Addressing cumulative effects, maritime conflicts and ecosystem services threats through MSP-oriented geospatial webtools.

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Abstract

To solve conservation and planning challenges in the marine environment, researchers are increasingly developing geospatial tools to address impacts of anthropogenic activities on marine biodiversity. The paper presents a comprehensive set of built-in geospatial webtools to support
5   Maritime Spatial Planning (MSP) and environmental management objectives implemented into the Tools4MSP interoperable GeoPlatform. The webtools include cumulative effects assessment (CEA), maritime use conflict (MUC) analysis, MSFD pressure-driven CEA and a CEA-based marine ecosystem service threat analysis (MES-Threat) . The tools are tested for the Northern Adriatic (NA) Sea, one of the most industrialized sea areas of Europe using a case study driven modelling strategy.
10 Overall results show that coastal areas within 0-9 nm in the Gulf of Trieste, Grado-Marano and Venice lagoon and Po Delta outlet are subjected to intense cumulative effects and high sea use conflicts mainly from port activities, fishery, coastal and maritime tourism and maritime shipping. Linking MES into CEA provided novel information on locally threatened high MES supporting and provisioning habitats such *Cymodocea* beds and infralittoral fine sands, threats to cultural MES are
15 most pronounced in coastal areas. Results are discussed for their geospatial relevance for regional planning, resource management and their applicability within MSP and environmental assessment.

1. Introduction

Current conservation and planning challenges of the marine environments require flexible tools that
20 ensure to different types of user the access, management, sharing, processing and visualization of a multitude of spatial and non-spatial dataset. Ideally, these datasets are stored within platforms capable to organize a multitude of data and convey them into easily and quickly accessible graphical user interfaces (GUI). The use of Maritime Spatial Planning (MSP, Directive 2014/89/EU) as practical process to achieve environmental, social and economic objectives and minimize conflicts (Hansen et
25 al., 2017) in European seas has posed novel demands to amount, quality and sources of data. Despite the ongoing governance process, considerable work has been done by the scientific community for the development of Spatial Data Infrastructure (SDI; Fowler et al., 2010) in support of a knowledge-based implementation of national and regional plans.

In recent years the application of cumulative effects assessment and sea use conflict analysis have
30 emerged as common analytical tool to support decision-makers in the development of spatial plans and in support of the ecosystem-based management of marine resources. This is also reflected in an emerging number of decision support tools enabling user to perform cumulative effects assessment in various contexts. An extended review of decision support systems performed by Krueger and

Schouten-de Groot (2011) showed that out of the 118 tools in support of MSP, about 46 (39%) implement CEA models whether serving decision support or scenario analysis development and management priorities identification. Examples of MSP oriented decision support system include sector specific tools such as Windspeed (Spatial Development of Offshore Wind Energy in Europe; www.windspeed.eu) for the identification of suitable areas for wind energy in the North Sea, MARA (Marine Aggregate Extraction Risk Assessment framework; www.mara-framework.org.uk) for probabilistic environmental risk assessment or the Isis-fish (Krueger and Schouten-De Groot, 2011), a predictive tool of fish population development under different management scenarios. Other tools that allow more comprehensive CEA analysis include the HARMONY tool (Development and demonstration of Marine Strategy Framework Directive tools for harmonization of the initial assessment in the eastern parts of the Greater North Sea sub-region; Andersen et al., 2013) for human impact assessment in the eastern North Sea sub-region or the SYMPHONY tool (MSP Platform, 2016).

Sea use conflict analysis has been extensively applied in different geographical contexts (Hadjimitsis et al., 2015; White et al., 2012) based on different decision support systems, such as the GRID tool (Georeferenced Interactions Database; Gramolini et al., 2010) providing a platform to spatialize use-use conflict in sea areas, the MaRS geotool (Marine Resource System; www.thecrownestate.co.uk/mars) to support identification and resolution of spatial conflicts and AquaSpace that enables integrated assessment of risks and opportunities for proposed aquaculture sites (Gimpel et al., 2018).

