which does not influence significantly on the species distribution in the Baltic Sea, was not also taken into account. Oxygen concentration was considered as an environmental pressure and thus not suitable for a primary description.

In contrast to the BALANCE, our approach identifies five different kinds of broad-scales characterizations of the marine environment. We are using also temperature and ice cover in addition to "primary" environmental parameters of the BALANCE. These parameters both are important for determining broad-scale distribution of species in a regional context such as south-eastern part of the Baltic Sea. Temperature shows most pronounced seasonal variability. Ice cover is relevant for shallow Curonian and Vistula lagoons.

Sediments were chosen, owing to the fact that it is fundamental for the distribution of benthic organisms. National seabed sediment classification needed to be harmonized in order to produce one classification scheme, which has to be as simple as possible, but still takes into account biological importance. The BALANCE sediment classes applied in our mapping marine landscapes are:

I. Sedimentary bedrock (sometimes covered with boulders).

II. Hard bottom composite, including complex, patchy hard surface and coarse sand (sometimes also clay to boulders).

III. Sand including fine to coarse sand (with gravel exposures).

IV. Hard clay sometimes exposed or covered with a thin layer of sand or gravel.

V. Mud including gyttja-clay to gyttja-silt.

The lithological map of investigated area (Zhamoida *et al.* 2010), was used as a base for surface sediments mapping. The legend of this map was adapted to the above mentioned sediment classification of the BALANCE project.

Salinity was chosen as it influences the species distribution throughout the Baltic Sea. Due to the Baltic strong stratification it was decided to use bottom salinity for the development of the benthic marine landscapes and differentiate surface to bottom salinity for the pelagic landscapes. The following four categories (part from 6 BALANCE categories) of annual mean salinity were applied for our mapping region:

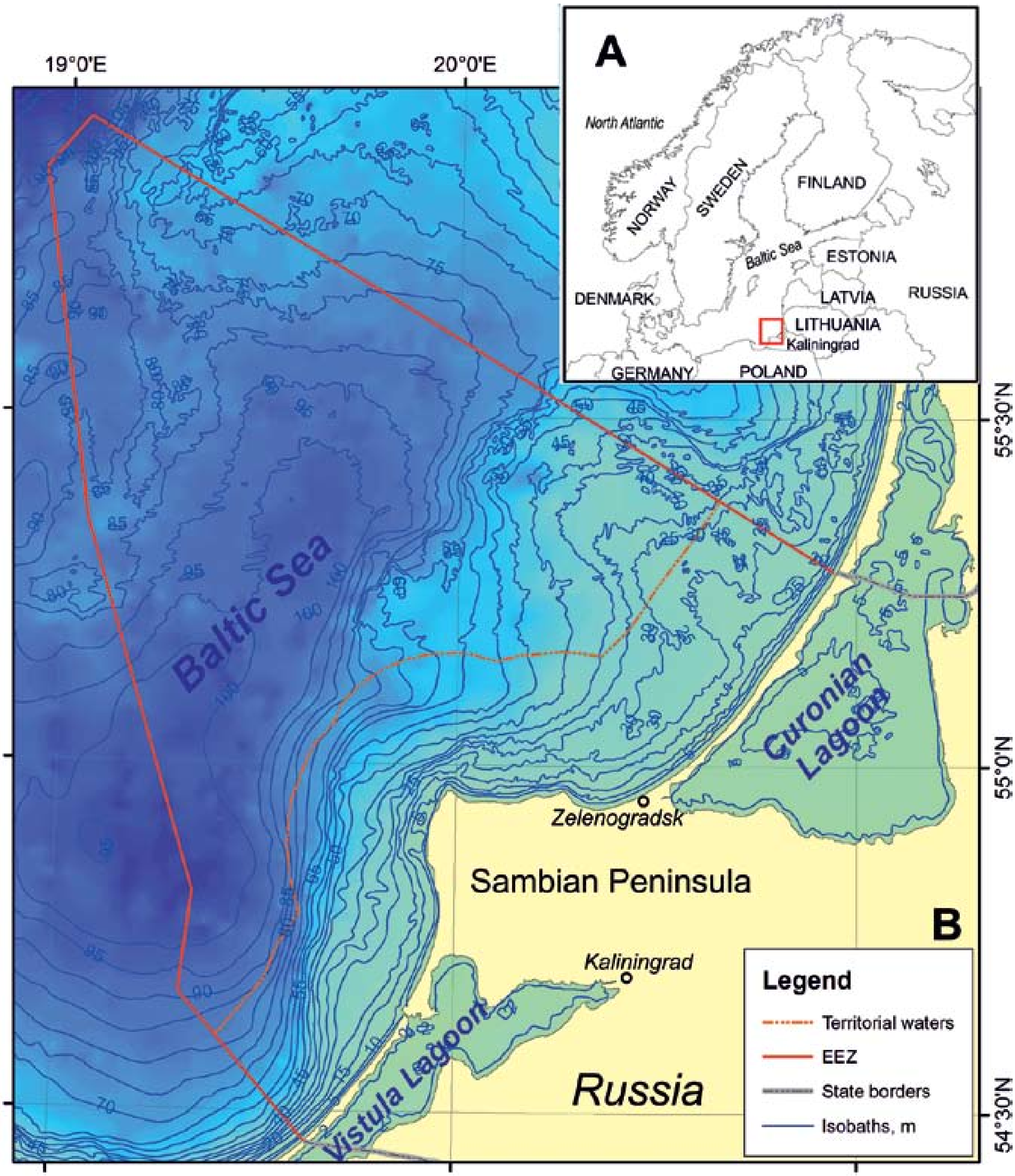

Fig. 1 Study area (A) and bottom relief (B) of the south-eastern part of the Baltic Sea (Russian sector). Bottom relief from Gelumbauskaitė *et al.* (1999). Compiled by E. Dorokhova, 2017.

I. Oligohaline I (< 5psu).
II. Oligohaline II (5–7.5psu).
III. Mesohaline I (7.5–11psu).
IV. Mesohaline II (11–18psu).

The bottom long-time annual average salinity distribution in the investigating area was taken from Dubravin *et al.* (2012) and Feistel *et al.* (2008).

From an ecological point of view, available light exposed seabed is one of the primary physical parameter influencing and structuring the biological communities in the marine environment, as it is the driving force behind the primary production by providing the energy for the photosynthesis – energy that is ultimately transferred to other organisms not capable of photosynthesis. The depth of the photic zone is traditionally defined, for benthic plants, as the depth where 1% of the surface irradiance (as measured just below the water surface) is available for photosynthesis. Only two intervals based on light regime were used. They reflect the significant ecological difference between the shallow water with the presence of submerged aquatic vegetation, and the deeper waters where fauna (and bacteria) dominates by diversity of species, abundance, and biomass. These intervals are:

I. The photic zone (where at least 1% of the available light touches the seabed).

II. The non-photic zone.

The photic zone depth was defined in the same way as in Al-Hamdani and Reker (2007) – measured Secchi depths multiplying by a factor of 1.9. Initial data for photic zone mapping were obtained during the industrial environmental monitoring of marine oil extraction conducted by oil producing company LUKOIL-KMN Ltd. (Dubravin, Navrotskaya 2008). According these data the annual transparency of near shore waters was approximate 4.5 m and photic zone depth about 9 m correspondingly. For the shallow waters of the Curonian and Vistula Lagoons the long-term (1999–2007) observations data (Alexandrov 2010) was used. The annual transparency value (during ice-free period) was 0.55–0.65 m in the northern part of Vistula Lagoon and 0.5–0.6 m in the south part of Curonian Lagoon. Correspondingly the averaged depth of photic zone of 1 m was accepted.

