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Towards sustainable use of marine resources in the south-eastern Baltic Sea (Lithuania): a review

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Abstract The article provides a consistent insight into the results and experience related to the implementation of activities fostering the development of marine economy in Lithuania. EU Strategy for the Baltic Sea Region and **the Blue Growth** concept explicitly focuses on maintenance of the good status of the marine environment of the European seas. Recently developed Lithuanian integrated maritime spatial plan aims to create the favourable conditions for sustainable development of marine economy, and particularly the offshore wind energy. Proposed and tested innovative solutions for selection of new disposal sites as well as handling the dredged soil in ports, contributes to more environmentally sound and economically feasible operations of the south-eastern Baltic Sea ports.

Keywords *• blue economy • marine spatial planning • beneficial use*

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INTRODUCTION

Growing demand for marine areas is being observed in the Baltics recently. This is related to the emerging new maritime related business, so called *'blue economy'*. Planning and implementation of different marine business requires better knowledge on marine environment. One of the main drivers pushing marine research forward is rapid development of the offshore wind energy sector in Europe and the worldwide. SE Baltic Sea proves the great potential and possibilities for electricity production from the offshore renewable energy sources. Being specific region with good wind conditions and still relatively low intensity of usage of the sea space the Baltic Sea is an area where considerable growth in the OWE development is expected in the coming 10–20 years. Along with growing economy, proper management of marine space and also resources was recognized as urgently needed. Developed concept of integrated maritime spatial planning and recently (July 2014) adopted EU Directive (2014/89/EU) encourages Member States to implement the planning of the Seas. The main principles of the planning of maritime activities are embedded in the international strategic documents. Among those are EU Integrated Maritime Policy; HELCOM Baltic Sea Action Plan (Recommendation 28E/9 on the "Development of Broad-scale Maritime Spatial Planning Principles in the Baltic Sea Area"); VASAB Long Term Perspective for the Territorial Development of the Baltic Sea Region and recently endorsed by European Parliament the new Framework Directive for Maritime Spatial Planning (Directive 2014/89/EU, adopted in July, 2014). The Directive sets the deadline for the Member States to establish the Maritime Spatial Plans (MSP) by 31st of March 2021. To achieve this a fundamental knowledge, and new, applicable for the planning, data sets and innovative solutions for improved management of marine resources are required.

The demand for maritime space in Lithuania increased considerably during past several years. Emerging new maritime uses such as offshore wind energy or/and marine aquaculture along with development of new port facilities; underwater electricity cables and underwater oil/gas pipelines concepts; development of liquid natural gas (LNG) market requires comprehensive maritime space planning (MSP) and proper management of the maritime uses. The main marine industry is related to Klaipėda State Seaport and marine cargo handling companies, Klaipėda LNG terminal, Būtingė and Klaipeda oil import-export terminals, Western Shipyard. The Lithuanian marine transport is growing, new sea uses (such us offshore energy) are emerging and requiring not only proper regulation, space and natural resources, but also having strong pressure on the integrity of the sea floor.

In 2012, Lithuanian Academy of Sciences has addressed to European Academies of Sciences Advisory Council (EASAC) several most critical environmental topics to be addressed in the south-eastern Baltic Sea (Lithuanian sector). Those were:

- Marine pollution by biogenic substances (nitrogen, phosphorus) transported from the mainland area – fostering the eutrophication.
- Pollution by oil products, chemical and synthetic materials.
- Impact on marine fauna and flora due to marine transport offshore and in port areas.
- Genetic risks to the fish gene pool related to submerged chemical weapons containing toxic substances (yperite, arsenic) including radionuclides.
- Ecological problems related to insufficient water exchange in and to the Atlantic Ocean.
- Adverse effects to marine benthic fauna and flora caused by introduced invasive species.
- Risks related to increasing extreme atmospheric events such as storms, hurricanes, exces rainfalls, deluges influencing the acceleration of sea level rise, coastal erosion, and degradation of natural sandy beaches.

Along with rapid growth of the maritime activities on a national scale, the fragile Baltic Sea ecosystem needs to be regarded and managed as single entity. This is possible when integrated marine spatial planning is introduced in each Baltic Sea Member State. There are key datasets that need to be used while developing the maritime spatial plan. Among those are bottom topography and morphology of the seabed; ge-