Also the recent growth of ecosystem services research contributed to the development of several geospatial tools in support of decision making in coastal and marine environments, such as the habitat risk assessment (HRA) tool from Marine InVEST toolset (Integrated Valuation of Ecosystem Services and Tradeoffs), that enables user to assess risks to marine ecosystems generated by different human activities (Wyatt et al., 2017), the SolVES tool (Social Values for Ecosystem Services) for the analysis and mapping of non-market values of cultural ecosystem services (van Riper et al., 2012) or the MIMES model (Multi-Scale Integrated Models of Ecosystem Services) which supports MSP for tradeoff analysis among competing uses (Center for Ocean Solutions, 2011).

The very diverse suites and packages of geospatial tools poses considerable opportunities in the development of new generation decision-support systems for strategic planning and environmental conservation in the marine domain. However this diversity is source of difficulties in identifying suitable tools addressing specific decision-making objectives, may produce a fragmented utilization of several tools leading to input and outputs procedures that can require a costly data treatment for harmonizing the processing workflow.

In this research we present the functionalities of three webtools implemented in the Tools4MSP Geoplatform (tools4msp.eu), namely Cumulative Effects Assessment (CEA), Maritime Use Conflict (MUC) analysis and a Marine Ecosystem Services Threat analysis (MES-Threat). The webtools were tested in a case study for the Northern Adriatic (NA) Sea, one of the most crowded sea areas of Europe. The application of webtools is presented using a stepwise workflow based on a structured case study driven modelling strategy. The paper is organized as follows: Section 2 presents the overall workflow, the theoretical background of the webtools and the stepwise procedure for the webtools' setup, in Section 3 the geospatial and geostatistical results of the model setup are presented and Section 4 discusses the results for their relevance in MSP, environmental management and the applicability of the webtool along EIA and SEA.

2. Materials and Methods

80   *2.1. The Tools4MSP Geoplatform*

The Tools4MSP Geoplatform is a community-based, open-source portal, based on GeoNode (GeoNode Development Team, 2018), a web-based Content Management System (CMS) for developing geospatial information systems (GIS) and for deploying spatial data infrastructures (SDI). The aim of the Geoplatform is to provide an operational set of webtools that can assist decision-

85   makers and strategists in undertaking MSP-oriented case studies and support the development of environmental management strategies.

The webtools are integrated as GeoNode Plugin into the Geoplatform, that provides a graphical user interface (GUI) facilitating the usability of the Tools4MSP core functionalities for different user communities (Menegon, 2018b). The Plugin reflects the Tools4MSP modelling framework

90   (Depellegrin et al., 2017, Menegon et al., 2016), a python-based Free and Open Source Software (FOSS) which combines several FOSS projects for geodata processing and scientific modelling: (1) NumPy and SciPy for efficient numerical computation (van der Walt, 2011); (2) Pandas and GeoPandas for data structures manipulation and data analysis (McKinney, 2010); (3) OWSLib which implements the client-side for OGC web services standard interfaces (OWSLib Development Team,

95   2018); (4) Rectifiedgrid for efficient 2D grid-based analysis (Menegon, 2018a) and (5) the interactive visualization of the Tools4MSP results are created through Bokeh (Bokeh Development Team, 2018). The Tools4MSP software package can be freely downloaded from github (https://github.com/CNR-ISMAR/tools4msp).

In order to demonstrate the functionalities of the Tools4MSP Geoplatform, we present   four

100   operational steps for its utilization (Fig. 1): (Step 0) Webtool selection depending on the scope and objectives of the analysis; (Step 1) case study area selection, available for different geospatial scales (from seabasin to regional level); (Step 2) dataset configuration defining human uses, environmental components and MSFD-pressures themes used for modelling and (Step 3) generation of geospatial and statistical outputs to be used for data curation and re-analysis within a dedicated GIS software

