Assessing marine ecosystem services richness and exposure to anthropogenic threats in small sea areas: a case study for the Lithuanian sea space

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Abstract

The Lithuanian sea space belongs to the smallest sea areas in Europe. The sea space incorporates multiple marine ecosystem services (MES) that support human-wellbeing and sustain maritime economies, but is also subjected to intensive anthropogenic activities that can affect its vulnerable ecological components. We present a flexible geospatial methodology to assess MES richness (*MESR*) and to analyse areas of exposure of MES to human impacts using a MES exposure index (*MESEx*). Source of anthropogenic threats to MES were firstly derived from the Marine Strategy Framework Directive and include marine litter (from ports and shipping), underwater noise (from offshore pile driving and shipping) and hazardous substances (from oil extraction platforms). Results were presented for the three main planning areas in Lithuania, the Lithuanian Coastal Stripe, territorial waters and EEZ. In detail areas of highest MESR are located in the coastal areas of the Lithuanian Mainland Coast that are particularly rich in ecosystem services such as nursery function from for Baltic Herring and cultural services related to valuable recreational resorts, landscape aesthetic values and natural heritage sites. Modelled pressure exposure on selected MES show that cultural ecosystem services in proximity of Klaipėda Port can be particularly affected by marine litter accumulation phenomena, while transboundary effects of potential oil spills from D6-Platform (Kaliningrad Region) can affect valuable fish provisioning areas and coastal cultural values in the Curonian Spit. Results were discussed for the relevance in MES assessment for marine planning in small sea areas and the methodological outlook of the application of geospatial techniques on cumulative impacts assessment within this region of the Baltic Sea.

1. Introduction

Marine and coastal ecosystems provide a wide range of benefits to human society, such as provision of sea food, habitat, space for offshore wind energy generation, nutrient cycling, recreational opportunities, coastal landscapes and natural and cultural heritage values (Manea et al., 2019; Teoh et al., 2019). Research on marine ecosystem services (MES) has evidenced the importance of integrating social, ecological, and economic aspects in the assessment of natural resources in support of planning and decision-making. In the last decade there has been an exponential growth of international initiatives for ES assessment such as the Millennium Ecosystem Assessment (MA 2005), The Economics of Ecosystem Services and Biodiversity (TEEB), the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES) and the Common International Classification of Ecosystem Services (CICES).

From a planning perspective, The Maritime Spatial Planning (MSP) Directive requires member states to apply the ecosystem-based management (EBM) for the sustainable development of their sea areas (EC, 2014). In order to implement EBM, methodologies that address the risks, impacts or trade-off analysis from sea use activities on marine environmental components are needed (Andersen et al. 2013; Holsman et al. 2017) to support decision-makers in the development of ocean management strategies that ensure sustainable marine resources use and ensure MES flow.

In the last decade several attempts for the integration of the ES concept as indicator for human well-being into risk and impact assessment occurred (Depellegrin and Blažauskas, 2013; Papathanasopoulou et al., 2015; Culhane et al., 2019). Nevertheless, methodologies in the marine realm are still lacking, mainly due to the complexity of the bio-physical processes in the marine environment and the lack of regional and macro-regional datasets (Liquete et al. 2013; Sousa et al. 2016). In particular methods that can be used for rapid screening of the effects from a multitude of anthropogenic pressures require extensive data infrastructure and intensive modelling procedures for their dispersion and behaviour modelling. A planning relevant MES assessment requires detailed monitoring campaigns needed to assess status of marine environmental components (e.g. habitats, benthic communities and marine mammals) at appropriate geographical scale to understand biotic and abiotic processes that generate MES provisioning. These are costly and time consuming endeavours (ICES, 2010; Liquete et al., 2013).

Across European sea basins several sea areas can be considered as small sea areas, such as Lithuania, Slovenia, Estonia or Belgium (MSP-Platform, 2017). Marine planning in small national jurisdiction areas can result into a challenging task, due to the high concentration of human activities in the sea space, the intensive land-sea interaction mechanisms in combination with ecological hot spots. In small sea areas anthropogenic pressures exerted by human activities such as hazardous substance release, marine litter or eutrophication can have serious effects on ecosystems and impair maritime economic activities of national importance.

In this research we present a geospatial methodology for the analysis of MES richness and MES threats on a case study for the Lithuanian sea space (South-Eastern Baltic Sea), one of the smallest sea areas in Europe. The methodology consists of a modelling procedure for MES richness (*MESR*) assessment and mapping based on twelve MES (four supporting, three provisioning, two regulating and three cultural MES). Based on the methodology we apply a MSFD-oriented exposure analysis of the most relevant anthropogenic activities and model the exposure to MES (marine litter, underwater noise and oil spills) using an exposure index (*MESEx*). Results were discussed for their geospatial constrains and for the relevance for marine spatial planning within small sea areas.

2. Material and methods

2.1. Case study area definition

The Lithuanian Baltic Sea space covers 6,411 km^2 and belongs to the smallest sea areas in Europe. The sea area can be divided into three units (Table 1): the Lithuanian Exclusive Economic Zone (4,579 km^2; 71%) and the Territorial Waters (1,832 km^2; 29%), which extend over 12 nautical miles (nm). The Coastal Stripe covers 411 km^2 (6%) as part of the Territorial Waters, refers to the coastal area under protection within the Coastal Stripe Law (2002), where economic activities are strictly regulated (Baltic Greenbelt 2011). The coastal stripe is part of the territorial waters and refers to sea areas comprising the 20 m isobath and the terrestrial boundary of the Curonian Spit in the south and the 300 m territory of the Lithuanian Mainland Coast in the north.

Table 1. Marine boundaries (perimeter and area) and depth ranges in the study area.

Boundary	**Perimeter (km)**	**Area in km^2 (%)**	**Depth range (m)**
Coastal Stripe*	349.6	411 (6)	0 to -20
Territorial waters	371.2	1,832 (29)	0 to -51
Exclusive Economic Zone	548.2	4,579 (71)	-24 to -120
Total	653.9	6,411 (100)	0 to -120

*The Coastal Stripe is part of the Territorial Waters and therefore not included in the total area.

The Lithuanian sea space borders with Latvia in the north, Russia (Kaliningrad Region) in the south and Sweden in the west (Figure 1). The Lithuanian coast can be divided into two distinct geomorphological segments: in the south the Curonian Spit a sandy peninsula of 51.3 km, which is a UNESCO World Heritage Site. The Curonian Spit separates the Baltic Sea from the Curonian Lagoon. In the north the Mainland Coast covers 38.49 km of shoreline. The length of coastline is 90.6 km long (Žilinskas 2008). Klaipėda region is the only coastal region of Lithuania and includes four municipalities sharing the coastal area: Klaipėda, Neringa, Kretinga and Palanga.