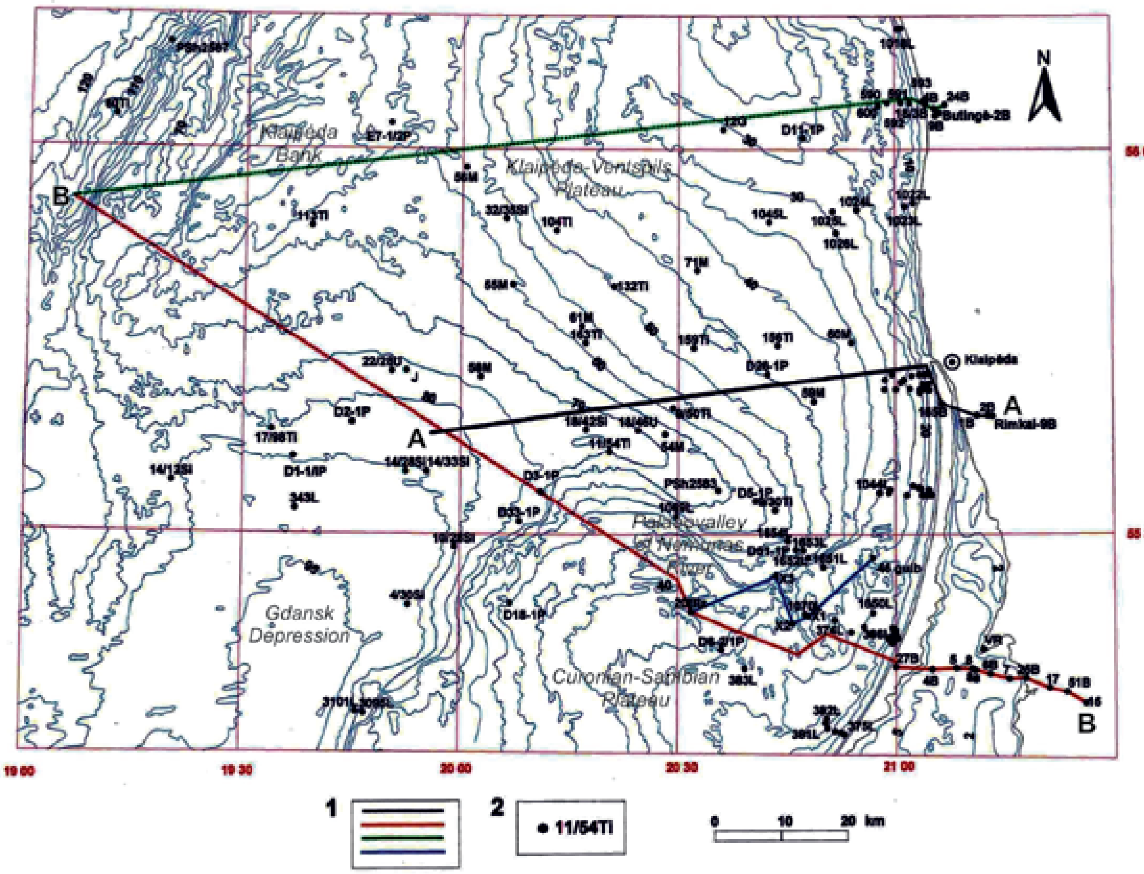

Fig. 1 Bottom topography of the south-eastern sector of the Baltic Sea (Lithuanian waters). Geo-seismic sections: A-A – Klaipėda traverse (see Fig. 3), B-B – Nida traverse (see Fig. 2). After L.Ž.Gelumbauskaitė, 2009, modified
Legend: 1 - geographical bearing of the geo-seismic sections; 2 - bore-holes and cores with their numbers. Isobaths drawn at sea every 5 m, at lagoon every 1 m

ological conditions, valuable bottom habitats, nursery and spawning grounds, areas important for wintering birds, hydrodynamic conditions, prospect of mineral resources and, finally, areas already occupied by the existing uses.

GEOLOGICAL CONDITIONS

Detailed bottom topography map, geo-seismic sections and simplified seabed surface sediments map have been developed in order to present the basic characteristics of the Lithuanian part of the Baltic Sea bottom (Figs 1-4). Deeper knowledge covering the sea bedrock geology including the pre-Quaternary geology map (age, lithology, tectonics) are published (Grigelis, 2011). It is important to note, that based on the tectonic evolution and petroleum potential studies of the Lower Palaeozoic entrails of the south Baltic Region, the Lithuanian Baltic Sea sector is well evaluated as containing possible oil-bearing resources (Stirpeika, 1999).

The palaeosurface of the sedimentary bedrock, according to latest data (Gelumbauskaitė, 2009), contains some denudation levels inserted in the Devonian / Triassic / Jurassic / Cretaceous rock surface (at 95–70, 65–50, 45–35 m b.s.l.). The thickness of Quaternary deposits offshore, at the depression flat, varies from 40 m to 5–15 m; yet at the coast it increases to 50–60 m. The Holocene sediments offshore are up to 3 m thick. However, the Baltic Ice Lake (early development stage of the Baltic Sea) sedimentary complex at the depression flat exceeds 17 m. Very uneven Late–Glacial–Holocene cover along the traced geo-seismic profiles evidents that eustatic / isostatic / tectonic dynamic in the postglacial basins are connected with glacial till deformations. Therefore, a deposition rate at offshore and near shore differs considerably.

All geological metadata used for data compilation are stored in the NRC database developed during the implementation of EMODNET-GEOLOGY and GEO-SEAS projects. Main deliverables were compiled at a scale 1:200 000 using ARC/GIS tools. Later on, different map layers have been fully integrated and stored into the One-Geology Europe (1G-E) portal (Stevenson, 2012).