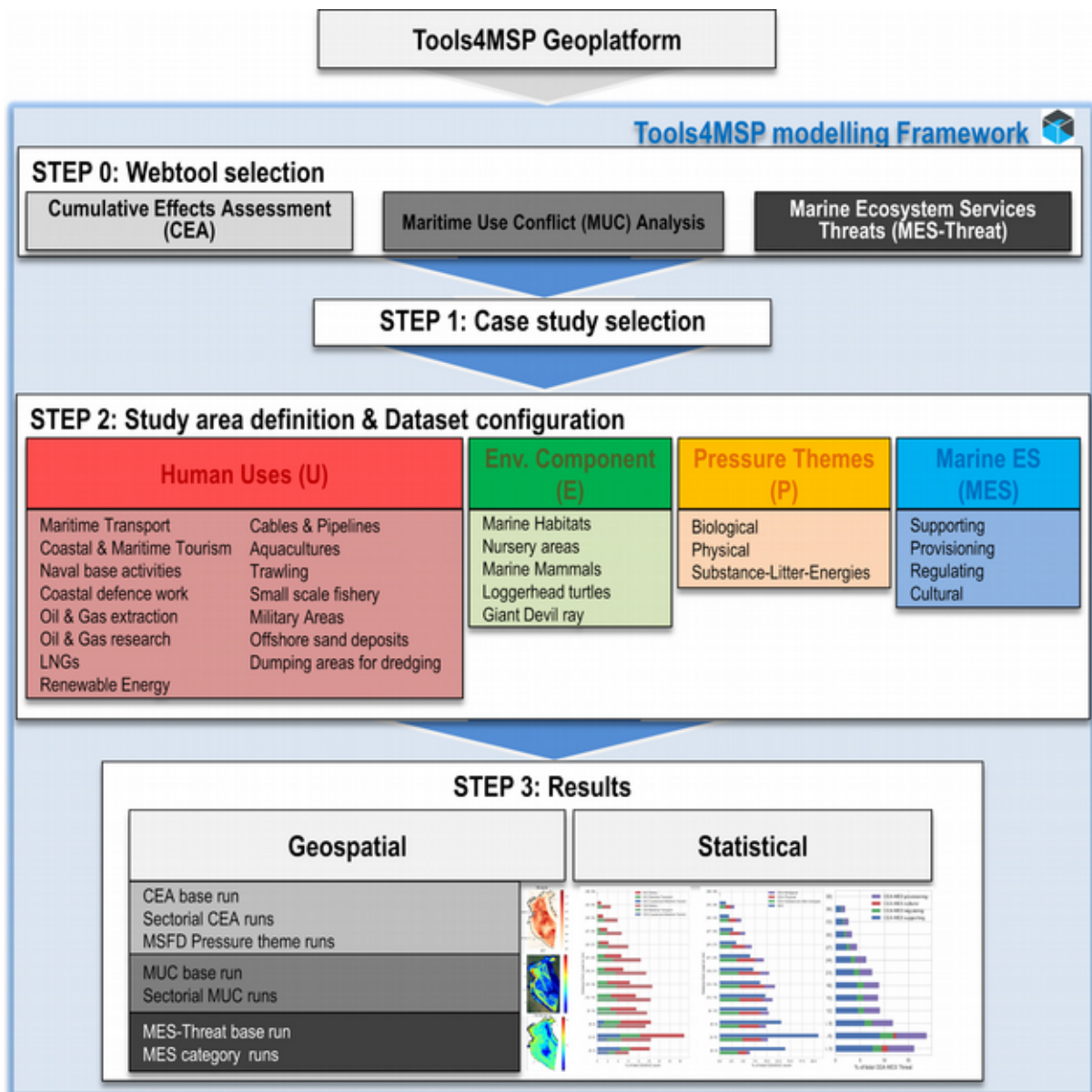105   such as Quantum GIS (QGIS Development Team, 2018).

Fig. 1. Workflow for webtools application in the Tool4MSP Geoplatform: Step 0 - Webtool selection; Step 1 - Case study area selection; Step 2 - Study area selection & Dataset configuration and Step 3 - Geospatial and statistical outputs.

