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Short communication

Baltic Sea biodiversity status vs. cumulative human pressures

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ABSTRACT

Many studies have tried to explain spatial and temporal variations in biodiversity status of marine areas from a single-issue perspective, such as fishing pressure or coastal pollution, yet most continental seas experience a wide range of human pressures. Cumulative impact assessments have been developed to capture the consequences of multiple stressors for biodiversity, but the ability of these assessments to accurately predict biodiversity status has never been tested or ground-truthed. This relationship has similarly been assumed for the Baltic Sea, especially in areas with impaired status, but has also never been documented. Here we provide a first tentative indication that cumulative human impacts relate to ecosystem condition, i.e. biodiversity status, in the Baltic Sea. Thus, cumulative impact assessments offer a promising tool for informed marine spatial planning, designation of marine protected areas and ecosystem-based management, and may prove useful for setting limits on allowable levels of human impact on ecosystems.

1. Introduction

One of the most daunting tasks for ecosystem-scale management, but also one of the most important, is to reliably assess and track ecosystem condition. Management ultimately aims to improve ecosystem condition, yet must achieve this task by sifting through hundreds of potential indicators, none of which individually tell the whole story and which collectively are expensive to monitor.

Recently a synthetic indicator has been proposed to solve this problem that pulls together the many different measures of human impact on ecosystems. This cumulative human impact indicator (Halpern et al., 2008) models the combined effect of all stressors (for which data exist) on all habitat types (and the taxa within). To date, however, these modelled impact scores have not been validated with empirical data on ecosystem condition, largely because such empirical data are rare and their integration still not common practice. Here we take advantage of a convergence of comprehensive empirical assessments of biodiversity status in the Baltic Sea with concurrent cumulative human impact measures to test how well models match reality.

2. Materials and methods

We have analysed linkages between human activities, pressures and impacts and the status of the marine biodiversity in the Baltic Sea.

The Baltic Sea is an inland regional sea in Northern Europe shared by nine countries whose habitats and species are widely recognized to be heavily impacted and impaired across most, but not all, sub-basins (HELCOM, 2010). In this study, we focus on the open parts of 9 Baltic Sea sub-basins. Assessments units 1 and 2 collectively form the Gulf of Bothnia. The Gulf of Bothnia is together with the Gulf of Finland (unit no. 3) connected to the Baltic Proper, which in this study is subdivided into the following assessment units: Northern Baltic Proper (unit no. 4), Eastern Baltic Proper

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(unit no. 5), south-eastern Baltic Proper (unit no. 6), the Bornholm Basin (unit no. 7) and the Arkona Basin (unit no. 8). The Kattegat (unit no. 9) forms the transition area, together with the Danish Straits, between the Baltic Sea and the North Sea region.

We have combined and re-analysed two existing data sets for these sub-basins, a detailed mapping of human pressures based on 52 individual Baltic-wide pressure layers (HELCOM, 2010; Korpinen et al., 2012, Fig. 1) and an integrated assessment of biodiversity status applying a multi-metric indicator-based assessment tool that assessed biodiversity status from the period 2001–2007 (HELCOM, 2010; Andersen et al., 2014). The methods and data used are briefly described in the following sections.

2.1. Pressures and impacts – data and methods

The Baltic Sea Pressure Index and the Baltic Sea Impact Index (BSPI/BSII) represent the first attempt in a European context to estimate potential impacts of multiple human stressors or so-called 'cumulative effects' of human activities (HELCOM, 2010; Korpinen et al., 2012). Similar studies have recently been carried out in the Mediterranean Sea and Black Sea as well as parts of the North Sea (Coll et al., 2012; Micheli et al., 2013; Andersen and Stock, 2013). The indices followed the methodology of the global index (Halpern et al., 2008), but were able to use more realistic pressure and ecosystem data sets than the global study and used regional expert knowledge to estimate impact strengths on habitats and species. In the BSII, cumulative impacts (I) for a 5 km × 5 km grid were estimated by Formula 1,