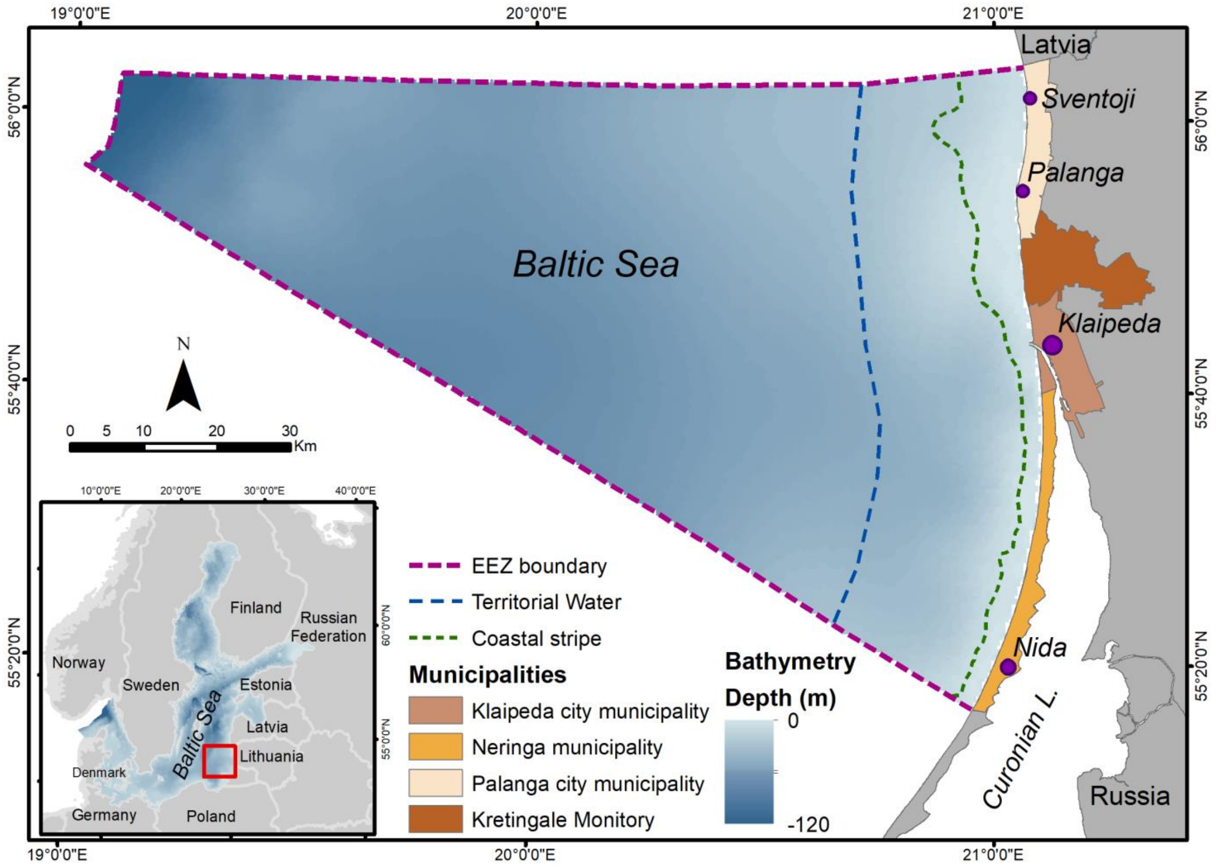

Figure 1. The Lithuanian sea space.

2.2. Modelling procedure

Figure 2 presents the methodological approach applied in this research: definition of study area, database creation for MES and human uses based on national (Lithuanian Statistic Department), seabasin wide (HELCOM Map & Data Service) and EU level (EEA and EMODnet) geospatial and statistical datasets, mapping of MES and human uses, MES richness (*MESR*) and prioritization mapping through average threshold index (*ATI*) analysis. Then, the definition of MSFD pressures applied in the study area (MSFD, 2017), application of pressure propagation model and finally threat exposure index (*MESEx*) mapping. In the following sections a detailed description of the procedure applied, including the datasets and algorithms involved in the analysis is provided.

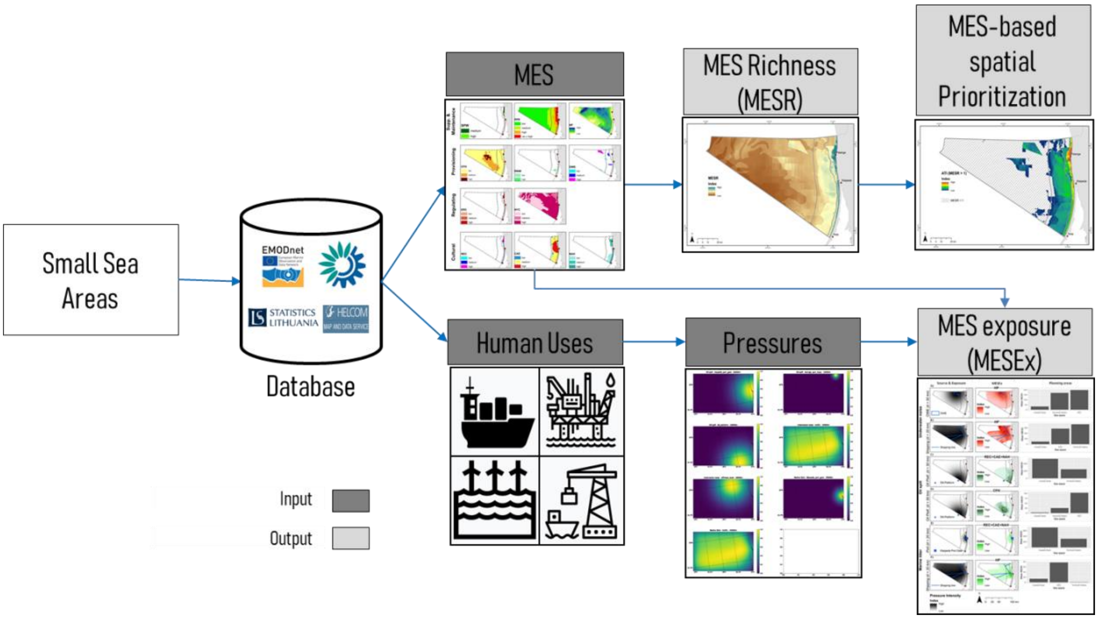

Figure 2. Modelling procedure applied in the study area.

2.3. MES definition and dataset preparation

The analysis of the MES in the study area was based on a structured review of existing MES frameworks for maritime spatial planning (MSP) and coastal zone managementacross Europe (Böhnke-Henrichs et al., 2013; Hattam et al., 2015; Ivarsson et al., 2017) and the Baltic Sea (Depellegrin and Blažauskas, 2013; Depellegrin et al., 2016; Inacio et al., 2018; Veidemane et al., 2017).

In order to better align the selection of MES within the study area, we analysed existing sea uses and ecological features proposed within the Lithuanian MSP data stocktake provided within BaltSeaPlan (2013).

In addition to planning relevant ES typologies it was essential to incorporate abiotic MES in to the analysis, as suggested within the CICES V5.1 (2018) as offshore wind energy constitutes an emerging future sea use in the study area (Depellegrin et al., 2013) into the analysis,

The MES dataset prepared for the study is based on twelve MES (Table 2): four supporting (biodiversity, Baltic Herring spawning grounds - *clupea harengus membras*, primary production and harbour porpoise habitats); three provisioning (sea food, renewable energy provision in terms of potential offshore wind sites, sand extraction sites), two regulating (nutrient recycling and coastal erosion) and three cultural (recreation, coastal aesthetics and natural and cultural heritage). Each indicator was rescaled and transformed into raster of 100 m resolution, then each raster was normalized (x/x_{max}) representing a scale of 1 (maximum provision) to 0 (no or negligible provision).

To produce the MES indicators, multiple geospatial datasets were collected such HELCOM Data & Map Service (2010; 2017) or EMODnet (2018).

Table 2. Twelve MES dataset (S – supporting; P – provisioning; R – regulating; C – cultural) implemented in the study area.

ES (abbreviation)	**Definition**	**Indicator**	**Reference**
S: Biodiversity (BID)	Capacity of ecosystems to support biodiversity	[*index*] Interpolated biodiversity status of the Baltic Sea based on the HELCOM Biodiversity Assessment Tool (BEAT)	HELCOM (2010)
S: Spawning grounds (SPW)	Capacity of marine to provide nursery and spawning grounds	[*high/medium*] presence of Baltic Herring spawns, weighted by bathymetry (4-9 m = 0.8; < 4 and > 9 + 0.6).	Lažauskienė and Vaitkus (1999)
S: Primary production (PPR)	Capacity of the marine environment to perform primary production	[*concentration*] Chlorophyll a concentration as water production surface.	HELCOM (2017)
S: Harbour porpoise (HP)	Capacity of marine environment to provide habitat	[*index*] Probability of presence of harbour porpoises (May-October and November-April)	HELCOM (2017)
P: Sea food (CFH)	Capacity of marine and freshwater bodies to produce fish food	[*hours/year*] Fishing intensity expressed in hours for the year 2012	Böhnke-Henrichs et al. (2013)
P: Offshore Wind Energy (OWE)	Capacity of the marine environment to provide renewable energy resources	[km^2] Potential offshore wind energy development sites	EMODnet (2018)
P: Raw material (RWM)	Capacity of the marine environment to provide raw material	[km^2] Sand extraction sites	EMODnet (2018)
R: Nutrient Cycling (NYC)	Potential for nutrient cycling by sediments	[*index*] Aggregated index of nutrient recycling potential as function of substrate type.	Adapted from Townsend et al. (2015) EUSeaMap, 2016
R: Coastal erosion (ECR)	Societal demand for regulation of sedimentary processes	[*index*] demand for erosion control from coastal population	EEA, (2005)
C: Recreation (REC)	Demand for recreational values in coastal municipalities	[*index*] Aggregated index generated through InVEST Recreation (PUD-Photo User Days) and Lithuanian tourism statistics (V_{OS} = overnight stays, N_{Hotels} = number of hotel infrastructure). $ES_{recrea} = \frac{PUD + V_{OS} + N_{hotels}}{N_V}$	Wood et al., 2013; Statistics Lithuania, (2014)
C: Coastal aesthetics (CAE)	Capacity of ecosystems to provide landscape aesthetic values	[*no. of obervations*] Cumulative viewshed from bathing areas using viewshed analysis techniques representing the sum of obervations with observer height 1.7 m $ES_{aesth} = \sum \mathrm{obs}_{\mathrm{views}}$	Egarter Vigl et al., 2017; Pınarbaşı et al., 2019
C: Natural and cultural Heritage (NAH)	Capacity to provide natural and cultural heritage	[km^2] Intensity of natural and cultural heritage protection based on the number of by number of protected areas overlapping N2000 = Natura 2000,	Depellegrin et al. (2014)