2.2. Step 0: Webtools selection

110　This step allows user to select a comprehensive set of webtools available in the Geoplatform (Fig. 2) namely a Cumulative Effects Assessment (CEA), Maritime Use Conflict (MUC) analysis and Marine Ecosystem Services Threat analysis (MES-Threat). In Fig. 2 (right) the buttons to prompt user to the webtool model run. In the following section a detailed description of theoretical and methodological

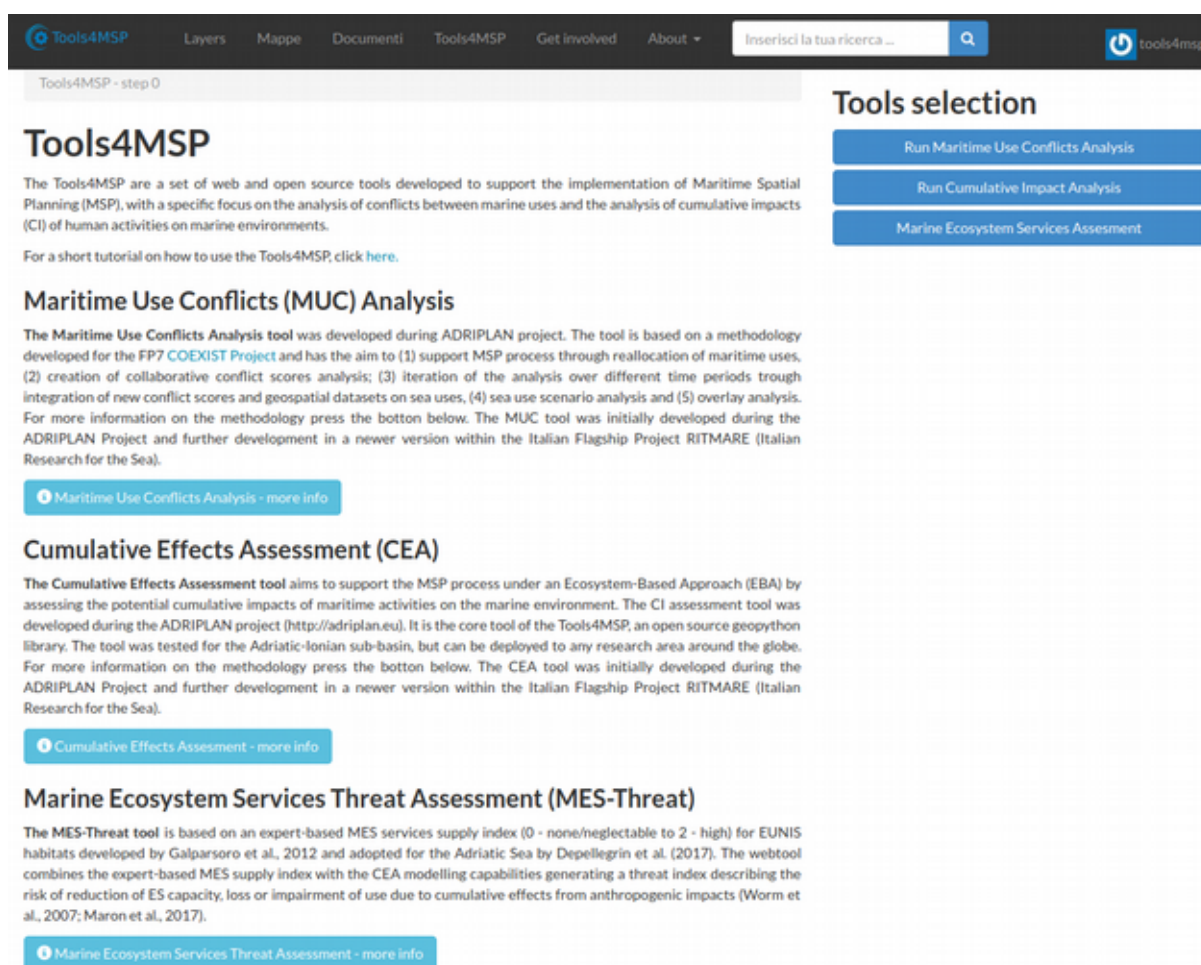115　background of the webtools is provided.

Fig. 2. GUI for the webtools selection within the Tools4MSP Geoplatform. The interface includes also background information of the CEA, MUC and MES-Threat webtool.