Temperature is one of the important physical parameters influencing the marine life. Annual temperature cycle in a specific region is relatively stable and provides marine organisms with predictable temperature conditions compared with conditions in terrestrial environments. Temperature influences the growth, reproduction and lethal tolerance of marine organisms and ultimately the overall geographic distribution of marine species.

Not only is the "secondary" (according to the BALANCE) parameter of temperature relevant for bottom landscape mapping due to influence on the marine life, but also because temperature determines the seasonal variability of marine ecosystem. Besides, this parameter is necessary for identification of vertical sea water structure of region, because of accepted from the BALANCE categories of annual mean salinity was chosen as they influence the species. Sharp salinity gradients called haloclines, which combined with temperature gradients (permanent thermoclines), define very robust boundary called a permanent pycnocline. This boundary is between a high salinity cold deep layer and a low salinity surface layer. The location of the permanent pycnocline is estimated as the depth with the strongest vertical density gradient.

During summer period the warm surface waters penetrate to the deep by turbulence through the action of wind and waves and form summer upper mixed layer (UML). Seasonal thermocline becomes sharp while it is going down and forces an obstruction for surface warm waters deeper penetration. By contrast, in winter period strengthening of wind-wave mixing (storm period) and thermal vertical convection, appeared as effect of surface evaporative cooling, result in sinking of cold surface waters and destroy the thermocline. Thus the winter UML is forming. Larger depth of winter UML in comparison with summer is responsible for development of summer cold intermediate layer, where the temperature even lower than in deep layer, which is not influenced by seasonal variations.

The temperature intervals are:

1) upper seasonal variable (0–55 m depth) - corresponds to the layer of maximum summer warming (depth 0–55 m, temperature varied during the year from 2 to 25 ^{o}C);

2) intermediate coldest – underlay upper layer and corresponds to the deepest part of the autumn – winter convection layer, is not influenced by summer warming (depth 55–75 m, most of the year the temperature is between 1–4 ^{o}C);

3) deep low variable relatively cold – corresponds to the layer of temperature increasing toward the sea bottom and is caused by North Sea waters inflows and subjacent near bottom waters (depth > 75 m, temperature 4–8 ^{o}C)

The bottom long-time annual average temperature data the same as salinity were taken from Dubravin *et al.* (2012) and Feistel *et al.* (2008).

Ice cover influences marine organisms by the potential destructive scouring of the substrate in a zone close to the water surface on which sessile organisms are attached. Ice cover also influences marine organisms indirectly through shading of available light for primary production or access to oxygen through exchange with the atmosphere. In according to the BALANCE for investigated area only two categories of ice cover was identified:

I. 0–90 days of ice cover.

II. No ice cover

In the shallow Curonian and Vistula lagoons ice cover destructive scouring can be appeared up to the depths of 1 m (Terziev 1992), i. e. 20 % from their maximum depths.

Listed above parameters do not take into account the ecological quality of individual marine landscapes at specific localities, and some regions (or landscapes) might be adversely influenced by e.g. oxygen depletion.

The bottom landscape map was created in ArcGIS software with using of above mentioned parameters as polygon vector layers. Vector layers were united and obtained polygonal objects were classified according to combination of marine bottom landscapes characteristics. Each of marine landscapes is assumed to reflect the broad-scale ecological requirements of the benthic species assemblages that may exist in the specific physical and geological environment defined by the individual landscape.

RESULTS

Combination of selected parameters allows distinguishing 21 types of bottom landscapes (Table 1, Fig. 2).

The dominant landscape type (number 21, Table 1) in the Russian part of the Gdansk Basin is located far beyond the surface photic zone, it is not under the ice-cover influence and characterized by mud sediment class, near-bottom salinity 11–8 psu and deep low variable relatively cold (4–7 ^{o}C) with ulterior seasonal variability. This landscape covers area about 3470 km^2 (30% from the all study area) and spatially almost coincides with the Gdansk Deep – the deepest part of the Gdansk Basin.