$$I = \sum_{i=1}^{n} \sum_{j=1}^{m} P_i \times E_j \times \mu_{i,j} \quad (1)$$

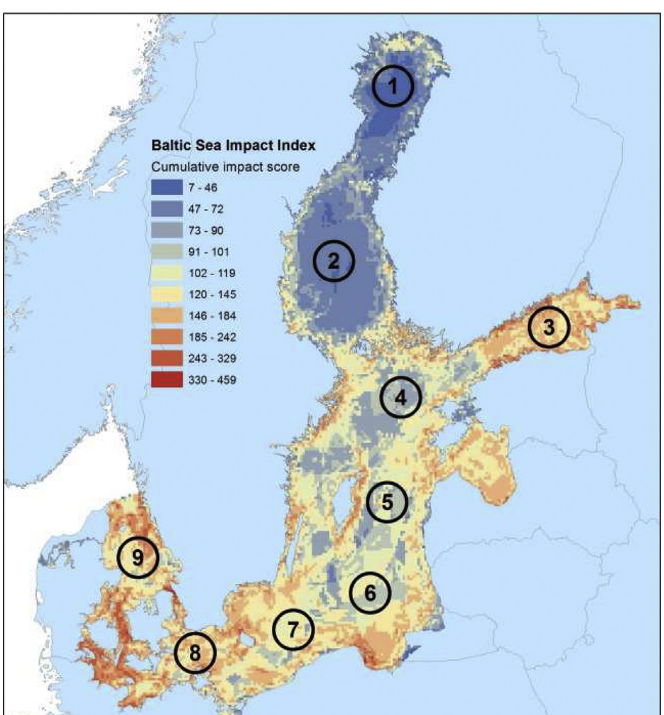

Fig. 1. Mapping of potential cumulative impacts in the Baltic Sea. Numbers indicate offshore biodiversity assessment units. The cumulative impact map is based on Korpinen et al. (2012).

where P_i is the log-transformed and normalised value of an anthropogenic pressure (scaled between 0 and 1) in an assessment unit, E_j is the presence or absence of an ecosystem component j (i.e. populations, species, biotopes or biotope complexes; 1 or 0, respectively), and $\mu_{i,j}$ is the weight score for P_i in E_j (range 0–4) (Halpern et al., 2008; Korpinen et al., 2012). In brief, the pressure intensity was estimated by the underlying activities in the grid cells, such as number of wind turbines, biomass of caught fish, average number of ships or amount of nitrogen deposited from atmosphere (see Korpinen et al., 2012). The ecosystem components consisted of underwater habitat maps, water-column habitat maps, distribution areas of marine mammals and spawning and nursery areas of cod. They were either present (value = 1) or absent (value = 0) in an assessment unit. The weight scores were formed on the basis of three criteria – functional impact, recovery time and resistance of the ecosystem against the pressure – by an expert panel through a workshop and a following expert survey. In total, 52 GIS data layers depicting human stressors and 14 GIS data layers depicting species and habitat distribution. The data were collected from the period of 2003–2007 and originate from HELCOM (2010), Korpinen et al. (2012) and Andersen et al. (2014). Values of each P were multiplied by each E and their common μ (Formula 1). If a pressure or an ecosystem component did not occur in an assessment unit, the zero value excluded it from the index. Also zero values in μ resulted in an exclusion of that P × E combination. The resulting BSII value was, hence, an additive sum of those pressures and ecosystem components which occur in the assessment unit and are each weighted by μ. Detailed description of the pressures, ecosystem components, weighting scores and the calculation of the index were given by Korpinen et al. (2012) and the method has been further discussed by Halpern and Fujita (2013). In the BSPI, the calculation lacked the E component and the μ component was an average of the BSII weight scores over all the ecosystem components (E). The BSPI is thus a weighted sum of pressure layers in the assessment units.

For this study, we extracted the average BSPI and BSII value for 9 sub-basins of the Baltic Sea (Table 1). The top underlying human stressors for those areas are: (1) inputs of nutrients and organic matter from land and atmosphere, (2) fisheries, (3) inputs of hazardous substances from land and atmosphere and (4) physical damage to seabed (e.g. dredging, bottom trawling, sand extraction) (HELCOM, 2010). Other stressors in the study were hunting of marine mammals, temperature increase, physical loss of seabed habitats, marine litter and underwater noise.

Further, we re-analyzed the HELCOM dataset of impacts to rank the major pressures in the 9 sub-basins of this study. The data consisted of impact values which were specific for each of the 52 pressures in the BSII. Thus, each P was multiplied by E and μ but not yet summed to the index (see Formula 1). We extracted the impact values of the sub-basins and used the mean value to rank the pressures from highest to lowest.

Table 1
Mean pressure values and impact values for the open parts of each assessment unit. Calculations are based on data from Korpinen et al. (2012).

Assessment unit	Pressure value	Impact value
1. Bothnian Bay	28	55
2. Bothnian Sea	37	64
3. Gulf of Finland	65	152
4. N. Baltic Proper	46	104
5. E. Baltic Proper	53	109
6. SE. Baltic Proper	64	120
7. Bornholm Basin	60	135
8. Arkona Basin	59	142
9. Kattegat	58	151