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2.2.1. Cumulative Effects Assessment (CEA)

The Tools4MSP Geoplatform implements a Cumulative Effects Assessment (CEA) for the analysis of cumulative effects generated by anthropogenic activities on marine environmental components. Its implementation is based on archetypical CEA implementations proposed in various geographical

125 scales (Halpern et al., 2008; Andersen et al., 2013). In detail, we define CEA as a systematic procedure for identifying and evaluating the significance of effects from multiple pressures and/or activities on single or multiple receptors (Judd et al., 2015). The CEA incorporates two major improvements, such as the modulation of propagation of pressures through a distance model $M(U_i, P_j, E_k)$ based on 2D Gaussian spatial convolution and the distinction of sensitivity scores ($s_{j,k}$) into

130 sensitivity values combined with use-specific relative pressure weight ($w_{i,j,k}$). The CEA algorithm implemented in the Geoplatform is described in Eq.1. The algorithm takes into account an additive effects combination, meaning that cumulative effects correspond to the sum of individual effects on an environmental component (CEAA-ACEE, 2016), and considers a linear response of the

environmental component to the pressure. The CEA score on a single grid cell is calculated as follows:

$$CEA = \sum_{k=1}^{n} d(E_k) \sum_{j=1}^{m} s_{j,k} \, eff(P_j, E_k)$$
(1)

where *eff* is the effect of pressure *P* over the environmental component *E*,

$$eff(P_j, E_k) = \Big(\sum_{i=1}^{l} w_{i,j,k} \, i(U_i, M_{i,j,k}) \Big)'$$

whereas,

U = *i*-th human use
P = *j*-th pressures derived from the MSFD (/EC, 2008)
E = *k*-th environmental components
$eff(P_j, E_k)$ = *effect exerted by the pressure Pj over the k-th environmental component, E_k.*
$s(P_j, E_k)$ = *sensitivity of the environmental component E_k to the j-th pressure P_j*
$w_{i,j,k}$ = *use-specific relative pressure weight*
$d(E_k)$ = *Intensity or presence/absence of the k-th environmental component on the cell (x, y), which is 1 for fixed E (seabed habitats), and varies from 0 to 1 for mobile special features (turtles, marine mammals and seabirds).*
$i(U_i, M(U_i, P_j, E_k))$ = *distance model propagating j-th pressure caused by i-th activity over the k-th environmental component*
$M(U_i, P_j, E_k)$ = *2D gaussian kernel function used for convolution considers buffer distances at 1 km, 5 km, 10 km, 20 km and 50 km*
' (tick) = effect rescaling operator (from 0 to 1)

Further details on proposed CEA algorithm can be obtained from Menegon et al. (2018a).

2.2.2. Maritime Use Conflict (MUC) Analysis
Maritime Use Conflict (MUC) analysis is based on a methodology developed within the COEXIST Project – Interaction in European coastal waters: A roadmap to sustainable integration of aquaculture and fisheries (COEXIST, 2013). In particular the methodology presented by Gramolini et al. (2010) enables the identification of current/potential human uses and assesses their interaction in terms of conflicts. The algorithm implemented for the MUC score on a single grid is presented in Eq. 2:

$$MUC = \sum_{i=1}^{l} \sum_{j=i+1}^{l} c_{i,j} \, p(U_i) \, p(U_j)$$
(2)

where,

c_{ij} = *potential conflict score between U_i and U_j*
$p(U_i)$ = *presence (1) or absence (0) of the i-th human use in the cell*
$p(U_j)$ = *presence (1) or absence (0) of the j-th human use in the cell*

The potential conflict score (c_{ij}) between two uses U_i and U_j can vary from 0 (no conflict) to 6 (very high conflict score) and was calculated following the COEXIST methodology: i) application of an expert judgment approach to characterize each human uses through four attributes (vertical scale, spatial domain, temporal domain and mobility); ii) automatic assessment of the potential score for each use combination based on uses characterization and COEXIST rules application; iii) supervised expert based adjustment of the c_{ij} coefficients to take into account legal and practical constraints between uses (see Appendix 1 for human uses characterization and COEXIST rules). Appendix 2 presents the potential conflict score matrix representing the c_{ij} coefficients applied for each use

combination. For further details on the methodology applied in the study area we refer to Barbanti et
al. (2015) and Depellegrin et al. (2017).