The second prevalence landscape (number 8, Table 1), is located on the shallow waters area outside of the photic zone and zone of seasonal ice-cover. It occupies the area of about 2400 km^2 (21%). The surface sediments presented by sand of different grain-size (with gravel exposures), near bottom waters are oligohaline II (5–7.5 psu) with pronounced seasonal temperature variability inherent for marine active layer.

The most perspective marine landscape from the point of view of nature conservation zones creation are the landscapes where bottom sediments represented by the hard clays partly covered by sands. These landscapes (numbers 13 and 14, Table 1) are located offshore near the root part of the Curonian Spit at water depth from 5 to 11 m (Fig. 2). Although these sediments have high organic matter content (more than 14%) they are referenced to hard clays sediment class because of its physical properties. It was supposed that

Table Marine landscape types of the south-eastern part of the Baltic Sea (Russian part). Compiled by D. Dorokhov, 2017.

Number	Landscape types
1	Sedimentary bedrock (sometimes covered with boulders), oligohaline II, upper seasonal variable
2	Hard bottom composite, including complex, patchy hard surface and coarse sand (sometimes also clay to boulders), oligohaline I, upper seasonal variable, photic, ice covered
3	Hard bottom composite, including complex, patchy hard surface and coarse sand (sometimes also clay to boulders), oligohaline II, upper seasonal variable
4	Hard bottom composite, including complex, patchy hard surface and coarse sand (sometimes also clay to boulders), oligohaline II, upper seasonal variable
5	Hard bottom composite, including complex, patchy hard surface and coarse sand (sometimes also clay to boulders), mesohaline I, intermediate coldest
6	Fine to coarse sand (with gravel exposures), oligohaline I, upper seasonal variable
7	Fine to coarse sand (with gravel exposures), oligohaline I, upper seasonal variable, photic, ice covered
8	Fine to coarse sand (with gravel exposures), oligohaline II, upper seasonal variable
9	Fine to coarse sand (with gravel exposures), oligohaline II, upper seasonal variable, photic
10	Fine to coarse sand (with gravel exposures), oligohaline II, intermediate coldest
11	Fine to coarse sand (with gravel exposures), mesohaline I, intermediate coldest
12	Fine to coarse sand (with gravel exposures), mesohaline I, deep low variable relatively cold
13	Hard clay sometimes exposed or covered with a thin layer of sand or gravel, oligohaline II, upper seasonal variable
14	Hard clay sometimes exposed or covered with a thin layer of sand or gravel, oligohaline II, upper seasonal variable, photic
15	Hard clay sometimes exposed or covered with a thin layer of sand or gravel, mesohaline I, intermediate coldest
16	Hard clay sometimes exposed or covered with a thin layer of sand or gravel, mesohaline I, deep low variable relatively cold
17	Hard clay sometimes exposed or covered with a thin layer of sand or gravel, mesohaline II, deep low variable relatively cold
18	Mud including gyttja-clay to gyttja-silt, oligohaline II, upper seasonal variable
19	Mud including gyttja-clay to gyttja-silt, mesohaline I, intermediate coldest
20	Mud including gyttja-clay to gyttja-silt, mesohaline I, deep low variable relatively cold
21	Mud including gyttja-clay to gyttja-silt, mesohaline II, deep low variable relatively cold

