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A modelling framework for MSP-oriented cumulative effects assessment

Stefano Menegon[a,*,1], Daniel Depellegrin[a,*,1], Giulio Farella[a,*,1], Elena Gissi[b], Michol Ghezzo[a], Alessandro Sarretta[a], Chiara Venier[a], Andrea Barbanti[a]

[a] CNR – National Research Council of Italy, ISMAR – Institute of Marine Sciences, Venice, Italy
[b] Department of Design and Planning in Complex Environments, Università Iuav di Venezia, Venice, Italy

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ABSTRACT

This research presents a comprehensive Cumulative Effects Assessment (CEA) based on the Tools4MSP modelling framework tested for the Italian Adriatic Sea. The CEA incorporates five methodological advancements: (1) linear and non-linear ecosystem response to anthropogenic pressures/effects, (2) modelling of additive, dominant and antagonist stressor effects, (3) implementation of a convolution distance model for stressor dispersion modelling, (4) application of a CEA backsourcing (CEA-B) model to identify and quantify sources of anthropogenic pressures affecting environmental components, based on the convolution distance model and (5) a novel CEA impact chain visualization tool based on Sankey diagrams. Results from CEA in the Italian Adriatic Sea show that highest CEA scores are located in the Northern Adriatic Sea (Port of Trieste and Venice Lagoon inlets) while abrasion, marine litter and selective extraction are the most pronounced pressures within the 12 nm. Results from CEA-B application for two case studies evidence a clear distinction among local human impacts (trawling, small scale fishery) versus long-range diffusive human impacts (underwater noise and marine litter). Results were discussed for their geospatial outcomes, importance for transboundary effects assessment, conservation planning and future application potentials.

1. Introduction

Cumulative effects assessment (CEA) have received increasing attention to aid the identification of marine conservation priorities and management actions (Halpern et al., 2008; Halpern et al., 2015; Micheli et al., 2013; Tulloch et al., 2015). Their application has been exemplified in many different geographical domains ranging from global (Halpern et al., 2015) or sea basin (Korpinen et al., 2012; Micheli et al., 2013) level to regional one (Menegon et al., 2017; Holon et al., 2015; Murray et al., 2015) assessments. Moreover, the need to address anthropogenic impacts on marine ecosystems is widely expressed through environmental legislations (MSFD), requiring coordinated management programs to reach the good environmental status (GES) and the marine spatial planning (MSP) directive, requiring an ecosystem-based approach aiming at ensuring that collective pressures from human activities are kept at levels compatible with the GES and contribute to the sustainable use of marine goods and services and their preservation for future generation.

Despite the methodological advancements, assessment methodologies still rely on major assumptions leading to potential bias of results (Gissi et al., 2017; Stock and Micheli, 2016): spatial accuracy of input dataset (Ban et al., 2010), assumptions on the additivity of impact, while synergistic and antagonistic effects are neglected (Crain et al., 2008), linear response versus more common non-linear response to pressures (Halpern and Fujita, 2013) are still unsolved bottlenecks within the scientific community dealing with cumulative impact assessment. In addition, another critical aspect is the inconsistency and poor specificity in the principles, definitions and approaches adopted in the CEA applications (Judd et al., 2015; Jones, 2016; Stelzenmüller et al., 2018) leading to large variation of CEA research agendas, creating difficulties in the comparing methods and outcomes and posing barriers to proper interpretation and communication of outputs (Stelzenmüller et al., 2018; Foley et al., 2017; Stock and Micheli, 2016). In order to address these issues, the improvement of a CEA framework within the principles of the ecosystem-based management and environmental risk assessment is a promising approach (Judd et al., 2015; Stelzenmüller et al., 2018). A key aspect of the risk assessment is the identification and understanding of the relationships between the source of a pressure, the pathways by which exposure might occur, and the environmental receptors that could be harmed (source-pressure-pathway-receptor linkages) (Judd et al., 2015). Similarly to other sea areas around the globe, also in the Adriatic-Ionian Region (AIR)

* Corresponding authors.
E-mail addresses: stefano.menegon@ismar.cnr.it (S. Menegon), daniel.depellegrin@ve.ismar.cnr.it (D. Depellegrin), giulio.farella@ve.ismar.cnr.it (G. Farella).
[1] Joined first authors.

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cumulative impact assessment techniques have been implemented on macro-regional level (Barbanti et al., 2015; Gissi et al., 2017), including regional case studies on high resolved geospatial datasets in Emilia-Romagna region (Barbanti et al., 2017). The CEA in the AIR was performed through the Tools4MSP Geoplatform (CNR-ISMAR, Tools4MSP Development Team, 2014-2018), an MSP-oriented and community-based web-platform for publishing, sharing and processing multi-disciplinary geospatial data. The portal supports the Spatial Data Infrastructure (SDI) capabilities and interoperable standard services enabling the data-sharing with external infrastructures and portals (e.g. EMODnet Data Portals, European Atlas of the Seas, EEA map services, SHAPE Adriatic Atlas). Based on Free and Open Source Software (FOSS) components, the Tools4MSP Geoplatform integrates and implements the Tools4MSP modelling framework allowing the user communities to perform shared analysis of Cumulative Effect Assessment (CEA), Sea Use Conflict (SUC) and Marine Ecosystem Services (MES) (Depellegrin et al., 2017; Menegon et al., 2016; Barbanti et al., 2015).