2.2.3. Threat analysis to Marine ecosystem services (MES-Threat)

The MES-Threat assessment builds on existing theoretical and practical approaches for the integrated
analysis and mapping of stressor/pressure effects on MES supply units within the Great Lakes
Restoration Initiative (Allan et al., 2013), North Sea (Hooper et al., 2017) or the ODEMM linkage
framework (Options for Delivering Ecosystem-Based Marine Management; White et al., 2013). We
define as MES-Threat the risk of MES reduction, partial or permanent loss of provision or impairment
of use due to single or multiple anthropogenic effects targeting the MES providing ecological
components (Worm et al., 2006; Maron et al., 2017). The tool incorporates an expert based MES
capacity scoring and mapping procedure implemented for the Adriatic Sea's EUNIS habitats (see
Appendix 3) with CEA modelling capabilities of the Geoplatform. The MES-Threat algorithm is
presented in Eq. 3:

$$MES - Threat = CEA \times MES = CEA \times \sum_{k=1}^{n} cap_k \, p(E_k) \qquad (3)$$

where,
CEA = cumulative effects assessment model as described in Eq. 1
cap_k = marine ecosystem services supply capacity (0-2, see Appendix 3)
$p(E_k)$ = Presence/absence of the k-th EUNIS habitat on the cell (x, y)

2.2. Step 1: Case study selection

After selecting the webtool to be applied, the system prompts the user to a pre-selected case study list.
At the current stage three different geospatial domains are available, namely Mediterranean Seabasin
level, macro-regional level for the Adriatic Sea and regional level for Emilia-Romagna Region (Fig.
3). Each case study represents a pre-configured set of webtool-specific data, with consistent spatial
coverage of human uses and environmental components and incorporating all other necessary
parameters for the model run. For the tools application in the case study a pre-configured grid
resolution of 500 m x 500 m was applied.

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Fig. 3. GUI illustrating the case study selection including case study domain, time reference and applicable grid resolution. Currently three study domains can be selected: Mediterranean Sea (2018), Adriatic Sea (2017) and Emilia-Romagna Region (2017).

215   *2.3. Step 2: Case study setup*

2.3.1 Study area definition

After selecting the case study, the Geoplatform prompts the user to the case study setup using an interactive web mapping application with a polygon selector tool (Fig. 4a). The Northern Adriatic (NA) Sea was selected as area of analysis based on the biogeographic boundaries defined by Bianchi

220   (2004). The NA biogeographic region covers about 22,500 km^2 and is delimited by the Conero Regional Park to the southern tip of Istrian Peninsula (Bianchi, 2004). The NA is relatively shallow, with depth not exceeding 50 m (Turk and Odorico, 2009). From an administrative point of view, the NA embraces three countries and five coastal regions, including Italy (Emilia-Romagna, Veneto and Friuli-Venezia-Giulia Region), Slovenia (Coastal Karst Region) and Croatia (Istria Region). The NA