MPA = Marine Protected Areas.

$$ES_{nather} = \frac{P_{N2000} + P_{MPA} + P_{UNESCO}}{N_P}$$

2.4. MES richness and MES-based spatial prioritization

Based on the developed dataset a MES Richness (*MESR*) index was applied (Gos and Lavorel, 2012), that represents an aggregated indicator for the capacity to provide a MES in a given study area. *MESR* can be defined by the arithmetic sum of the normalized values of the twelve MES presented in Table 2 using ArcGIS spatial overlay functionalities. Eq. 1 defines the algorithm as follows:

$$MESR = \sum V_{ij}\ x\ 1000$$

eq. 1

whereas,

V = normalized value per raster cell
i = raster cell
j = marine ecosystem services

Based on the analysis of MESR, we implemented a spatial prioritization method to identify sea areas with particularly high MES provision using an above threshold index (ATI). The $MESR_{ATI}$ determines the raster cells with an above average ecosystem services richness score ($MESR_{ATI} \geq 1$), The algorithm is defined in eq. 2 as follows:

$$MESR_{ATI} = \frac{MESR}{\bar{m}_{MESR}}$$

eq. 2

whereas,

MESR = MES richness score of raster cell i
$\bar{m}$ = mean MESR score calculated using zonal statistics in ArcGIS (ESRI)

2.3. Human uses, pressures and case studies

Anthropogenic activities in the marine environment can have multiple effects on marine ecosystem services and deplete relevant ecosystem services flow that sustain human health and well-being (Drius et al., 2019; Townsend et al., 2018). To analyse the exposure of MES to different threats we located four of the most relevant maritime activities in the Baltic Sea region using geospatial dataset on human activities from the HELCOM Data & Map Services (2019): including the geospatial location of Klaipeda port, potential offshore wind energy sites, AIS ship traffic intensity for the year 2017 and the location of the D6 Oil and Gas platform located in Russian sea waters of the Kaliningrad District. Each sea use was attributed to single of multiple pressure definition according to MSFD (Annex III), a distance of propagation and a *MESEx* case study definition as follows:marine litter from land-based activities such as Klaipėda Port and shipping (Arroyo Schnell et al. 2017; Balčiūnas 2012); underwater noise from pile driving in potential offshore wind energy sites of the Lithuanian Mainland coast (Bagočius 2015; Depellegrin et al., 2014; Klusek 2016); underwater noise and marine litter from shipping lanes and oil spills from transboundary sea areas at the Kaliningrad-Oblast district (Russia; Depellegrin and Pereira 2016; Pålsson 2012). Table 3 provides an overview of the human activities, the MSFD pressures analyses, the propagation distance (in km) retrieved from existing applications of the pressures (Gissi et al., 2017) and the effects definition on MES through the MES exposure index (*MESEx*).

Table 3. Source of human activity exerting the MSFD pressure and *MESEx* case study definition.

Human activity	**MSFD Pressure definition**	**Distance (d)**	**MESEx case study**
Klaipėda port	*Marine litter* is a major source of anthropogenic impacts and can have negative effects on coastal recreational resources and affect the aesthetic and heritage values of coastal landscapes (Balčiunas 2012; Newman et al., 2015).	20 km	Marine litter effects on cultural ES in proximity of Klaipėda Port Gate.
Potential offshore wind energy site	*Underwater noise* can cause major pollution effects on a multitude of provisioning and supporting MES. Potential future offshore renewable energy installations can be source of	50 km	Underwater noise effects on harbour porpoise habitats from pile driving from potential

	continuous underwater noise in terms of pile driving (HELCOM 2017) and can cause major effects harbour porpoise (Dähne et al., 2013; Kastelein et al., 2013).		offshore wind energy sites installation in offshore areas in front of the Lithuanian Mainland Coast.
Shipping	Maritime transport activities can be source of *underwater noise* and *marine litter* discharge (State of the Baltic Sea, 2019).	50 and 20 km	Shipping traffic from Klaipeda Port.
D-6 Oil Platform	*Hazardous substances* such oil spills can have substantial effects on coastal and marine ecosystem. Oil extraction from the D6-Platform in Kaliningrad Region (Russia) can have complex interactions and effects within marine ecosystem and mammals. In particular the South-Eastern Baltic Sea has been subjected to the largest oil spill in the Baltic Sea history in 1982, leaking over 17000 tons of mazut oil along Lithuanian and Latvian shorelines (Andrjustchenko et al. 1985).	50 km	1. Oil spill effects on commercial fishery food provisioning areas from D6-Platform located in sea areas of Kaliningrad Region (Russia). 2. Oil spill effects on cultural ES.

2.4. MES threat exposure index (MESEx)

The *MESEx* can be defined as the action of a pressures on a receptor (single or multiple MES), with regard to the extent (the area of influence), the magnitude and the duration of the pressure (Robinson et al., 2008).

The *MESEx* is composed by the MES Richness (*MESR*) of service providing unit *i* and p_j, which is the pressure propagation function of the *j-th* pressure defined according to Table 3. The *MESEx* is described in eq. 3 as follows:

$$MESEx = MESR_i \; x \; p_j \qquad \text{eq. 3}$$

The propagation of the presented pressures was based on the open source Tools4MSP geo-python library downloaded from Github (2018) presented within Menegon et al. (2018c). The library was selected for its flexible geospatial modelling functionalities that can be used to propagate MSFD pressures (Depellegrin et al., 2017; Menegon et al., 2018a).In more detail we applied the pressure propagation model (p_j) based on an isotropic convolution function, considering behaviour of the function is the same in all directions (Menegon et al., 2018c) in order to map the area and intensity of exposure of the MES to the pressures defined in Table 3.

The propagation distance (*d*) for each pressure is used to define the area of exposure of the pressure (Table 3). Beyond that distance impacts to a MES can be considered as negligible (HELCOM 2017b). The generic equation of the *j-th* pressure is described in eq. 4 as follows:

$$p_j(A_i, x, y) = \sum_{m=-w}^{w} \sum_{n=-w}^{w} A_i(m,n) G\left(d_{i,j}, x-m, y-n\right)$$

eq. 4

whereas,

p_j = pressure j
A_i = anthropogenic activity i
x, y = center coordinate of the raster cell
G = Gaussian function with standard deviation to distance d_{ij}
d_{ij} = propagation distance of the pressure j generated anthropogenic activity i
w = half-size of the analysis window defining the surrounding cells used for the calculation
m, n = column and row indices to walk over the cells of the analysis window

3. Results and Discussion

3.1. MES richness assessment and mapping

In Figure 3A the geospatial results for *MESI* mapping are presented. On overall areas located in the Coastal Stripe have a much higher ES capacity compared to Territorial Waters and offshore areas of the Exclusive Economic Zone. In particular the northern segment of Coastal Stripe on the Lithuanian Mainland Coast concentrates the highest MESR score and the most valuable ecological resources such *Furcellaria Lumbricalis* algal beds (Bučas et al. 2007), Baltic Herring spawning grounds (Šaškov et al. 2014), Marine Protected Areas of national and international relevance or important recreational areas, such as Palanga Seaside resort (Depellegrin et al. 2014). Also the northern tip of the Curonian Spit has high *MESR* score, due to the valuable recreational area (especially in proximity of Klaipėda

City), valuable coastal landscapes and the presence of the Curonian Spit UNESCO World Heritage Sites.

