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Assessing cumulative visual impacts in coastal areas of the Baltic Sea

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ABSTRACT

Anthropogenic activity such as offshore wind energy farm development, shipping activity, resource extraction platforms or marine aquaculture can have adverse impacts on the visual quality of coastal landscapes. GIS-based viewshed analysis is the most widely used technique to address visual impacts. However, despite the wide application its spatial extent remains limited to local and regional studies. This study presents a GIS-based model for cumulative visual impact assessment on macro-regional scale based on a case study for the Baltic Sea. The viewshed model was deployed over a visibility zone covering 54% (223.641 km^2) of the Baltic Sea space using a database of 63,672 observation points integrated by geospatial data on existing and planned sea uses representing potential visual stressors. Results show that areas of highest potential visual impact are sheltered coastal areas with complex geomorphological features such as barrier islands, peninsulas, straits, archipelagos and lagoons in combination with intensive anthropogenic activity and presence of nature protected areas. The methodology can be applied to any coastal area of the world to classify coastal areas due to their cumulative viewshed characteristics and as early monitoring tool for visual impact assessment on transboundary scale.

1. Introduction

Coastal areas are rich in aesthetic resources (Ogawa, 2007). Anthropogenic activity in coastal areas can have adverse impacts on the visual quality of coastal landscapes due to the alteration of natural features of vistas and viewpoints. On European level the Directive 2014/52/EU (amending former Directive 2011/92/EU) on "*the assessment of the effects of certain public and private projects on the environment*" defines visual impacts as the change in the appearance or view of the built or natural landscape and urban areas. Although visual impact assessment (VIA) are a key aspect in environmental impact assessment (EIA) because supporting the preservation of the historical-cultural heritage and the landscape in public and private projects, there are no clear guidelines for the implementation of VIA on national and international level, resulting into subjective analysis techniques (Mouflis et al., 2008; Falconer et al., 2013) with difficult interpretation and implementation by decision-makers (Ogawa, 2007).

The most important analytical tool for the analysis of visual impacts are Geographic Information Systems (GIS), which include viewshed functionalities (Brabyn and Mark, 2011; Kim et al., 2004; Sander and Manson, 2007; Sander and Polasky, 2009). These functions use as input data a Digital Elevation Model (DEM), combined with single or multiple observation points datasets, which can estimate the portion of land, water and air visible by a given observer in a landscape (ArcGIS, 2015). A special case is considered the cumulative viewshed analysis, where a large number of viewsheds from random observers are overlaid in order to assess locations with high environmental exposure.

Many popular open source and commercial GIS applications offer viewshed tools, such as the Integrated Valuation of Ecosystem Services and Tradeoff (InVest) models (Bagstad et al., 2013), the aesthetic quality functionality of InVest package assesses the scenic and aesthetic values provided by marine and coastal seascapes (Guerry et al., 2012), the Social Values for Ecosystem Services (SolVES) model is designed to assess social dimension of an environment, such as recreational and aesthetic values in landscapes (Sherrouse et al., 2014). Open source software like GRASS GIS 6.4 also implemented advanced viewshed analysis functionalities in R programming language such as r.viewshed (GRASS GIS, 2015) and r.wind.sun (Minelli et al., 2014).

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In recent years viewshed analysis has been successfully applied in archaeological science (Gonçalves et al., 2014; De Montis and Caschilli, 2012), light pollution analysis (Verutes et al., 2014) visual impact of terrestrial and marine wind park development (Ladenburg, 2009; Mekonnen and Gorsevski, 2015), suitability analysis of aquaculture development (Falconer et al., 2013), urban planning (García and Rodriguez, 2015) and landscape analysis (Chamberlain and Meitner, 2013; Jakab and Petluš, 2012). However the variety of methodological setups presented a geographic scope usually limited to local and regional assessments (Bongers et al., 2012; Germino et al., 2001; Merrouni et al., 2014; Sevenant and Antrop, 2007).

The aim of this research is to present a GIS-based methodology for macro-regional analysis of cumulative visual impacts on coastal and marine landscapes of the Baltic Sea using a refined methodology for cumulative threat analysis (CTA) developed by Halpern et al. (2007, 2008). The cumulative visual impacts are assessed for shipping activity, existing and or planned offshore wind energy (OWE) prospects, offshore oil platforms and nature protected areas using the HELCOM Data and Maps Service (HELCOM GIS, 2015). It is the first attempt for cumulative viewshed model application on macro-regional scale covering a visibility zone of 223,641 km^2 (54% of the entire Baltic Sea space) with 63,672 observation points. The study should be considered as preliminary assessment tool for macro-regional viewshed analysis and is particularly suitable for decision-makers to monitor potential visual impacts from traditional and new sea uses in coastal areas, provide a linkage between the geomorphological features of coastal areas and the sea-borne environmental and socio-economic conditions affecting the visual quality of coastal landscapes.