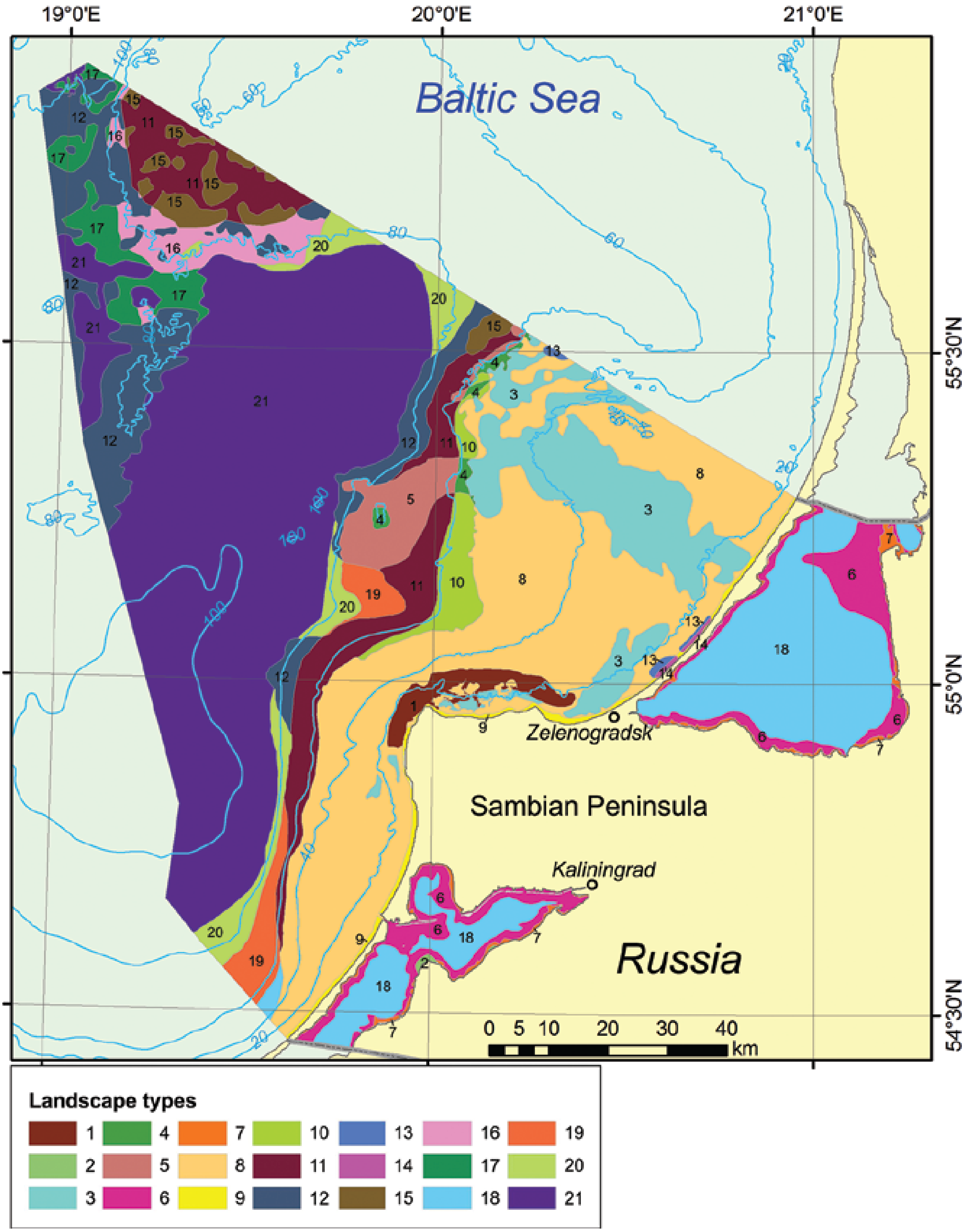

Fig. 2. Marine landscapes in the south-eastern part of the Baltic Sea (Russian sector). Landscape type numbers are referred in table. Compiled by D. Dorokhov, 2017.

these dense clays are transformed mud of paleolagoon (Curonian Lagoon) (Zhamoida *et al.* 2009; Sergeev *et al.* 2016). The lagoon mud was compacted and dehydrated by the pressure of dunes moving eastwards during the Litorina Sea transgressions. Note that in contrast with almost lifeless background of sand areas the landscape with ancient lagoon hard clay sediments is unique bottom oasis where the numbers of species sharply increase.