The geological setting presented in this article is

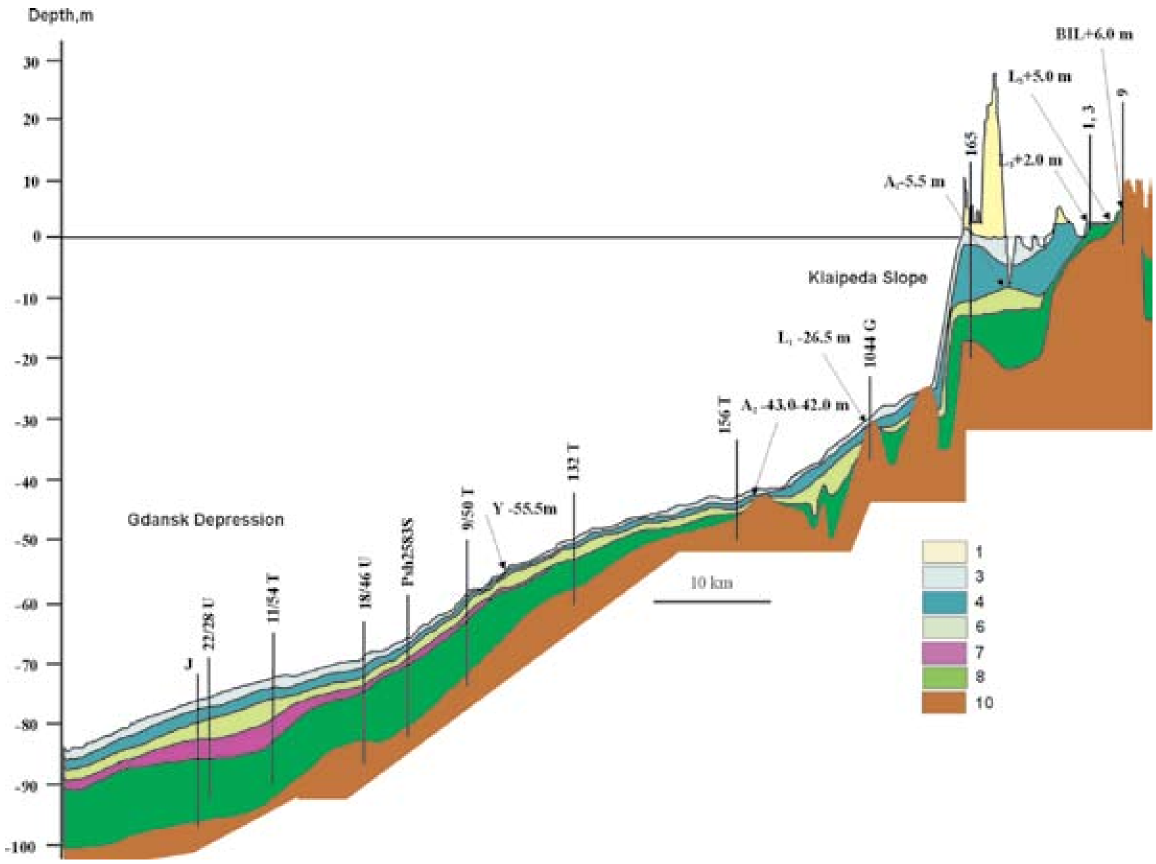

Fig. 2 Geological section on the traverse Nida (Gelumbauskaitė, 2009). Legend: 1–aeolian sand; 2–peat; 3–deposits of Postlitorina Stage; 4–deposits of Litorina$_{1\text{-}2\text{-}3}$ Sea Stage; 5–deposits of Postlitorina and Litorina Stages without internal stratification; 6–deposits of Ancylus$_{1\text{-}2}$ Lake stage; 7–deposits of Yoldia Sea Stage; 8–deposits of Ice Lakes and Baltic Ice Lake Stage without internal stratification; 9–limnoglacial deposits of Baltija (Pommeranian) Stage; 10–till of Baltija–Grūda Stage (Upper Nemunas–Late Weichselian); 11–till of Medininkai (Warthe) Stage; 12–till of Žemaitija (Warthe) Stage; 13–fliuvioglacial deposits of Grūda Stage; 14–transgression–regression peaks (marked by arrows) of different Baltic Sea stages

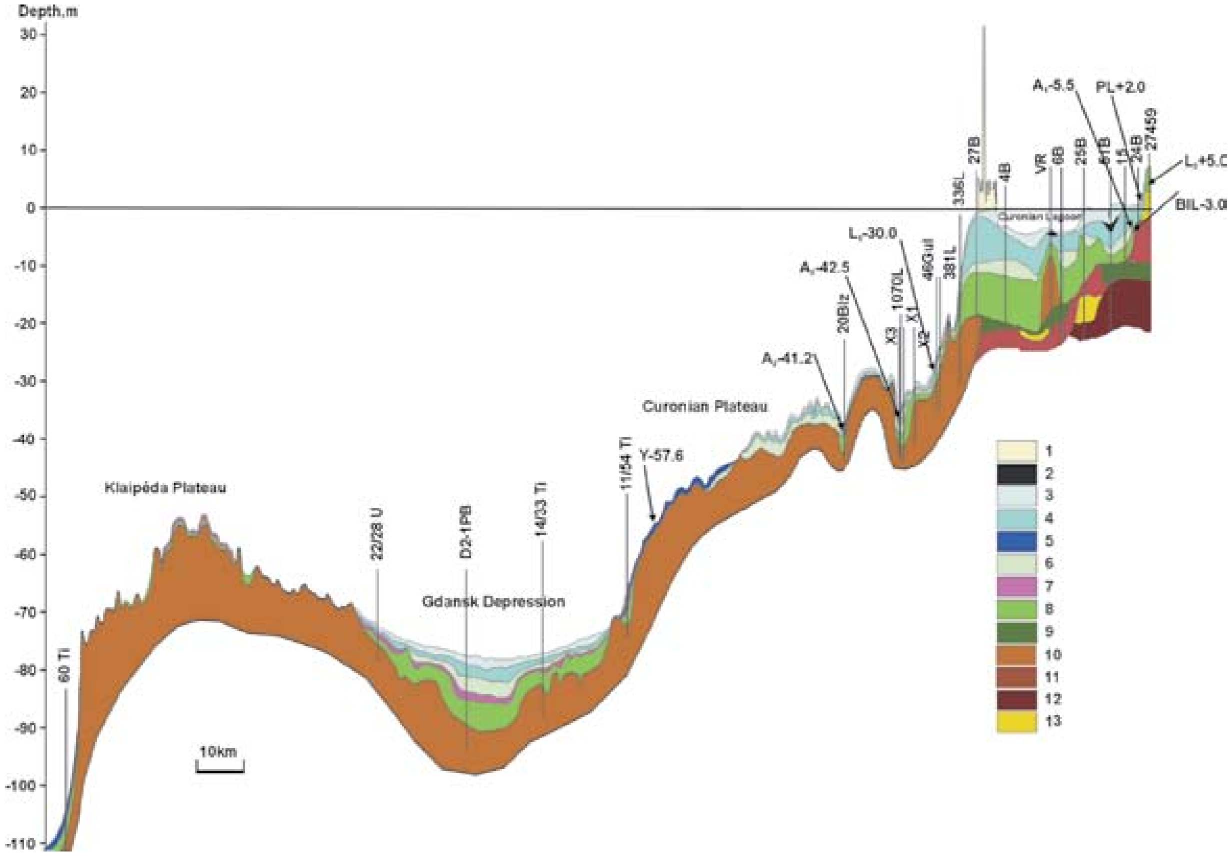

Fig. 3 Geological section on the traverse Klaipėda. (Gelumbauskaitė, 2009). Legend explanation see at the Fig. 2.

based on analysis of geological-geophysical data of different sources: seismo-acoustic profiling made on R/V "Doctor Lubecki" (1997-1999), bore–holes and cores of geological mapping at a scale 1:50000 (2000, 2004); bore–holes drilled from R/V "Kimberlite" (1997); cores of geological mapping at a scale 1:200000 (1975-1978; 1989); cores of geological mapping at a scale 1:50000 (1997); coring done during implementation of the programme "Word Ocean" (1982), owner ABIO RAS (1998); bore–holes made from "PETROBALTIC" (1989-1990) and from R/V "YUNIKON" (1995).