In terms of single MES, Figure 3B shows that the Coastal Stripe aggregates the majority of MES analysed, with exclusion of offshore wind energy (OWE mainly EEZ) and raw material extraction (sand extraction) in territorial waters, which are activities that occur beyond the 20 m isobath. In particular cultural MES occur with high intensity in coastal area, including erosion control processes. In the territorial waters beyond the 20 m isobath is to notice the importance of coastal aesthetic values (CAE), while in the EEZ most relevant MES are related to offshore activities such commercial fishery (CFH), offshore wind energy (OWE) and the presence of potential harbour porpoises.

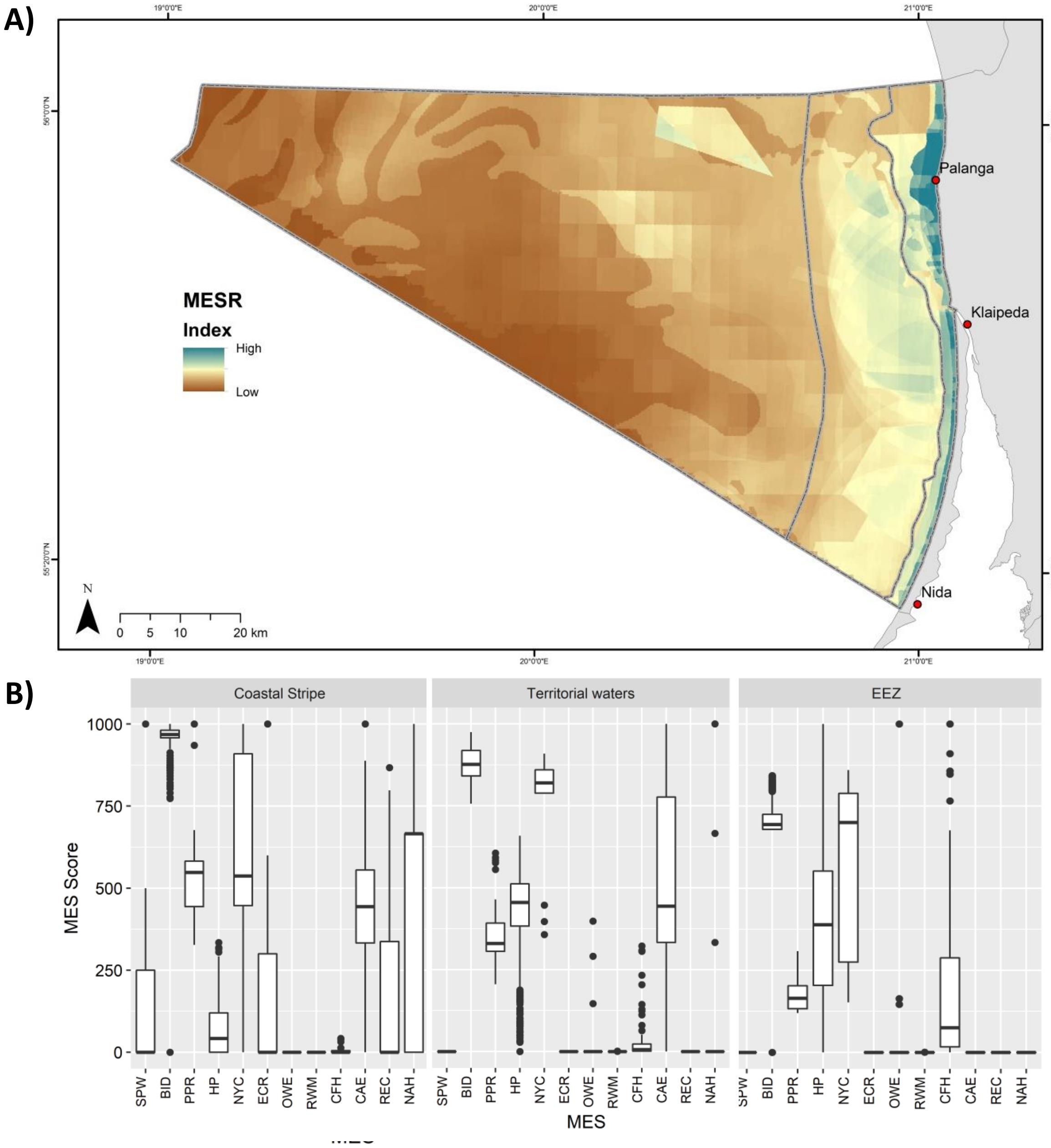

Figure 3. A) Geospatial representation of MES rich (MESR) sea areas of the Lithuanian Sea. B) Boxplots representing MESR scores for three different planning areas: coastal stripe (sea area up to 20 meter depth), territorial waters (excl. coastal stripe) and EEZ. Note: SPW – spawning grounds, BID – biodiversity, PPR – primary production, HP – harbour porpoise, NYC – nutrient cycling, ECR – erosion control, OWE – offshore wind energy, RWM – raw material extraction, CFH – commercial fishery, CAE – coastal aesthetics, REC – recreation and NAH – natural and cultural heritage, and. Boxplots show maximum/minimum outliers, boxes enclose first and third quartiles and box centres define median.Statistics were done using R 3.5.3. (R Core Team, 2019).

3.3. MES-based prioritization mapping

In Figure 4 results from average threshold index ($MESR_{ATI}$) application are presented. ATI areas cover 85% of the coastal stripe, 69% of territorial waters and 9% of the EEZ. Sea area in proximity of 0 – 3 km from coastline are the areas of highest planning priority, especially located in the in front of Palanga and the Klaipeda port entrance (Figure 5A). $MESR_{ATI}$ score distribution in terms of distance from shore (Figure 5B) show that there are four priority areas for planning : Several areas of territorial waters are considered as priority area, this is in particular driven by coastal aesthetic values in terms of seascape integrity. In the EEZ prioritization for planning is detected in front of the Mainland Coast at distance ranges from 25 to 34 km and 40 to 50 km from coastline. These areas are dedicated mainly to offshore activities such as potential wind energy development and commercial fishery extraction.