DISCUSSION

Previously, following marine landscapes in the study area were identified by Balzhchishin (1992): in *coastal zone* (under wave action) – bottom landscapes of flexible sand deposits, boulder pavement, stepped relief of bedrocks surface (often connected with boulder pavement), calm sheltered zones of mud deposition, debris cones of industrial pulp material; 2) in *transitional zone* (depths of 20–60 m) – horizontal plains, abrasion and abrasion–accumulative terraces, ancient cliffs, relict accumulative landscapes, separate areas of submerged eolian deposits, peat deposits covered with thin sand layer; 3) *deep zone* (deeper than 60–70 m) – landscape of slowly sedimentation (corresponds with halocline), landscapes of the Gdansk Deep slopes and floor with local pockmarks ("gas craters").

This study shows much more complete and variable marine landscape structure than previous study. Obtained detail marine landscapes can be used for creating and management of MPAs as they show the rarity and area covered by a specific marine landscape within the study area. The small areas of unique marine landscapes (like number 13 and 14, Table 1) must receive a higher protection level, as they are more vulnerable compared to the marine landscapes that cover larger areas. Besides, these landscapes adjoin to the coast of ecologically protected Curonian Spit, which is in the UNESCO World Heritage List.

It should be also taken into account, that the marine landscape maps are not better than the data used to develop them. In some regions, especially offshore, initial data points are rare. Consequently, further refinements need to be made through obtaining new data and improving area coverage, especially with sediment type data.

The following next steps can be made concerning landscape mapping in the study area (after BALANCE approach):

- The future advances should be continued to apply a transnational (Poland, Lithuania, Sweden) approach considering relevant scientific disciplines.
- It is necessary to add biological information which is vital for the marine landscape maps and for making ecosystem-wide environmental assessments.
- The identification of habitats associated with each type of marine landscape should be made in order to perform a proper validation of the produced maps. For example, such attempt was presented for the small area of near shore zone of the south-eastern Baltic (Kochezhkova *et al*. 2014).
- Tools, which improve accuracy and precision of the individual modelled environmental data layers, should be refined. This will increase the confidence rate of the resultant marine landscape maps.
- The new data set layers should be added, such as annually updated oxygen concentration maps.
- A sensitivity map associated with the individual marine landscapes should be developed, such as fragmentarily developed map (Blazauskas, Dorokhov 2014).
- 3D ecological modeling should be made for the study area that will help to estimate volume and show the temporal variation characteristics of the marine environment.
- The usual *one nation – one approach* is not desirable as it acts against the entire purpose of a broad-scale ecosystem-based characterisation of an ecoregion.

CONCLUSIONS

The presented map is a step to the integration of Russian sector of the south-eastern part of the Baltic seabed with landscape mapping of whole Baltic, composed on the base of coordinated international approach. It allows obtaining first objectives for future spatial planning studied marine regions in consideration of cross-border conditions. Adding of two nonbasic parameters to the three "primary" environmental parameters of the BALANCE project allows giving more detail and ecologically meaningful marine landscape map. According to the improvements the resulting map is more relevant to marine habitats.

The new landscape map allows to reveal the unique marine bottom landscapes of relict lagoon clays sediments with oligohaline II near-bottom water salinity, upper seasonal variable near-bottom water temperature, under as photic and non-photic conditions. These landscapes could be recommended for MPA development, especially because they are located near the Curonian Spit national park boundary.

It is obvious that for the purposes of real environmental management further improvement of created map is needed, such as scale enlargement and selection of the most significant parameters of mapping. This aim may be achieved only if the new ecological data, having high spatial resolution, will be collected. The process of assessment of individual landscapes ecological sensitivity to various types of anthropogenic influence should being developed simultaneously that needs biological parameters using.

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