Bottom topography and morphology features are exposed on detailed bathymetry map (Fig. 1). The basic marine and coastal zone units are distinguished there, including the Curonian and Klaipėda plateaus, with inter–Klaipėda gentle slope of the Gdansk Depression; Curonian Lagoon and the barrier island Curonian Spit; Nearshore zone; Palaeovalley of the Nemunas river.

The geological sections (Figs 2, 3) demonstrate the palaeomorphology and internal structure of the Lithuanian part of the Baltic basin. The sections reveal the evidences of former transgressions and regressions. Interpretation is based on the curves of the relative sea level fluctuations related to Post-glacial time (Gelumbauskaitė, 2009). The geomorphometry and morphogenetic features of the modern relief are

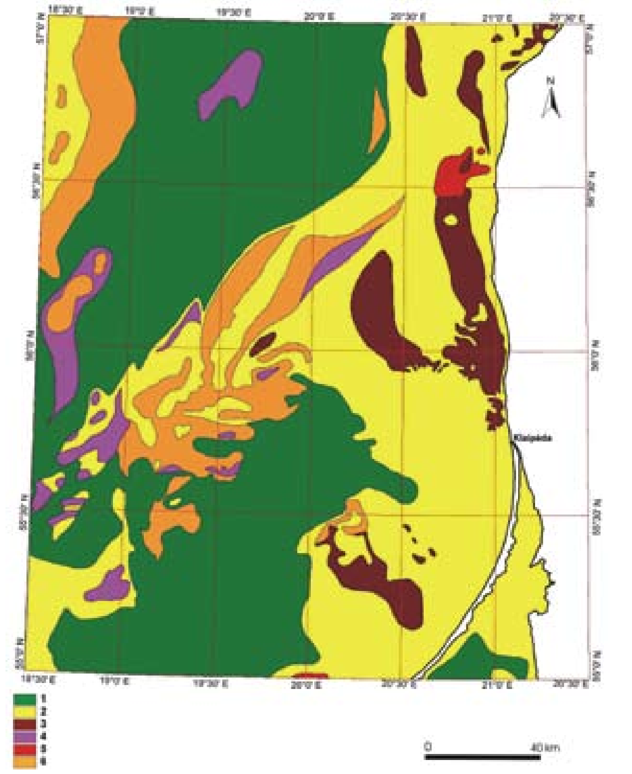

Fig. 4 Seabed surface sediments map, modified after the Folk classification system. Legend: 1 – mud to sandy mud; 2 – sand to muddy sand; 3 – coarse-grained sediment; 4 – mixed sediment; 5 – bedrock; 6 – till. After L. Ž. Gelumbauskaitė, 2010

examined using detailed bathymetry (at 2 m intervals) and seismo-acoustic records. Lithological composition and sorting of the sediments, identified ancient coastal bars and scarps as well as fragments of terraces allows tracing different hypsometric levels of subaqueous ancient shore formations. Seismic records of strong reflectors penetrating the Late Glacial and Holocene sequence clearly indicate the differences in lithology, allows distinguishing seismic units and correlate litho–biostratigraphy of the profiles with the cores and/or boreholes.

The sections explain palaeogeography and depositional–erosional history of fluctuations of the Late Glacial and Holocene basins in the south-eastern part of the Baltic Sea (Gelumbauskaitė, 2009). Large complex of the geomorphologic, geo–seismic and radiometric methods have been used and surveys of the subsiding SE Baltic coast carried out. This allow to recognise and investigate fragments of ancient shore levels and, even more - to reconstruct an internal structure and morphology of the ancient shore formations, to identify boundaries and oscillation peaks of the Late Glacial and Holocene basins. According these data the model of the relative sea level changes on the Lithuanian coast following from south to north has been constructed.

Seabed surface sediments map (Fig. 4) is produced following the EUSeaMap requirements. Data harmonisation includes an evaluation of the different classification schemes of seabed sediments and construction of the seabed substrate map to be integrated with a broad-scale habitat mapping (Kaskela, Gelumbauskaitė, Grigelis *et al*. 2010). The approach was adapted and seabed surface material reclassified accordingly. Six substrate classes were distinguished based on the modified Folk triangle classification system (mud to sandy mud; sand to muddy sand; coarse-grained sediment; mixed sediment) and taking into account two additional classes (bedrock, and till). The substrate reclassification scheme provides an estimate of the substrate from the uppermost 30 cm of the sediment column. One seabed substrate map was developed for the study area. Estimated (from sediment core data) sediment accumulation rate (SAR) for the open sea waters is 0.01–0.50 cm/year and 0.5–1.5 cm/year for the Curonian Lagoon.

Coastline. According to the coastal typology Lithuanian Baltic coastal area can be described as a combination of wave dominated sediment soft rock coast with micro-tidal dunes (Janukonis, 1994; Žaromskis, Gulbinskas, 2010). Regarding coasts composition two different parts can be distinguished – sandy coast of the Curonian Spit and mainland coast (north from the Klaipėda State Seaport entrance channel) represented by accumulative-erosional sandy beaches mainly. Here only a small part of the coast north to the Klaipėda port entrance channel, between Giruliai and Nemirseta, can be dedicated to the coastal scarps and bluffs of glacial drift deposits.

The main threat to the coast is imposed by natural and artificial reasons. On the one hand, sea level rise and becoming more often stormy weather events are continuously affecting the coastal behaviour. On the other hand engineering port developments as prolonged breakwaters at the entrance channel of Klaipėda Port are blocking the sand migration along the shore and there why the sediment deficit is increasing in the northern part of the coastal area.