This research presents a comprehensive Cumulative Effects Assessment (CEA) methodology based on the Tools4MSP modelling framework applied to the Italian Adriatic Sea. The CEA approach adopts a new CEA model that better formalizes the source-receptor conceptual linkage, combines linear and non-linear ecosystem response, additive, dominant and antagonist effect models and presents a convolution distance model for flexible stressor dispersion modeling. A CEA impact chain visualization is proposed using Sankey diagrams. Based on the convolution distance model we propose a novel method to identify and quantify sources of anthropogenic pressures affecting specific environmental components, named CEA backsourcing (CEA-B). The CEA-B is a reverse CEA application demonstrated for two case studies: effects of underwater noise on hotspots of Loggerhead Turtles (*Caretta caretta*) in the Northern Adriatic Sea and multiple effects on environmental components of coastal Natura 2000 sites in Apulia Region in the Southern Adriatic Sea. Modeling results are discussed for their geospatial outcome, importance for transboundary impact assessment and future application potentialities.

2. Material and methods

2.1. CEA definition

The comprehensive CEA modelling approach builds on the definition of CEA provided by Judd et al. (2015). In particular, we consider "*CEA as a systematic procedure for identifying and evaluating the significance of effects from multiple pressures and/or activities on single or multiple receptors. CEA provides management options, by quantifying the overall expected effect caused by multiple pressures and by identifying critical pressures or pressure combinations and vulnerable receptors. The analysis of the causes (source of pressures), pathways, interactions and consequences of these effects on receptors is an essential and integral part of the process*". Moreover, we use the terms "*human activity*", "*uses*" and "*source*" as synonyms and define "*pressure*" (Judd et al., 2015) as "*an event or agent (biological, chemical, or physical) exerted by the source to elicit an effect*". In Appendix A we also report the definitions for the terms "*effect, sensitivity, vulnerability, pathway receptor, and impact*" (Stelzenmüller et al., 2018) adopted for CEA in the Tools4MSP modelling framework.

The following sections present the CEA approach adopted in the Italian Adriatic Sea including a CEA backsourcing (CEA-B) model.

2.2. Study area

The Italian Adriatic Sea covers about 143,000 km^2 and ranges from coastal waters to the maritime boundary delimiting the italian part of the continental shelf (Fig. 1). Its coastline spans from Friuli-Venezia-Giulia Region to Apulia southern coast. The area falls within the "Adriatic Sea" subregion according to the Marine Strategy Framework Directive (2008/56/EC). Its maritime boundaries are shared with Slovenia, Croatia, Montenegro and Albania. The Adriatic Sea is a semi-enclosed basin that communicates with the Ionian Sea through the Otranto Strait. The Northern Adriatic Sea is the most extended shelf area of the entire Mediterranean, with a very smooth coastal area and a softly sloping bottom. The Southern Adriatic Sea is characterized by the presence of a circular pit (South Adriatic Pit), bordering the Apulian continental shelf with a maximum depth of 1200 m. The Adriatic Sea features extremely diverse coastal and seabed landscapes with a wide heterogeneity of geomorphological features and bottom sediments (UNEP/MAP-RAC/SPA, 2015a). The Northern and Central Adriatic seabed sediments are predominantly composed by sandy-muds, influenced by fluvial supply, while in the Southern Adriatic sea coarser sediments of rocky bottoms featuring bio-constructions (e.g. coralligenous assemblages) and *Posidonia oceanica* meadows are more frequent. The Adriatic Sea is a recognized hotspot of biodiversity within the Mediterranean Sea, hosting invertebrate species, fish species, resident marine mammals, turtles and seabirds (Coll et al., 2010). Its relatively small sea space is subjected to intense anthropogenic activities such as shipping, commercial fishery, oil and gas extraction, coastal tourism, aquaculture or cabling that can exert multiple pressures on its valuable ecological resources.

2.3. CEA dataset

The geospatial dataset implemented for the study features 41 layers: 28 environmental components (E) and 13 human uses (U). Appendices B and C present a detailed overview of the geospatial dataset implemented. The units of the spatial indicators U and E are presence/absence, weighted dummy and intensity indicators. For intensity indicators a log[x + 1] transformation and a rescaling from 0 to 1 was applied. Land-based activities (LBA) were modelled for nutrient distribution for Nitrogen (N) and Phosphorus (P) exerted by 80 rivers in the sea basin and 40 coastal urban areas using SHYFEM (Shallow Water Finite Element Model; Umgiesser et al. (2004). Full E, U and P geospatial datasets and relative metadata references can be downloaded under Menegon (2017).

2.4. CEA processing: Tools4MSP Modelling Framework

The Tools4MSP Modelling Framework is a regularly updated open source software suite (Menegon et al., 2016) providing multi-objective toolsets for maritime spatial planning (Depellegrin et al., 2017). The framework supports the development of spatially explicit results, graphics, tables and multi-dimensional grid dataset that can be utilized for more detailed spatial investigations. Currently, the framework implements a Cumulative Effect Assessment (CEA), sea use conflict (SUC) analysis model and a marine ecosystem services (MES) capacity model. Tools4MSP can be flexibly deployed to different geospatial contexts ranging from macro-regional (Menegon et al., 2017; Gissi et al., 2017) to local/regional level assessments (Barbanti et al., 2017). There are two modes of access of the framework: (1) The Tools4MSP Geoplatform (data.tools4msp.eu) provides a user-friendly interface enabling users to run customized scenarios of CEA by choosing the area of analysis, the data layers and the resolution of the model outputs (Menegon et al., 2016). Modelling results were automatically published on the portal and shared among the user community. (2) Another option to use Tools4MSP model functions is via a stand-alone open source geopython library available in its latest version on Github (Menegon, 2015–2017).

2.4.1. CEA model

Originally, the presented CEA model is based on the methodology developed by Halpern et al. (2008) and later modified by Andersen et al. (2013). In Fig. 2 the CEA impact chain is presented defining the relationship of multiple human uses (U) generating single or multiple pressures/effects (P/Eff) causing impacts on single or multiple