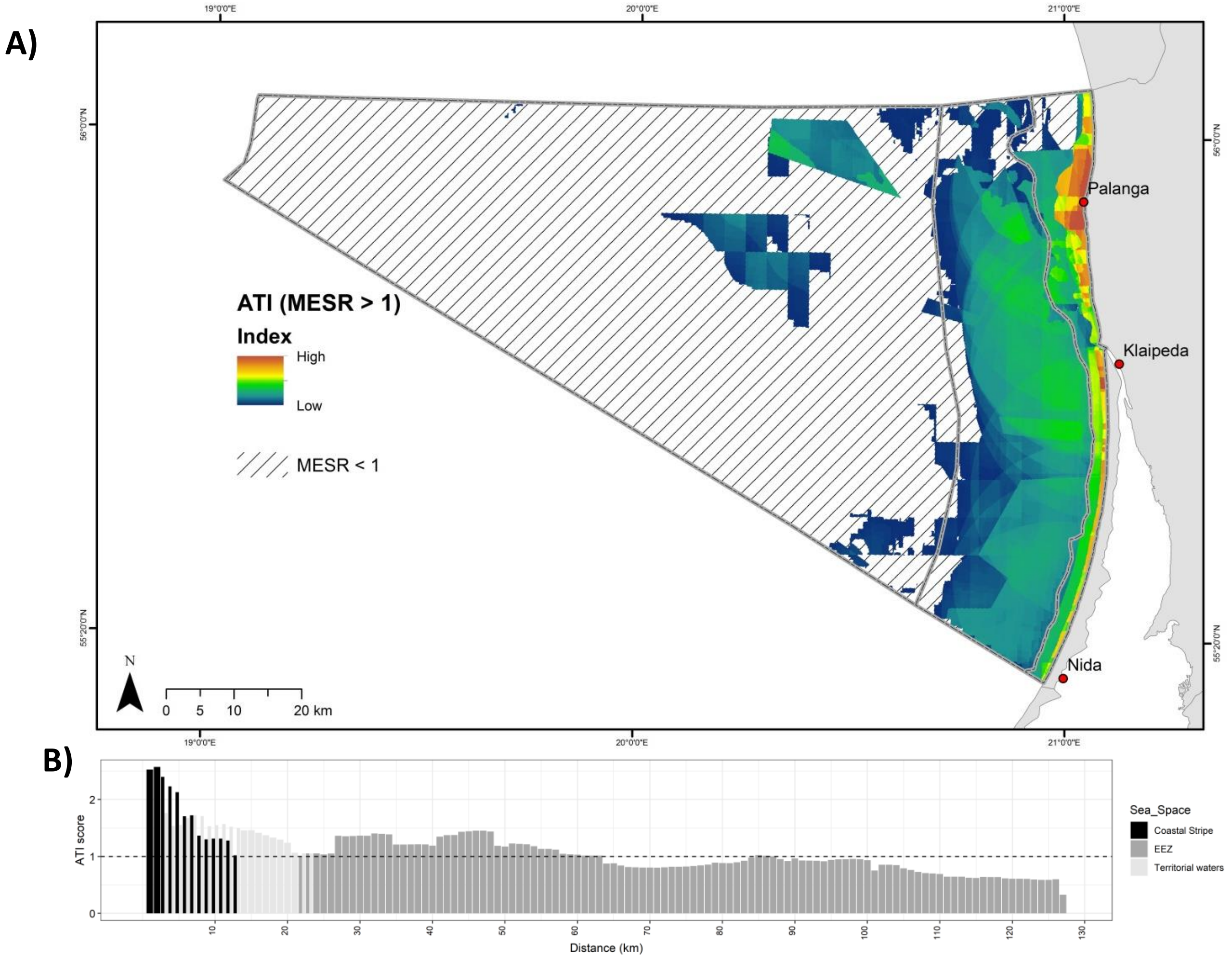

Figure 4. A) MES-oriented spatial prioritization areas using ATI algorithm. B) Distance plot illustrating prioritization areas (ATI > 1) as function of distance from shoreline. Statistics were done using R 3.5.3. (R Core Team, 2019).

3.2. MES threat exposure

Figure 5 presents the geospatial analysis of the main pressure sources (oil platforms, ports, shipping and OWE pile driving) and propagation of the three MSFD pressures (underwater noise, marine litter and oil spills), the *MESEx* for specific MES (HP – Harbour porpoise; REC – recreation, CAE – coastal landscapes, NAH – natural/cultural heritage sites; CFH – commercial fishery) and the distribution of mean score across the three planning areas.

Underwater noise (Figure 5A and B). Sea areas of highest exposure include from OWE pile driving on HP are located in the EEZ, while from shipping the areas of highest exposure are identified in the territorial waters.

Oil spill (Figure 5C and D). Exposure to oil spills in proximity of the southern Lithuanian coast line are represented as potential transboundary threat from D-6 Platform in Kaliningrad Region (Russia; (Kostianoy and Lavrova 2012). Highest exposure is considered in the Coastal Stripe, due to the presence of valuable recreational sites in the settlement of Nida, Juodkrantė, Preila and Pervalka. Oil spill may cause also disruption of landscape aesthetic values (Rabalais and Turner, 2016). In addition the Curonian Spit is an area of considerable natural and cultural heritage in terms of NATURA 2000 Site and UNESCO WH. For commercial fishery In particular, the model assesses the potential effects on valuable commercial fishery areas in the southern segment of the Lithuanian Exclusive Economic. In this context post-spill fishery bans are a common practice in areas affected by oil spill (Ainsworth et al. 2018) and cause economic losses to the local fishery industry (Chang et al. 2014).

Marine litter (Figure 5E and F). Results for marine litter show that high impacts can occur in the Coastal Stripe in proximity of Klaipėda Port Gate entrance and in particular in areas of recreational importance of Smiltynė belonging to the UNESCO World Heritage Site of the Curonian Spit and the Melnragė beach located on the Mainland Coast. In addition marine litter can deteriorate coastal aesthetic value of coastal recreational area and cause additional cost to society for keeping beach area clean and attractive (Werner et al. 2016). The geomorphological characteristics of the coastline, the south to north sediment drift (Jarmalavičius et al. 2011) and the presence of hydro-technical structure such as Klaipėda pier can induce accumulation phenomena (Depellegrin and Pereira 2016) and therefore chronic pressure from marine debris in this segment of the coastal area that can affect different environmental components.

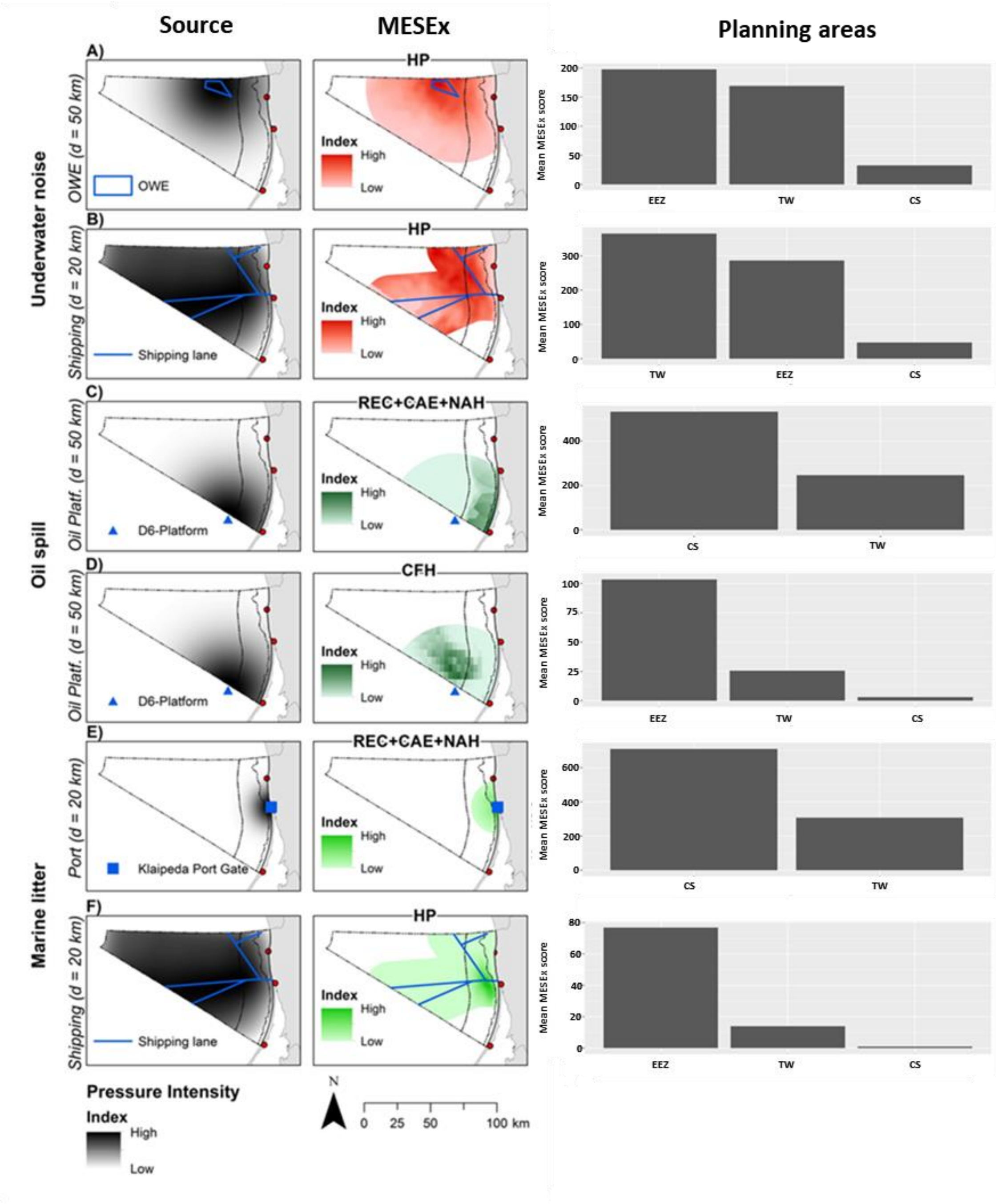

Figure 5. Source of pressure propagation maps (left column), *MESEx* maps (middle column), MESEx mean score by planning areas (right column): (A) Marine litter pressure propagation from Klaipėda with impact distance of 20 km; (B) impact of cultural ES in coastal areas; (C) Underwater noise pressure propagation with impact distance of 50 km and (D) impact map on harbour porpoise distribution; (E) oil spill pressure propagation with impact distance of 50 km and (F) impact on food provisioning expressed as commercial fishery activities. Note (1): not all three planning areas are affected by a single pressure. Note (2): HP – Harbour porpoise; REC – recreation, CAE – coastal landscapes, NAH – natural/cultural heritage sites; CFH – commercial fishery; EEZ – Exclusive Economic Zone; TW – Territorial Waters; CS – Coastal stripe. Statistics were done using R 3.5.3. (R Core Team, 2019).

