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Assessing oil spill sensitivity in unsheltered coastal environments: A case study for Lithuanian-Russian coasts, South-eastern Baltic Sea

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ABSTRACT

This study presents a series of oil spill indexes for the characterization of physical and biological sensitivity in unsheltered coastal environments. The case study extends over 237 km of Lithuanian-Russian coastal areas subjected to multiple oil spill threats. Results show that 180 km of shoreline have environmental sensitivity index (ESI) of score 3. Natural clean-up processes depending on (a) shoreline sinuosity, (b) orientation and (c) wave exposure are favourable on 72 km of shoreline. Vulnerability analysis from pre-existing *Kravtsovskoye* D6 platform oil spill scenarios indicates that 15.1 km of the Curonian Spit have high impact probability. The highest seafloor sensitivity within the 20 m isobath is at the Vistula Spit and Curonian Spit, whereas biological sensitivity is moderate over the entire study area. The paper concludes with the importance of harmonized datasets and methodologies for transboundary oil spill impact assessment.

1. Introduction

Oil spills are a global environmental problem with dramatic effects on local and regional scale. An essential component for oil spill response planning is environmental sensitivity index (ESI) maps, which are used for response prioritization, by displaying most vulnerable coastal and marine areas and allow the early definition of clean-up strategies (Santos and Andrade, 2009).

ESI atlases originated in the 1970s in the United States and in the last four decades considerably evolved towards dynamic mapping approaches based on Geographic Information Systems (GIS) and remote sensing technologies (Gundlach and Hayes, 1978; Jensen et al., 1998; Petersen et al., 2002). The study area of ESI tools is coastal, lacustrine, or riverine environments, always comprise and display three main types of information: shoreline habitats, biological resources and human-use resources. Shoreline habitats determine the 'sensitivity index', attaching a vulnerability value from 1 to 10. In fact, from exposed rocky shores to sheltered tidal flats or mangroves, shoreline vulnerability to oil spills is first classified and then mapped (Petersen et al., 2002). Although originally sensitivity mapping guidelines by the National Oceanographic and Atmospheric Administration (NOAA) suggest simply to compile and map sensitive biological and human-use resource without any categorical sensitivity rank (NOAA, 1997), in recent years scientific research has proposed several solutions for biological and socio-economic sensitivity mapping as integrative part of oil spill sensitivity assessment (Kokkonen et al., 2010; Pogrebov et al., 2003; Romero et al., 2013). Despite the biological and socio-economic dimension of oil spill impacts emerging methodological challenges in oil spill fate and impact assessment focus on seafloor sensitivity in near- and offshore areas. There is a very little amount of case studies addressing the linkage of geomorphological, hydrodynamic and biological components of seafloors to oil spill sensitivity in the Baltic Sea (Leiger et al., 2012), the Mediterranean Sea (Alves et al., 2014, 2015) and Atlantic Ocean (Li et al., 2014).

This study was carried out to develop a harmonized oil spill sensitivity mapping procedure for open, unsheltered coastal areas tested in Lithuanian-Russian coastal areas of the South-Eastern Baltic Sea. The mapping procedure starts from ESI based classification based on NOAA standards, the determination of physical components of the shoreline enhancing natural clean-up capacity in case of oil spills, the assessment of the geospatial vulnerability of the shoreline using pre-existing oil spill propagation scenarios by Kostianoy and Lavrova (2012) and propose a seafloor sensitivity index applied within seafloors of 20 m isobath based on bathymetric, geomorphological, hydrodynamic and biological components of the seafloor.

1.1. Oil spill sensitivity mapping in the Baltic sea region

The Baltic Sea is one of the most trafficked seas in the world, accounting for about 15% of the world's cargo transportation. Every

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Table 1
Overview of ESI methods and assessment levels in the Baltic Sea and other European seas (yes [+]; no [−]; partly [+/−]). Adopted from Depellegrin (2011) and Offringa and Lahr (2007).

	Methods	Country	Assessment level			Reference
			Sensitivity/ Vulnerability	Ecological risk	Socio-eco. component	
Baltic Sea	OILECO	Finland/Estonia	+	+	+/−	OILECO (2007)
	Overall ESI	Lithuania	+	−	+	Depellegrin et al. (2010)
	VPS/*Sensitivitätsraster*	Germany	+	−	−	van Bernem et al. (1994), Lahr et al. (2003)
	Miljöatlas	Sweden	+	+	−	Forsman (2012)
	Risk analysis	Denmark	+/−	+/−	+/−	COWI (2007)
	Environmental sensitivity maps	Latvia	+	+/−	+/−	Forsman (2012)
	Total sensitivity	Poland	+	+	−	Baltic Master II (2007)
	MOB/MRDB	Norway	+	+	−	Brude (2005)
	Integral Vulnerability	Russia (Kaliningrad & St. Petersburg Region)	+	+	−	Pogrebov et al. (2003, 2004)
	BRISK	Baltic Sea	+	−	+/−	COWI (2012)
European seas	Integrated vulnerability	Spain (Cantabria)	+	+	+	Castanedo et al. (2009)
	RAMA[a]	Belgium	+/−	+	+	Le Roy et al. (2006)
	V-maps	The Netherlands	+	+	−	Offringa and Lahr (2007)
	Coastal vulnerability	France	+	−	−	Fattal et al. (2010)
	SensMaps/MarLIN	UK (+ Irish Sea)	+	+	−	Offringa and Lahr (2007)
	Differential coastal vulnerability	Portugal	+	+/−	+	Frazão-Santos et al. (2013)