INTEGRATION OF ENVIRONMENTAL DATA IN THE PLANNING PROCESS

According to the Law of Territory Planning (1995), the general plans of territory of the Republic of Lithuania, territories of counties, municipalities and their parts are obligatory planning documents in order to ensure the long-term sustainable development and reasoned use of the area, finances and natural resources. During the planning of the Lithuanian marine areas, new functional Open Sea zone was established. Already existing in terrestrial plan – Coastal zone (including territorial waters) was prioritized for recreation, nature conservation and fishery as well as transport. Newly established Open Sea zone is an area that has specific functional role (see also Mileriene *et al.* 2014). Defined priorities here are shipping, fishing and development of marine infrastructure for oil prospect and marine energy projects. Spatial plan considers the possibility for exploration and exploitation of marine mineral resources in marine area of Lithuania, except near shore and marine protected areas. The exploration of marine mineral resources in Lithuania is not started yet, therefore the specific, most suitable or reserved areas could not be defined at this stage. As a result of planning, several main zones have been distinguished:

- Nearshore zone up to 20 m water depth – important zone for land sea interaction, ports development, area where most of the biological assets are concentrated, zone important for recreation and coastal stability.
- Sea floor elevations – Klaipėda-Ventspils Plateau and Klaipėda Bank in the north and Curonian-Sambian Plateau in the south are characterized by relatively shallower waters in the open sea – favourable conditions for marine infrastructure development and mineral resources extraction and potentially suitable for development of valuable bottom habitats.
- The deepest parts of the marine area – Gdansk Basin, palaeovalley of Nemunas River and slopes of Gotland Basin are reserved for navigation, fishing and future needs.

The developed map of planned marine activities (Fig. 5) delineates seven functional regions with specific prioritization for marine activities. Those are zones of (1) decentralized development; (2) use of renewable energy sources; (3) shipping; (4) military training and ecosystem conservation; (5) mixed purpose; (6) port development and (7) protection of coastal ecosystem.

Each of the region has the unique set of the priorities sea uses identified and indexed to reflect the primary and secondary group of uses to be developed in the delineated region.

APPLICATION OF PLANNING PRINCIPLES

Assessment of offshore wind energy potential

The vision to develop wind energy offshore (OWE) has been supported by throughout analysis of the existing legislative system and the existing obstacles for the developments at the sea, stocktaking of existing maritime uses; OWE targets set by the national authorities. Selection of the most suitable sites for offshore wind power parks construction depends on certain pre-conditions:

- Sea depth. Assuming that technically reasonable maximum depth is 50 m;
- Wind speed. Modelling data versus real measurements at the pre-selected site;
- Seabed geology. Geological structure of the seabed for optimal choice of foundations for wind towers and cable laying routes;
- Transmission grid. Distance from-to the shore, available substations, capacity of existing/planned power lines;
- Current and planned sea use;
- Existing natural heritage and mineral resources;
- Limitations (reserved zones and areas dangerous for development) for economic activities.

According the above-mentioned conditions, six potential zones suitable for offshore wind energy development in the Lithuanian EEZ have been identified (Fig. 6).

All six identified areas have been preliminary assessed for impact on the different natural components such as geological conditions, seabed habitats, fishes, birds and related protected areas, visual pollution; and in relation with some of the economic activities such as shipping, fishery, dumping and mineral resources and engineering infrastructure.

Geological conditions. Possible negative impact on the seabed integrity was analyzed. If developed

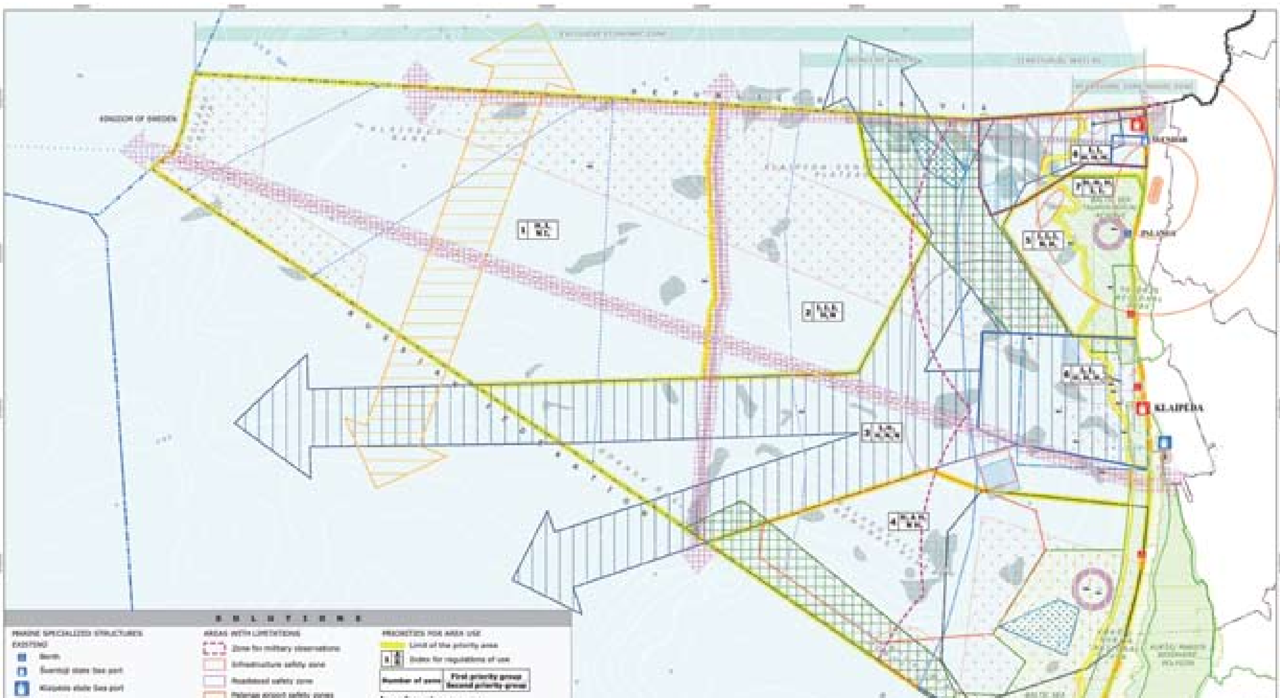

Fig.5 Zoning of maritime activities development in the Lithuanian marine area. ©State Enterprise State Land Fund, 2014