3.4. Implementation of exposure model

The application of a convolution based propagation model to identify the potential exposure of MES to different pressures originated by distributed anthropogenic sources can be flexibly applied to different MSFD pressures and is originally implemented in Menegon et al. (2018a). The application of a distance model to assess the area of influence from the pressure origin (e.g. oil platform or port facilities) is a common implementation in decision support tools for cumulative effects assessment, and include for instance Euclidean distance (Wyatt et al. 2017), such as Habitat Risk Assessment model of the InVEST (Integrated Valuation of Ecosystem Services Trade-offs) or linear decay functions (Stock and Micheli 2016). Main advantage of the presented MES exposure methods is the possibility to incorporate flexible distance ranges through expert elicitation and literature review. Although the modelling framework has been tested within a model sensitivity analysis for the Adriatic-Ionian Region (Gissi et al., 2017) using ecological components (e.g. marine mammals, nursery areas and marine habitats), further research is needed for testing sensitivity using a socio-ecological framework as proposed through this study.

Nevertheless the linear approach is a major shortcoming at the current stage as the pressure intensity over time and distance might differ significantly and may lead to unexpected model results. This is in particular the case of underwater noise, which is a pressure determined by temporary activities in the water column. On the other hand effects on ecosystem services can have a positive synergetic effects on the sea space, leading to multi-use opportunities, such as the artificial habitat that may be generated by hard substrates produced by OWE installations (Depellegrin et al., 2019). Potentialities for MES bundling for a joined use of the sea space require further research in the near future.

Although several operational MES classifications for coastal and marine planning were proposed, shortcomings still remain in the identification of common set of ES indicators to be implemented in support of MSP. Depending on the knowledge baseline available, frameworks for MES accounting were usually adapted to data shortcomings within a given study area. However major focus should be given to the definition of common data requirements for the fulfilment of a specific ES indicator, that are applicable also in other sea areas and ensure comparability of results and distinguishing among intermediate and final MES (Ivarsson et al. 2017). In future the approach will provide the opportunity for a full MES-based cumulative effect assessment in the study area.

3.5. Implementation in small sea areas

Especially in small sea areas where environmental and socio-economic assets are highly aggregated, the effect of a given risk (e.g. oil spill) can have relevant consequences on national level. For this reason the actual occurrence of the pressure in a given area should be supported by more sophisticated propagation models, especially when considering pressure dispersion that depend on hydrodynamic regimes and environmental conditions of the marine domain, such as synthetic and non-synthetic compounds, pathogens, invasive species or nutrients dispersion. Therefore pressures models need to be further developed by taking into consideration the use hydrodynamic models, to better represent the pressure dispersion dynamics (e.g. Seatrack Web; Ambjörn et al. 2011). Especially in small areas, that may require dedicated planning regimes (MSP-Platform, 2017), the support of high resolved risk and impact assessment models is of essential importance to implement ecosystem-based management.

In future, the presented single pressure assessment techniques need to be extended to all relevant existing and ongoing anthropogenic activities in the Lithuanian sea space (e.g. shipping, cabling, or port extension projects) and provide the basis for a full MES-based cumulative effects assessment model. Although there is an emerging literature in MES-oriented application of cumulative effects assessment (Culhane et al., 2019; Ivarsson et al., 2017; Menegon et al. 2018b), further research is needed to operationalize the ES concept into the marine planning domain and in procedures for environmental impact assessment. In particular, the design of indicators should better respond to ecosystem changes from single or multiple pressures in order to be relevant for ecosystem based management. This includes in particular the analysis of supporting MES that are responsible for the actual services provision. Improving the scientific base on these MES can increase their policy and planning relevance (Posner et al. 2016).

The presented techniques for MES assessment and pressure-based exposure analysis can support the planning objectives outlined within the existing (and currently under revision) national plan on marine planning solutions (MSP-Platform 2016): for instance the balanced development of economic activities and the preservation of the marine environment can be supported through the use of ES approach in trade-off and synergy analysis among sea uses (Brown et al. 2001). This is particularly relevant for small sea areas like the Lithuanian sea space, where a multitude of marine uses co-exist, potentially competing for the same sea space and marine resources. The pressure-based exposure analysis can be flexibly applied for planning scenario development aiming at addressing the potential environmental effects of spatial management strategies, such as the implementation of a new use, re-location of a use or support the design of protected areas (Depellegrin et al., 2019; Menegon et al., 2018b). Compared to other existing impact and risk assessment methodologies implemented around European Sea, the presented approach based on the Tools4MSP Modelling Framework, that is a location-based pressure model that considers human use position as source for a pressure. This provides substantial advantage to better design planning target, focus on sectorial oriented approaches to impact assessment and provide opportunity to better communicate methods and results to decision makers and other relevant stakeholders.

The presented methodology for MES and MES exposure assessment has been applied already in other relevant large scale transboundary planning areas, such as the Adriatic Sea (Menegon et al., 2018b) however with major focus on the effects on ecological components. The purpose of this study was to focus on the underlying pressure models and therefore provide operational approach to the implementation of MSFD and possible techniques to monitor MSFD descriptors through geospatially explicit modelling techniques. Shortcomings remain the use of predefined distance scores that would require sound sensitivity analysis to address knowledge gaps and optimal ranges of distance modelling to better guide precautionary impact assessment in marine and coastal planning. A MES oriented analysis can support the objective of enhancement of ecosystem preservation and restoration. In particular monetary evaluation of ES can contribute to the analysis of direct and indirect benefits (Depellegrin and Blažauskas 2013) obtained by society and better guide conservation planning (Verhagen et al., 2017). Monetary indicators for ES can have higher impact on policymaking (von Haaren and Albert 2011), as they provide easily understandable measure on how MES are linked to human well-being and can better formalize externalities of specific planning objectives (Pandeya et al. 2016).

Conclusions

In this research we present a modelling technique for the analysis of MES combined with a pressure-based threat exposure analysis. The presented *MESR* and *MESEx* can be flexibly applied in other sea areas of the Baltic Sea and around the globe. The assessment of socio-ecological resources using an ecosystem services assessment approach allowed to spatially detect areas of highest MES supply capacity and therefore identify areas of highest conservation priority and management need. The method has shown that for small sea areas like Lithuania, prioritizing conservation is challenging due to the multitude of anthropogenic activities combined with its unsheltered geomorphological characteristics and the dense distribution of ecological resources. MES resources in small sea areas can be particularly vulnerable to pressures, such as oil spills or underwater noise, due to their extended area of influence (up to 50 km) and determine environmental and socio-economic impacts of national magnitude. The presented techniques are particularly useful to regional authorities and planners seeking for decision support tools that can be deployed for sectorial analysis of anthropogenic effects on marine resources and provide means for the ecosystem-based approach into planning.

References

1. Ainsworth CH, Paris CB, Perlin N, Dornberger LN, Patterson WF, Chancellor E et al. (2018) Impacts of the Deepwater Horizon oil spill evaluated using an end-to-end ecosystem model. PLoS ONE 13(1):e0190840. https://doi. org/10.1371/journal.pone.0190840.
2. Ambjörn C, Liungman O, Mattsson J, Håkansson B (2011). Seatrack Web: The HELCOM Tool for Oil Spill Prediction and Identification of Illegal Polluters. Oil Pollution in the Baltic Sea pp 155-183.
3. Andersen JH, Stock A, Heinänen S, Mannerla M, Vinther M, (2013) Human uses, pressures and impacts in the eastern North Sea. Technical Report from DCE – Danish Centre for Environment and Energy No. 18.