[a] Risk analysis of marine activities in the Belgian part of the North Sea.

year around 120–140 accidents occur with an increase of 20% since 2006 (HELCOM, 2011). While its vulnerable biological resources and dense anthropogenic pressure are recognized by its nine neighbouring coastal countries (Janßen et al., 2013), many efforts are taken for the development of integrated oil spill sensitivity assessment methods (Table 1). In most of the cases standardized ESI mapping is a baseline method, which then advances to ecological and or socio-economic sensitivity modelling: The Finnish–Estonian OILECO project (2007) has a strong ecological component, supporting prioritization of oil combating methods for endangered species and impact on nature conservation areas in the Gulf of Finland and Estonian marine areas (OILECO, 2007). The Lithuanian OESI (Overall ESI) includes archetypical shoreline ESI integrated by socio-economic resources and economic estimations of commercial fishery in the Lithuanian coastal zone (Depellegrin et al., 2010). The German *Sensitivitätsraster* includes species abundance and distribution maps for the Wadden Sea and the Baltic Sea (van Bernem et al., 2007). In Denmark an oil spill risk model is based on the expected frequency of oil spills, release quantities, environmental risks and effects of response activities (COWI, 2007). The risk analysis also includes environmental damage maps. Oil spill sensitivity mapping in Latvia has been performed through the Carlo Bro Ltd. in 1999, which included an ESI according to IMO standards and GIS data on biological and socio-economic resources (DANCEE, 2001; Forsman, 2012). The Swedish *Miljöatlas* (environmental atlas) is a mapping tool for the identification and prioritization of protection efforts in case of oil spill in Swedish marine areas (Forsman, 2012). Polish sensitivity mapping approaches integrates marine biological resources (Baltic Master II, 2007) and *Dynamic sensitivity maps* based seasonality, sensitive environmental and socio-economic resources and an integrated sensitivity applied for the Gulf of Gdansk (EfficienSEA, 2015). The Norwegian Marine Resources DataBase (MRDB) is a tool to map vulnerable marine resources and prepare contingency plans and the Monitoring Database (MOD) can be used to prepare environmental surveys, documentation and historical data collection (Offringa and Lahr, 2007). Similarly to the Gulf of Gdansk a pilot study in the Southern Sunnmøre Coastal Region also applied a *Dynamic Sensitivity map* approach (EfficienSEA, 2015). The Russian *Integral sensitivity* mapping is a cumulative method applied in the Kaliningrad Region (Pogrebov et al., 2004), St. Petersburg Region (Pogrebov et al., 2003). This method integrates marine and coastal biota in the sensitivity assessment.

The sub-regional risk of spill of oil and hazardous substances in the Baltic Sea project (BRISK) aimed to enhance sub-regional preparedness and cooperation against medium sized oil spills also included environmental vulnerability analysis mainly based on ecosystems and the distribution of habitats and selected organisms for the entire Baltic Sea (COWI, 2012).

2. Materials and methods

2.1. Step 1 — study area definition

The study area boundary is the 237 km shoreline shared by Lithuania (90 km) and by the Kaliningrad Region of the Russian Federation (147 km) in the east, and the aquatory till the 20 m isobath in the west. In more detail the study area can be divided into four geomorphological segments (Fig. 1a; Table 2):

The Russian segment of the Vistula Spit (VS) extends over 26.3 km and is delimited by the Russian-Polish seaborder and the Baltiysk Strait. Beaches are fine to medium grain-sized, beach width is 1–45 m (Kobelyanskaya et al., 2011). The VS together with its Polish part belongs to the HELCOM Baltic Sea Protected Areas (BSPAs) and to the Vistula Spit Landscape Park (Schernewski and Schiewer, 2013). The VS belongs to the Baltiysk urban district with 36.2 thousand inhabitants and population density of 357.4 inhabitants/km^2.

The Sambian (*Samland*) Peninsula (SP) extends over 73.2 km from Baltiysk Strait to the settlement of Zelenogradsk. Beaches of SP consist of gravels (Burnashov et al., 2010). The most important recreational resorts are located in Svetlogorsk (Vapnyarskaya et al., 2014). The Zelenogradsk urban district includes 32.5 thousand inhabitants with 16.1 inhabitants/km^2 (Domnina and Chubarenko, 2012). Other urban centres on the SP include Svetlogorsk, Pionersky, Donskoy and Yantarny.

The Curonian Spit (CS) is shared by Russia and Lithuania and extends over approx. 99.8 km from the Zelenogradsk settlement in Russia to the Klaipėda Strait in Lithuania. Beaches are composed by medium-sized grains with admixture of gravels (Jarmalavičius et al., 2011). Since 2000 the Curonian Spit (russ. *Kurshskaya kosa*; lit. *Kuršių nerija*) was included into the UNESCO World Heritage Site as important cross-border cultural landscape (Povilanskas, 2011). On Lithuanian side the most important recreational areas are Nida, Juodkrantė, Preila and Pervalka (Depellegrin and Blažauskas, 2013). Neringa Municipality administers the Lithuanian part of the CS, which includes 3600 inhabitants with a population density of 38.1 inhabitants/km^2 (Baltic Greenbelt, 2011). On Russian side of the CS the most important recreational area is Zelenogradsk (Pickaver, 2003). The area is administrated under Zelenogradsk County and includes 1600 inhabitants with population