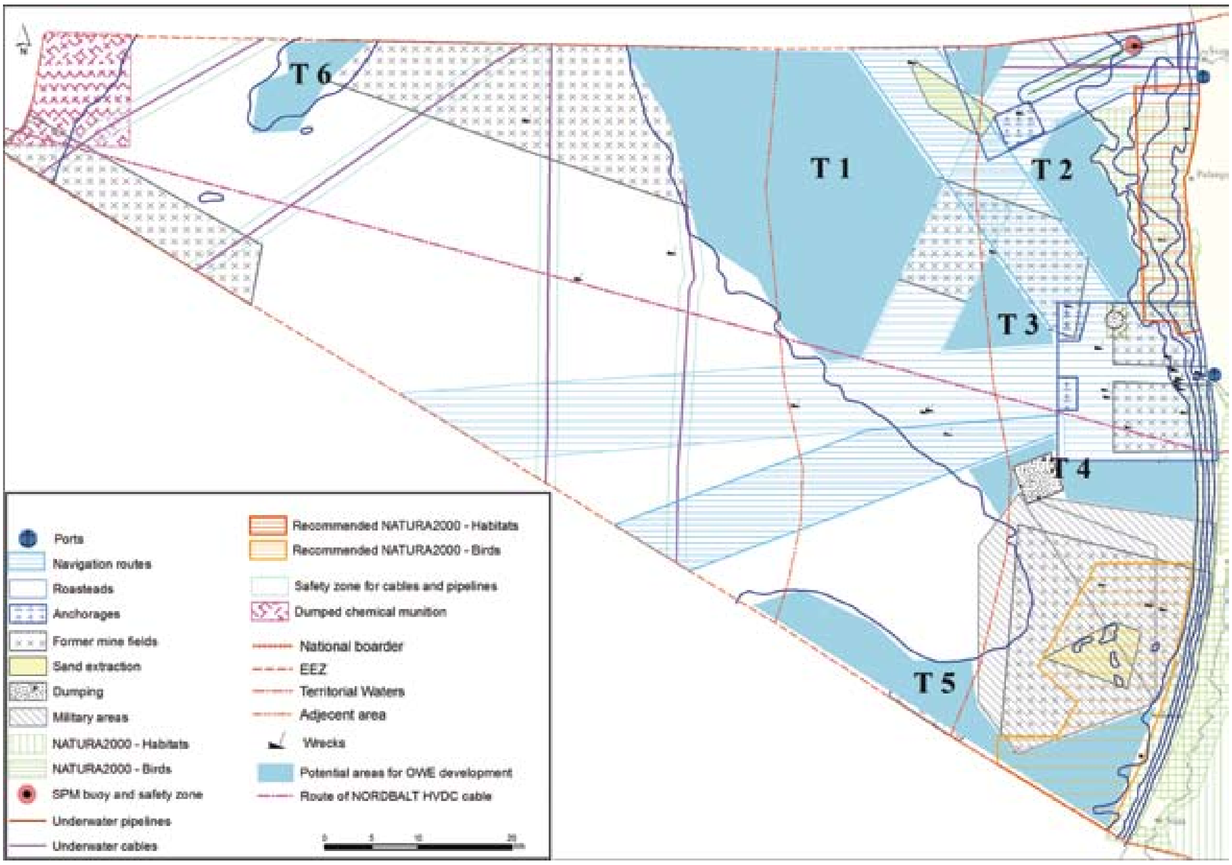

Fig. 6 Sea use and potential OWE areas (as for 2013). Compiled by V. Jurkin, 2013

in the areas T2, T4 and T5, OWE installations would have only local impact for the recent sedimentary processes and deposition of the bottom sediments. In all of the areas, foundations would penetrate the entire Quaternary section and enter the pre-Quaternary sedimentary rocks or remain within the hard Quaternary deposits. Engineering geological conditions for substructure installations are favourable.

Seabed habitats. Possible direct destruction of benthic habitats in OWE park foundation construction sites; the negative effects on benthic organisms are due to an increase in water turbidity during construction. The positive impact is the possible occurrence of secondary habitat structures after installation of foundations. In most of the pre-selected areas, important seabed habitats are not present, only T2 is bordering the important reefs.

Fishes. During construction, there is a possibility of scaring away or of physical impact due to noise and vibration, impact on feeding due to increased water turbidity as well as loss of the feeding base on the site of the foundations constructed. During operation, a positive indirect impact is possible due to an increase of potential nutrition objects and appearance of a new spawning ground. In the areas T1, T3 and T6, there is no impact on fish migration and spawning expected. T2, T4 and T5 are close to the important fish migration paths and spawning grounds.

Birds. The biggest impact is possible on migrating and wintering birds. Only T3 and T4 are out of the important areas for birds, others – T1 and T6 are partly overlapping with research areas devoted for development of *Natura 2000* network; T2 and T5 are partly overlapping with existing areas important for birds' protection.

Protected areas. Possible impact on protected heritage, thus it is important to pay special additional attention. Only T4 and T5 are bordering the Curonian Spit National park, the rest of the areas are away from protected areas.

Soil disposal and mineral resources. The available sand and oil resources need to be taken into consideration as an objective of competition for the same sea space. Only T1 area overlaps with potential areas for oil extraction, but until the proper exploration of the existing resources has not been carried out, information is uncertain.

Engineering infrastructure. It is important for planning the sites of foundation establishment and cable laying routes. Safety zones of the cables may limit the establishment plans of the wind power plants and cables. All pre-selected areas are away from existing underwater cabling and pipelines, only T1 is traversed by underwater cables of un-identified origin and ownership.

Shipping. A safe distance must be kept from the shipping lanes, port roadstead and anchorages. T5 and T6 have no influence to the shipping as they are away from the main shipping corridors. All others are away, but bordering the important shipping corridors. Proper safety zones will have to be established.