4. Andrjustchenko V, Afanasjeva N, Kolosov V, Korshenko A, Morozov V, Olenin S (1985) The Complex Investigation on Estimation of After-effects (consequences) of Mazut (Black-oil) Spill From the “Globe Assimi” Tanker in the Region of Klaipėda. Symposium on Ecological Investigations of the Baltic Sea Environment (Under Auspices of HELCOM). Valton painatuskeskus, Helsinki, pp. 190–203.
5. Arroyo Schnell A, Klein N, Gómez Girón E, Sousa J, (2017) National marine plastic litter policies in EU Member States: an overview. Brussels, Belgium: IUCN viii+64 pp.
6. Bagočius D, (2015) Piling underwater noise impact on migrating salmon fish during Lithuanian LNG terminal construction (Curonian Lagoon, Eastern Baltic Sea Coast). Mar Pollut Bull. 2015 Mar 15;92(1-2):45-51. doi: 10.1016/j.marpolbul.2015.01.002.
7. Balčiūnas A (2012) Marine litter in the different functional zones of the Lithuanian coast line**.** Baltic International Symposium (BALTIC), 2012 IEEE/OES.
8. Baltic Greenbelt (2011) National report from Lithuania Concerning the Baltic Green Belt (the coastal zone). http://www.balticgreenbelt.uni-kiel.de/fileadmin/fileexchange/OutcomesDocumentation/Reports/20120131-BGB-CountryReport-Lithuania.pdf. Accessed 23 March 2018.
9. Böhnke-Henrichs A, de Groot R, Baulcomb C, Hussain S, Koss R, Fofana A, (2013) Typology and indicators of ecosystem services for marine spatial planning and management. J. Environ. Manage. 130, 135–145.
10. Brown K, Adger WN, Tompkins E, Bacon P, Shim D, Young K (2001) Trade-off analysis for marine protected area management. Ecol Econom, 37 (2001), pp. 417-434.
11. Bučas M, Daunys D, Olenin S (2007) Overgrowth patterns of the red algae Furcellaria lumbricalis at an exposed Baltic Sea coast: The results of a remote underwater video data analysis. Estuar. Coast Shelf Sci. 75(3) 308–316.
12. Chang SE, Stone J, Demes K, Piscitelli M, (2014) Consequences of oil spills: a review and framework for informing planning. Ecol. Soc. 19(2): 26. http://dx.doi.org/10.5751/ES-06406-190226.
13. CICES V5.1 (2017) Towards a common classification of ecosystem services. Web: https://cices.eu/, accessed 23/07/2018.
14. Culhane F., Teixeira H., Nogueira A.J.A., Borgwardt F., Trauner D., Lillebø A., Piet G., Kuemmerlen M., McDonald H., Tim O'Higgins T., Barbosa A.L., Jan Tjalling van der Wal J.T., Iglesias-Campos A, Arevalo-Torres J., Barbière J., Robinson L.A., 2019. Risk to the supply of ecosystem services across aquatic ecosystems. Science of the Total Environment 660 (2019) 611–621.
15. Dähne M, Gilles A, Lucke K, Peschko V, Adler S, Krügel K, Sundermeyer J, Siebert U (2013) Effects of pile-driving on harbour porpoises (Phocoena phocoena) at the first offshore wind farm in Germany. Environ Res Lett. 8 025002: 1-16.
16. Depellegrin D, and Blažauskas N, (2013) Integrating Ecosystem Service Values into Oil Spill Impact Assessment. Journal of Coastal Research: Volume 29, Issue 4: pp. 836 – 846.
17. Depellegrin D, Blažauskas N, Egarter Vigl L (2014) An integrated visual impact assessment model for offshore windfarm development. Ocean Coast Manag. 98: 95-110.
18. Depellegrin D, Menegon S, Farella G, Ghezzo M, Gissi E, Sarretta A, Venier C, Barbanti A (2017). Multi-objective spatial tools to inform maritime spatial planning in the Adriatic Sea. Sci Total Environ 609: 1627–1639. https://doi.org/10.1016/j.scitotenv.2017.07.264.
19. Depellegrin D, Pereira P (2016) Assessing oil spill sensitivity in unsheltered coastal environments: A case study for Lithuanian-Russian coasts, South-eastern Baltic Sea. Marine Pollution Bulletin. http://dx.doi.org/10.1016/j.marpolbul.2015.12.005.
20. Depellegrin, D., Venier, C., Kyriazi, Z., Vassilopoulou, V., Castellani, C., Ramieri, E., Bocci, M., Fernandez, J., Barbanti, A. (2019). Exploring Multi-Use Potentials of the Euro-Mediterranean sea space. Science of The Total Environment, Volume 653, 25 February 2019, 612-629. DOI: 10.1016/j.scitotenv.2018.10.308.
21. Drius, M., Bongiorni L., Depellegrin, D., Menegon S., Pugnetti A., Stifter S., 2019. Tackling challenges for Mediterranean sustainable coastal tourism: An ecosystem service perspective. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2018.10.121.
22. EC (European Council), 2014. Directive 2014/89/EU of the European Parliament and of the Council of the 23 July 2014 establishing a framework for Maritime Spatial Planning. Off. J. Eur. Union L257, 135.
23. Egarter Vigl L, Depellegrin D, PauloPereira P, de Groot R, Tappeiner U, (2017). Mapping the ecosystem service delivery chain: Capacity, flow, and demand pertaining to aesthetic experiences in mountain landscapes. Science of The Total Environment, Volume 574, 1 January 2017, Pages 422-436.
24. EMODNet, 2018. Human activities. Web: http://www.emodnet-humanactivities.eu/view-data.php, accessed 23/07/2018.
25. EUSeaMap, 2016. EMODnet Seabed Habitats. Web: https://www.emodnet-seabedhabitats.eu/access-data/download-data/, accessed 23/03/2019.
26. Gissi, E., Menegon, S., Sarretta, A., Appiotti, F., Maragno, D., Vianello, A., Depellegrin, D., Venier, C., Barbanti, A., 2017. Addressing uncertainty in modelling cumulative impacts within maritime spatial planning in the adriatic and ionian region. PLoS One 12 (7), 0180501.
27. Github, 2018. Tools4MSP Library. Web: https://github.com/CNR-ISMAR/tools4msp, accessed 20/07/2018.
28. Gos P, Lavorel S (2012) Stakeholders’ expectations on ecosystem services affect the assessment of ecosystem services hotspots and their congruence with biodiversity. Int J Biodivers Sci Ecosyst Serv Manag 8(1–2):93–106
29. Hattam C, Atkins JP, Beaumont N, Börger T, Böhnke-Henrichs A, Burdon D, de Groot R, Hoefnagel E, Nunes P, Piwowarczyk J, Sastre S, Austen MC (2015). Marine ecosystem services: Linking indicators to their classification. Ecological Indicators 49 (2015) 61–75.
30. HELCOM (2010) Map and Data Service. Interpolated biodiversity status. Web: http://maps.helcom.fi/website/mapservice/index.html, accessed 21/07/2018.
31. HELCOM (2015) Regional Action Plan for Marine Litter in the Baltic Sea. 20 pp.
32. HELCOM (2017a) SAMBAH probability of detection of harbour porpoises. http://maps.helcom.fi/website/mapservice/. Accessed 23 March 2018.
33. HELCOM (2017b) The assessment of cumulative impacts using the Baltic Sea Pressure Index and the Baltic Sea Impact Index - supplementary report to the first version of the HELCOM ‘State of the Baltic Sea’ report 2017. Available at: http://stateofthebalticsea.helcom.fi/about-helcom-and-the-assessment/downloads-and-data/.
34. Holsman K, Samhouri J, Cook G, Hazen E, Olsen E, Dillard M, Kasperski S, Gaichas S, Kelble CR, Fogarty M, and Andrews K (2017) An ecosystem-based approach to marine risk assessment. Ecosyst Health Sustain. 3(1):e01256. 10.1002/ehs2.1256.
35. ICES. 2010. Report of the Working Group on Marine Habitat Mapping (WGMHM), 3– 7 May 2010, Calvi, Corsica, France. ICES CM 2010/SSGSUE:01. 86 pp.
36. Ivarsson M, Magnussen K, Heiskanen A-S, Navrud S, and Viitasalo M (2017) Ecosystem services in MSP. Ecosystem services approach as a common Nordic understanding for MSP. Nordic Council. TemaNord 2017:536.
37. Jarmalavičius D, Satkūnas J, Žilinskas G, Pupienis D. (2011) Dynamics of beaches of Lithuanian coast (the Baltic Sea) for the period 1993–2008 based on morphometric indicators. Environ. Earth Sci. (2011), pp. 1727-1736