225   is an extremely complex environment as it combines intensive anthropogenic activities (e.g. maritime transport, commercial fishery, aquaculture, coastal and maritime tourism), with sensitive coastal and marine ecosystems (e.g. essential fish habitats, nursery and spawning grounds of species of high commercial interest, seabirds and hotspots of Species of Community Interest such as *Caretta caretta* turtles and marine mammals, mainly *Tursiops truncatus*).
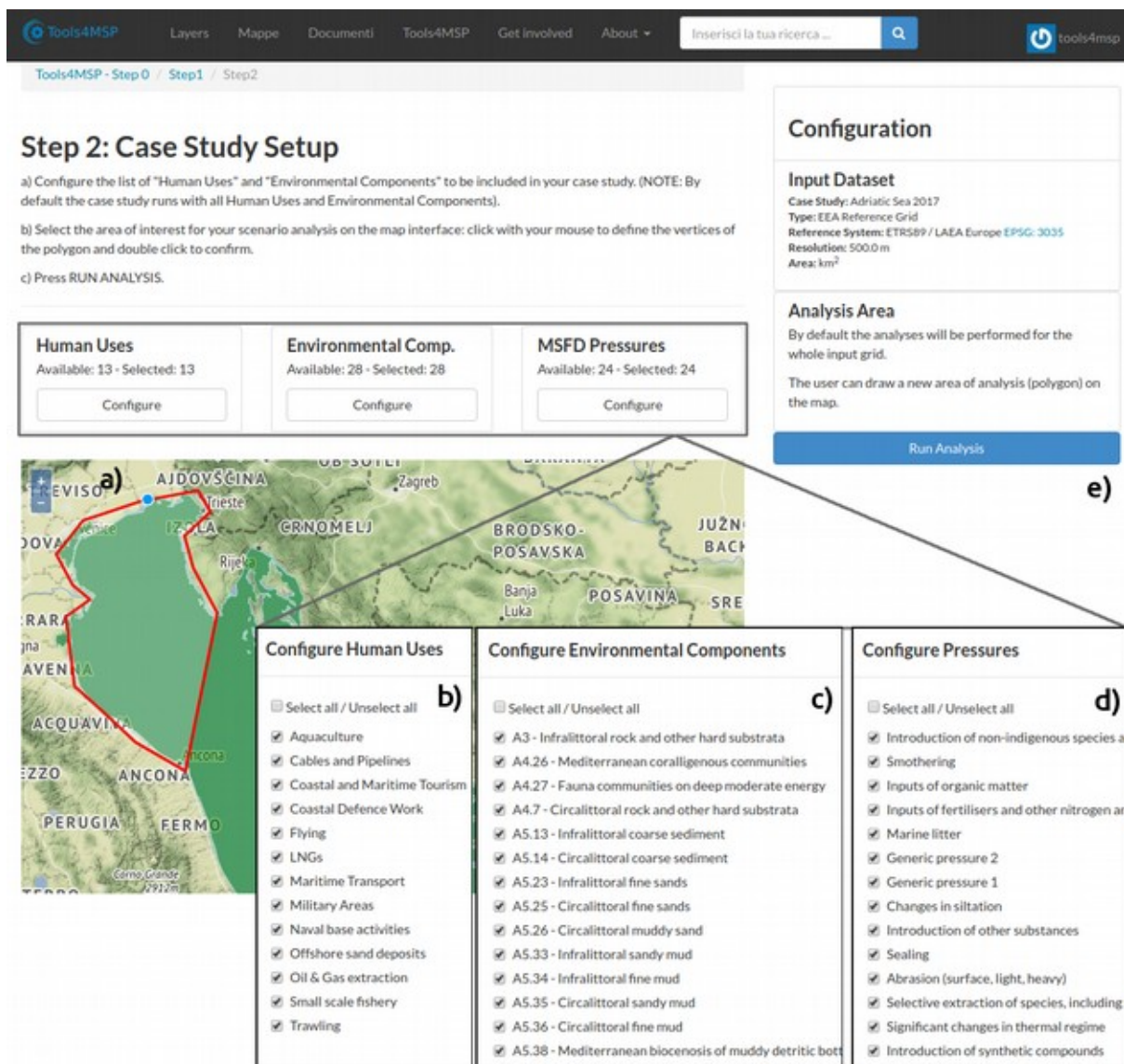
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Fig. 4. Example of GUI illustrating the CEA setup for the Northern Adriatic Sea: a) Study area selection, dataset configuration for (b) human uses, (c) environmental components and (d) MSFD pressure selection. On the top-right (e) the button for initiating CEA model run is provided.

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2.3.2. Dataset configuration

After the selection of the study area, the user can select the configuration of the geospatial dataset to be modelled (Fig. 4b-d). The Geoplatform incorporates a stocktake of over 65 MSP relevant geospatial layers for viewing, querying and download (Table 1). The user can select the human uses,
240 the environmental components and the MSFD pressures to be included in the case study development. The dataset configuration is a key element for a case study development strategy as it allows to customize model outputs. The most updated version of the dataset can be freely download at Menegon et al. 2018b (https://doi.org/10.5281/zenodo.1173764).

245 Table 1. Geospatial layers and indicators implemented (P/A = presence/absence; I = normalized intensity indicator; PR = proxy; wP/A = weighted presence/absence), adopted from Depellegrin et al., 2017. Note: a detailed version of this table and the most updated version of the dataset can be freely download at Menegon at al. 2018. https://doi.org/10.5281/zenodo.1173764.