The demand of renewable energy and high pressure by the investors and researchers being in line with commitments to the EU, ensured that in May 2011 the Law on Renewable energy sources of Republic of Lithuania has been approved. Next and essential step unlocking the possibilities to switch from the OWE vision to the real implementation – decision of the Ministry of Environment (in 2012) to extend the spatial solutions of the National General Plan to the sea.

Sustainable use of marine resources

Maintenance of the navigable depths in ports and entrance waterways is the key for successful operation. This tightly relates to the dredging and disposal activities. If no beneficial use of the dredged material is possible, using of maritime spatial principles while selecting the new disposal sites might create favourable conditions for economically and environmentally sound operations. This include a risk assessment and sustainable management planning, considering ecologic, economic and social issues. The process of sustainable management requires the application of Best Environmental Practise (BEP) as described in the HELCOM Guidelines for the Disposal of Dredged Material at Sea as well as accordance to EU and national legislation throughout all stages of the management process. On one hand disposal of non-contaminated sediments might be considered as secondary resource for recovery of sediment balance in the nearshore zone, on the other hand selection of the site close to the dredging area might have positive economic effects, which also contributes to the less environmental impact. Although officially approved planning procedures are not adopted, countries have clearly identified general principles of selection the disposal sites. The main ecological concerns are related to the potential contaminants from port areas, maintenance of sea floor integrity, and protection of sensitive and valuable natural assets. If developed, MSP is the first document to consider while looking for the most sustainable disposal site. If MSP is not in place, identification of new site for disposal has to follow the main principles and steps of MSP including identification of the relevant stakeholders, analysis of existing ecological and socio-economic conditions, mapping of current uses, screening the existing regulations and legal framework, evaluation of economic viability.

The concept was tested for the Šventoji Port. Four new potential places for the disposal of dredged material offshore have been identified (Fig. 7B) applying the MSP principles, *i.e.*, taking into account the current and planned uses of the sea, considering the

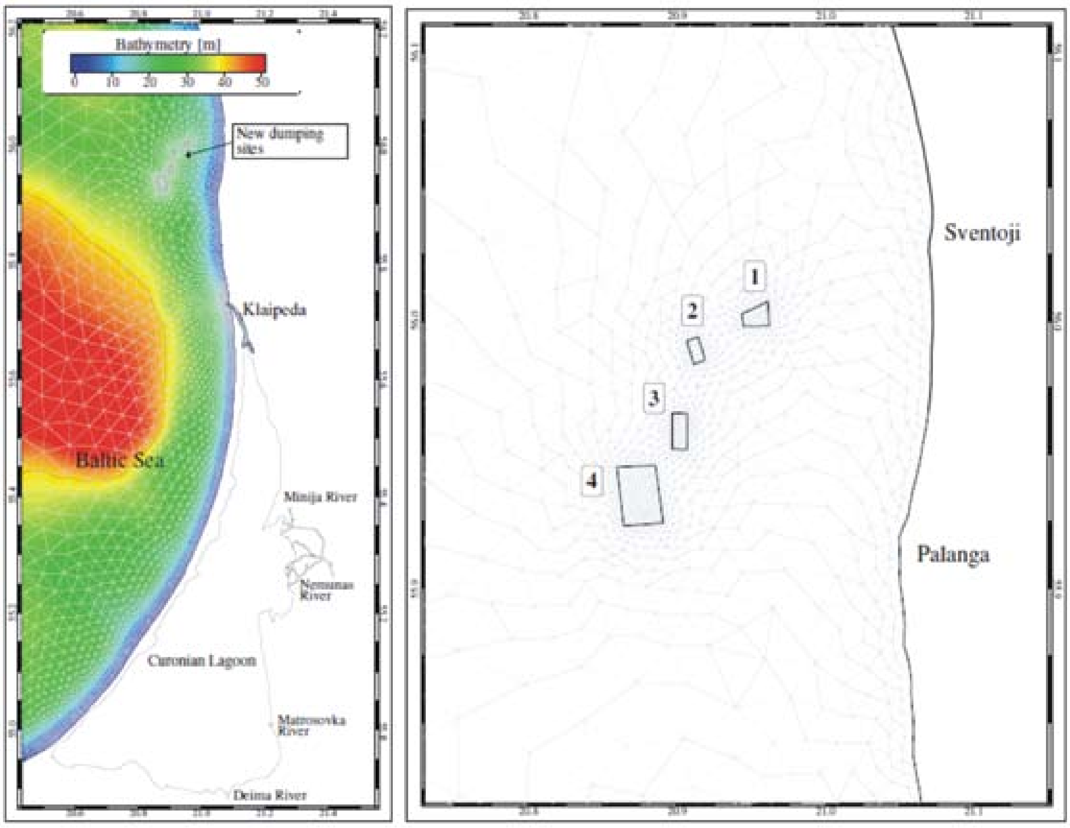

Fig. 7 (A) Computational finite element grid and (B) alternatives of the offshore disposal places and numerical mesh. Compiled by Ch. Ferrarin, 2013

environmental conditions, geological-geomorphological structure of the sea bottom, lithodynamic conditions, distribution of ecosystem components. The distribution of disposed material (bedload, suspended) has been modelled using the 3D sediment transport model SHYFEM (Ferrarin *et al*. 2008, 2010). Modelling involve the spread of dredged sediments during disposal and after the sediments being settled with given scenario of multiple disposal events for one year. Selected spatial domain represents the Klaipėda Strait and the Lithuania coastal area of the Baltic Sea until the 70 m depth contour through a finite element grid. As shown in Fig. 7A, the finite element method gives the possibility to follow the morphology and the bathymetry of the system and better represent the zones where hydrodynamic activity is important to consider. High spatial resolution was used to describe the areas of the four potential disposal sites. In these areas the model resolution is about 150 m (Fig. 7B). The water column is discretized into maximum 16 vertical zeta levels with progressively increasing thickness varying from 1 m for the first 12 m to 18 m for the deepest layer of the outer continental shelf. The open boundaries of the considered system are the edges of the Baltic Sea area and the Klaipėda Strait. Open sea boundary water temperature, salinity, water levels and water velocity were obtained by spatial interpolation of 1 nautical mile spatial resolution forecasts by the operational hydrodynamic HIROMB (Funkquist, 2003) provided by the Swedish Meteorological and Hydrological Institute. The temperature and salinity initial fields were also spatially interpolated from data of model HIROMB while spatially uniform water level was used for initial condition.