38. Kastelein RA, van Heerden D, Gransier R, Hoek L (2012) Behavioral responses of a harbor porpoise (Phocoena phocoena) to playbacks of broadband pile driving sounds. Mar Environ Res 92: 206-214. doi: 10.1016/j.marenvres.2013.09.020.
39. Klusek Z, (2016) Seasonal and diel variability of the underwater noise in the Baltic Sea. The Journal of the Acoustical Society of America 139, 1537 (2016); https://doi.org/10.1121/1.4944875.
40. Kostianoy AG, Lavrova OY (2012) Oil Pollution in the Baltic Sea. Springer-Verlag Berlin Heidelberg pp. 185–220. http://dx.doi.org/10.1007/698_2012_108.
41. Lažauskienė, L., Vaitkus, G., 1999. Environmental atlas of sensitive to oil pollution environmental components. Lithuanian National Oil Spill Contingency Plan. Technical Documentation, 1–17.
42. Liquete C, Piroddi C, Drakou EG, Gurney L, Katsanevakis S, Charef A, et al. (2013) Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review. PLoS ONE 8(7):e67737. https://doi.org/10.1371/journal.pone.0067737.
43. MA (Millennium Ecosystem Assessment), 2005. Ecosystems and human well-being: synthesis. Washington, DC. ISBN 1-59726-040-1. https://www.millenniumassessment.org/en/index.html. Accessed 23 March 2018.
44. Manea E., Di Carlo, D., Depellegrin, D., Agardy, T., Gissi, E., 2019. Multidimensional assessment of supporting ecosystem services for marine spatial planning of the Adriatic Sea. Ecological Indicators, Volume 101, June 2019, Pages 821-837.
45. Menegon S, Depellegrin D, Farella G, Gissi E, Ghezzo M, Sarretta A, Venier C, Barbanti A (2018a) A modelling framework for MSP-oriented cumulative effects assessment. Ecological Indicators, Volume 91, August 2018, Pages 171-181.
46. Menegon S, Depellegrin D, Farella G, Sarretta A, Venier C, Barbanti A (2018b). Addressing cumulative effects, maritime conflicts and ecosystem services threats through MSP-oriented geospatial webtools. Ocean & Coastal Management, Volume 163, 1 September 2018, p 417-436.
47. Menegon S, Depellegrin D, Farella G, Sarretta A, Venier C, Barbanti A (2018c). Tools4MSP: an open source software package to support Maritime Spatial Planning. PeerJ Comput. Sci. 4:e165; DOI 10.7717/peerj-cs.165.
48. MSP-Platform, (2016) MSP Country Information. Lithuania. Web: https://www.msp-platform.eu/sites/default/files/download/lithuania_15.06.2016_copy.pdf, accessed 23/07/2018.
49. MSP-Platform, (2017) Workshop Briefing Paper. Maritime Spatial Planning in Small Sea Spaces. Web: https://www.msp-platform.eu/sites/default/files/20180228_briefingpaper_mspinsmallseaspacesworkshop.pdf, accessed 23/7/2018.
50. Newman S, Watkins E, Farmer A, Brink Pt, Schweitzer JP (2015) The Economics of Marine Litter. In Bergmann M et al. (eds.) Marine Anthropogenic Litter. Springer International Publishing pp. 367-394.
51. Pålsson J, (2012) Oil spill preparedness in the Baltic Sea countries" (2012). Baltic Master II. 3. http://commons.wmu.se/baltic_master2/3.
52. Pandeya B, Buytaert W, Zulkafli Z, Karpouzoglou T, Mao F, Hannah DM, (2016). A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions. Ecosystem Services, Volume 22, Part B, December 2016, Pages 250-259.
53. Papathanasopoulou, E., Beaumont, N., Hooper, T., Nunes, J., Queirós, A.M., 2015. Energy systems and their impacts on marine ecosystem services. Renewable and Sustainable Energy Reviews, Volume 52, December 2015, Pages 917-926.
54. Pınarbaşı, K., Galparsoro, I., Depellegrin, D., Bald, J., Perez-Moran, G., Borja, A. (2019). A modelling approach for Offshore Wind Farm Feasibility with respect to Ecosystem-based Marine Spatial Planning. Science of The Total Environment, 667, 306-317. DOI: 10.1016/j.scitotenv.2019.02.268.
55. Posner SM, McKenzie E, Ricketts TH, (2016) Policy impacts of ecosystem services knowledge. Proc Natl Acad Sci U S A. 2016 Feb 16; 113(7): 1760–1765, doi: 10.1073/pnas.1502452113.
56. R Core Team, 2019. The R Project for Statistical Computing. Web: https://www.r-project.org/.
57. Rabalais N.N., Turner R.E, 2016. Effects of the Deepwater Horizon Oil Spill on Coastal Marshes and Associated Organisms Oceanography, Vol. 29, No. 3, Special Issue on GoMRI Deepwater Horizon Oil Spill and Ecosystem Science, pp. 150-159.
58. Robinson, L.A., Rogers S. & Frid, C.L.J. 2008. A marine assessment and monitoring framework for application by UKMMAS and OSPAR - Assessment of Pressures and Impacts. Phase II: Application for regional assessments. JNCC Contract No: C-08-0007-0027. UKMMAS, 2010. Charting Progress 2.
59. Šaškov A, Šiaulys A, Bucas M, Daunys D (2014) Baltic herring (Clupea harengus membras) spawning grounds on the Lithuanian coast: current status and shaping factors. Oceanologia 56 (4): 789–804.
60. Sousa LP, Sousa AI, Alves FL, Lillebø AI, (2016). Ecosystem services provided by a complex coastal region: challenges of classification and mapping. Scientific Reports | 6:22782 | DOI: 10.1038/srep22782.
61. State of the Baltic Sea, 2019. Cumulative impacts on the marine environmentWeb: http://stateofthebalticsea.helcom.fi/cumulative-impacts/
62. Statistics Lithuania (2014). Web: https://www.stat.gov.lt/en.
63. Stock A, and Micheli F, (2016). Effects of model assumptions and data quality on spatial cumulative human impact assessment. Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2016) 25, 1321–1332.
64. Teoh S.H.S., Symes W.S., Sun H., Pienkowski T., Carrasco L.R., 2019. A global meta-analysis of the economic values of provisioning and cultural ecosystem services. Science of The Total Environment, Volume 649, 1 February 2019, Pages 1293-1298.
65. Townsend M, Thrush SF, Lohrer AM, Hewitt JE, Lundquist CJ, Carbines M, Felsing M, (2015) Overcoming the challenges of data scarcity in mapping marine ecosystem service potential. Ecosystem Services, Volume 8, June 2014, Pages 44-55.
66. Townsend M, Davies K, Hanley N, Hewitt JE, Lundquist CJ and Lohrer AM (2018) The Challenge of Implementing the Marine Ecosystem Service Concept. Front. Mar. Sci. 5:359. doi: 10.3389/fmars.2018.00359.
67. Kristina Veidemane, Anda Ruskule, Solvita Strake, Ingrida Purina, Juris Aigars, Sandra Sprukta, Didzis Ustups, Ivars Putnis & Andris Klepers (2017). Application of the marine ecosystem services approach in the development of the maritime spatial plan of Latvia, International Journal of Biodiversity Science, Ecosystem Services & Management, 13:1, 398-411, DOI: 10.1080/21513732.2017.1398185.
68. Verhagen, W, Kukkala AS, Moilanen A, van Teeffelen AJA, Verburg PA (2017) Use of demand for and spatial flow of ecosystem services to identify priority areas. Conservation Biology, Volume 31, No. 4, 860–871.
69. von Haaren C., Albert C., 2011. Integrating ecosystem services and environmental planning: limitations and synergies, International Journal of Biodiversity Science, Ecosystem Services & Management, 7:3, 150-167.
70. Werner S, Budziak A, van Franeker J, Galgani F, Hanke G, Maes T, Matiddi M, Nilsson P, Oosterbaan L, Priestland E, Thompson R, Veiga J and Vlachogianni T (2016) Harm caused by Marine Litter. MSFD GES TG Marine Litter - Thematic Report; JRC Technical report; EUR 28317 EN; doi:10.2788/690366.
71. Wood, SA, Guerry AD, Silver, JM Lacayo. M., 2013. Using social media to quantify nature-based tourism and recreation. Scientific Reports 3: 2976.
72. Wyatt KH, Griffin R, Guerry AD, Ruckelshaus M, Fogarty M, Arkema KK (2017) Habitat risk assessment for regional ocean planning in the U.S. Northeast and Mid-Atlantic. PLoS ONE 12(12): e0188776. https://doi.org/10.1371/journal.pone.0188776.

73. Žilinskas G (2008) Distinguishing priority sectors for the Lithuanian Baltic Sea coastal management. Baltica 21 (1-2): 85-94.

Supplementary material 1.

Geospatial datasets for marine ecosystem services assessment. Note: SPW – Spawning grounds, PPR – Primary Production, Harbour Porpoises, CFH – Commercial Fishery, RWM – Raw material extraction, OWE – Offshore Wind Energy, ERC – Erosion Control, NYC – Nutrient Cycling, REC – Recreation, CAE – Coastal Aesthetics, NAH – Natural and Cultural Heritage.