2. Study area

The Baltic Sea covers approximately 417,600 km^2 (HELCOM, 2013a), with a south to north extension of 1,300 km and a west to east extension of 1,200 km (Bonsdorff, 2006). The sea is one of the biggest brackish waters worldwide due to its limited saline water inflow from the North Sea, through the Danish Strait and the Kiel Canal, and the extensive riverine freshwater inflows (Danielsson, 2014). Its catchment includes about 85–90 million people (BACC, 2015) and can be divided into nine subbasins (Fig. 1 and Table 1).

The study area (hereafter visibility zone) for the application of the cumulative visual impact assessment model is defined by the aquifer located between the shoreline and the 20 km sea space (Fig. 1). The visibility zone of 20 km distance is considered as one of the possible visual limits for VIA studies in coastal and marine environments (Bishop and Hull, 1991). This zone covers approximately 223.641 km^2, about 54% of the entire Baltic Sea area (Table 1). For this study, visual impacts beyond the 20 km distance limit are considered as not significant. However the visibility zones can be flexibly adapted to any visual limit, taking into account the dimensions and colour of the infrastructure or the atmospheric conditions determining visibility distance.

The Baltic Sea is an industrialized sea with highly developed transport system and infrastructure (Rydén et al., 2003). The intensive anthropogenic activity is heavily affecting its sensitive biological resources and the integrity of coastal and marine landscapes (HELCOM, 2013b, 2010). Furthermore the coming into effect of the Marine Strategy Framework Directive (MSFD, 2008/56/EC) is propelling mechanisms for marine planning by European countries (Adriplan, 2015; BaltSeaPlan, 2012a; MESMA, 2009; TPEA, 2014). In the Baltic Sea, the drafting of multiple-use marine spatial plans will inevitably increase the demand for marine space and increase pressure on coastal and marine environments (BaltSeaPlan, 2012a; HELCOM, 2013c; Zaucha, 2014). Besides traditional sea uses such as commercial fishery, shipping and tourism (Kyriazi et al., 2013), also new potential sea uses like OWE farms (Erneuerbare-Energien, 2015; Tonderski et al., 2013), wave energy technologies (Submariner, 2012), marine aquaculture (Aquafima, 2014), potential oil extraction sites (BaltSeaPlan, 2012b; ESaTDOR, 2013; LEGMC, 2015), on- and offshore infrastructure for subsea CO_2 storage (Anthonsen et al., 2014; Beyerlin and Marauhn, 2011), coastal infrastructure for connectivity of subsea pipelines and cables to land (Grigas, 2015), land-based and floating LNG terminals (LNG, 2015; Weintrit and Neumann, 2015), deep-water port extension (Zavadskas et al., 2015) and development of marinas network (Domnina and Chubarenko, 2012; Marriage, 2015; Paulauskas et al., 2011) will increase the presence of anthropogenic structures in sensitive coastal and marine landscapes of the Baltic Sea.

3. Methodology

A GIS-based method was developed using ModelBuilder application available in ESRI ArcGIS 9.3, which combined a set of geoprocessing tools chained into a workflow (ArcGIS, 2015). The method followed an incremental approach initiated by single geospatial datasets towards complex indexing models. For this purpose a four step approach was defined as presented in Fig. 2: The first step referred to the development of a geospatial dataset including a digital elevation model (DEM), generation of observation points, and the collection of existing and or planned sea uses relevant for visual impact assessment. The second step assessed the cumulative visual index (*CVI*) through the application of viewshed functionalities over the pre-defined visibility zone of 20 km (Fig. 1). The third step assessed the positive and negative visual stressors (*CVSI*) within the visibility zone. The fourth step integrated the *CVI* and *CVSI* for the calculation of the cumulative visual impact index (*CVII*). A detailed description of each step and the data and methods applied is provided in the following paragraphs.

3.1. Step 1: Dataset development

In order to perform a viewshed analysis a Digital Elevation Model (DEM) was obtained from the NASA ASTER program with surface resolution of 30 m $\times$ 30 m (Global ASTER, 2015). The observation points database was composed by 1910 point features reflecting official bathing and recreational sites under the EU – Water Framework Directive (EU – WFD, 2000/60/EC) and 61,762 observation points grid interpolated along the entire shoreline of the Baltic Sea in intervals of 1 km (Fig. 3). In total 63,672 observation points were applied with observer height to the ground of 1.7 m, the average human height (Connoly and Lake, 2006).

The HELCOM Map and Data Service (HELCOM GIS, 2015) was used as geospatial dataset to retrieve existing and or planned sea uses in the study area as follows:

Raster data on average monthly shipping density based on automated identification system (AIS) in the Baltic Sea calculated on average monthly data for 2011 (Fig. 4a), existing and or planned Offshore Wind Energy (OWE) farms based on data from European Wind Energy Association/4C Offshore Limited (EWEA) and offshore oil platforms (Fig. 4b), nature protected areas (Natura 2000 sites, Ramsar sites, UNESCO Heritage sites and HELCOM marine protected areas; Fig. 4c) and the distribution of EU – WFD bathing sites (Fig. 4d).

3.2. Step 2: Cumulative visual index (CVI)

The phenomenon of sighting an object or infrastructure from