The Klaipėda Strait water fluxes, water temperature and salinity were obtained by a numerical simulation of the SHYFEM model over a domain which comprise both the Curonian Lagoon and the Baltic Sea (Zemlys *et al*. 2013). Meteorological forcing fields were obtained by forecasts of the operational meteorological model HIRLAM (www.hirlam.org) provided by the Lithuania hydro-meteorological service. The simulations were carried out with a variable time step with a maximum value of 20 s for the time period between 1 January and 31 December of the year 2010. The model results show that the area is located in the centre of a surficial circulation cell and therefore the average surface currents have intensity lower than 2 cm/s. In the numerical simulation, the material for disposal was considered as a mixture of sediment types, ranging from clay to coarse sand.

The applied methodology allows to describe the principal processes involved in the sediment spreading and deposition and to reproduce the fate of sediments during disposal and after the sediments being settled (Fig. 8). Generally, in all cases sediments tend to spread at the surface towards north and south-east, while in the bottom they concentrate inside or nearby the disposal area.

The pilot studies has proved that adopted methodology is a powerful tool for selecting the place and investigating the fate of disposed material and could be used to delineate a sustainable management of dredged sediments. Introduction of so called "eco-dumping" concept, among mentioned above, goes along with

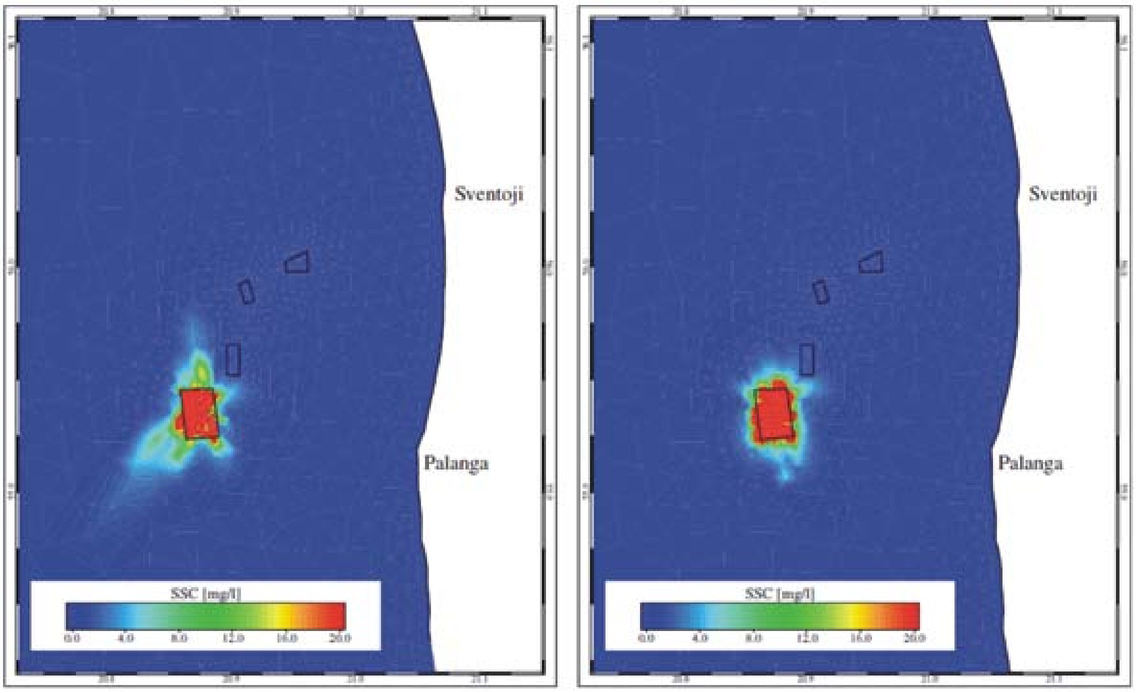

Fig. 8 Maximum suspended sediment concentration at the surface (left panel) and at the bottom (right panel) at the 4th disposal site. Compiled by Ch. Ferrarin, 2013

modelling exercises and therefore ensures that disposed sediments are in balance with geological, hydrodynamic and ecological conditions on and adjacent to the disposal site. When planned as introduced, disposal activity might be recognized as economically beneficial and environmentally sustainable action.

CONCLUSIONS

The planning of Lithuanian maritime space was the first attempt to integrate the environmental, economic and social needs into one comprehensive plan. Prepared spatial solutions creates the pre conditions for future developments at the sea and at the same time require new quality of the scientific research while investigating the marine resources and evaluating the economic effect as well as environmental consequences. The conceptual solutions supplementing the General Plan with marine part were based on MSP principles developed by the Cross-border Oceanographic Commission of UNESCO, adopted by VASAB – HELCOM and followed by the actions defined in the EU Baltic Sea Region Strategy Action Plan. Both were based on specifics of natural framework and conditions required to facilitate the developments of future uses as well as optimize existing ones. Relevant for planning data is research based, limited in time and funding. This often results in discontinuity and fragmentation of the knowledge. Dispersal of data is a problem at both national as well as the pan-Baltic scale. The spatial and temporal resolution of the available data is also highly influencing the resolution and quality of the plan (Zaucha, 2014). In order to facilitate planning, complex environmental information needs to be translated into parameters, which can be used in the assessment. However, it is not always clear which parameters are actually needed or even suitable for the planning purpose. Usually, planners cannot use basic ecological information unless there are clear procedure for translating ecological and hydrographic data into relevant planning information – generalized and integrated maps and schemes.

The results of MSP principles application for offshore wind energy development and selection of new sites for offshore disposal of dredged material from the port were provided. Presented applications promotes the integration of findings of scientific research, modelling of hydrodynamic conditions and behaviour of disposed mater. Additionally the principles of marine spatial planning while finding the suitable places for beneficial disposal at sea have been applied.

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