Dataset	Indicator

Human uses	
Aquaculture[1,2], Cables and Pipelines[2], Coastal Defence Work[2], Dumping area for dredging[2], LNGs[3], Military areas[2,5], Off-shore sand deposit [1,4,5,7], Oil and Gas Extraction [2,8,9,10], Oil and Gas Research[2,8,9,10], Renewable Energy facilities (Offshore Wind farms) [6]	P/A
Coastal and Maritime Tourism[11]	I/PR – distance from the marinas and number of boats/marinas
Naval Based Activities[15]	I/PR – distance from the cargo ports and port capacity
Maritime Transport[4]	I – Traffic density (vessels/year)
Small Scale Fishery[4]	I – fishing effort expressed in 5 classes of intensity: from very low to high
Trawling[12]	I – hours of activities calculate through Vessel Monitoring System (VMS)
Environmental components	
Seabed habitats[15]	P/A
Marine Mammals[13], Giant Devil Ray[13], Turtles[13], Seabirds[13], Nursery Habitats[14]	wP/A

[1] Veneto Region (www.regione.veneto.it); [2] SHAPE – Shaping a Holistic Approach to Protect the Adriatic Environment between coast and sea (www.shape-ipaproject.eu); [3] OGS – Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (www.ogs.trieste.it); [4] CNR-ISMAR – Italian National Research Council – Institute of Marine Sciences (www.cnr-ismar.it); [5] MIPAAF – Italian Ministry of Agriculture, Food and Forests (www.politicheagricole.it); [6] Emilia Romagna Region (www.regione.emilia-romagna.it); [7] Arenaria S.r.l. (www.arenariasabbie.com); [8] MEDTRENDS-The Mediterranean Sea, Trends, Threats and Recommendations (www.medtrends.org);[9]CHA – Croatian Hydrocarbons Agency (www.azu.hr); [10] MISE – Italian Ministry for Economic Development (www.sviluppoeconomico.gov.it); [11] modeled on the basis of https://www.pagineazzurre.com data; [12] Blue Hub, JRC in-house platform to exploit big data in the maritime domain (www.bluehub.jrc.ec.europa.eu); [13] UNEP-MAP-RAC/SPA, Regional Activity Center for Specially Protected Areas; [14] MEDISEH MAREA Project (www.mareaproject.net/medviewer); [15] EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu); [15] modeled on the basis of Eurostat data (http://ec.europa.eu/eurostat/statistics-explained/index.php/Maritime_ports_freight_and_passenger_statistics).

In total 13 layers of human uses were available in the Tools4MSP Geoplatform. The dataset is used by all three webtools (CEA, MUC and MES-Threat). Sources of the dataset are multiple and include: EU wide datasets (e.g. EMODnet Data Portals, European Atlas of the Seas, EEA map services), project portals specific datasets (e.g. the SHAPE Adriatic Atlas, COCONET WebGIS), data made available by research institutions (e.g. HCMR - Hellenic Centre for Marine Research; CNR-ISMAR – Italian National Research Council – Institute of Marine Sciences) and from national (e.g. OTE S.A. – Hellenic Telecommunication Organization; MIPAAF – Italian Ministry of Agriculture, Food and Forests) and regional authorities (Veneto and Emilia-Romagna).

The dataset of environmental components is used for the CEA and MES-Threat analysis and is based on 20 layers. Marine habitat layers include 15 distinct habitats, which were derived from EUNIS classification based EUSeaMap dataset (Populus, 2017). Layers for marine mammals, Loggerhead turtles and Giant Devil Ray densities were obtained from UNEP-MAP-RAC/SPA (Fortuna et al., 2015) and are based on a weighted presence/absence (wP/A) in terms of individuals per 20 km x 20 km. The nursery areas of 33 valuable commercial fishery species, including European pilchard (*Sardina pilchardus*), common sole (*Solea solea*), Norway lobster (*Nephrops norvegicus*), red mullet (*Mullus barbatus*) were obtained from the MEDISEH MAREA (Mediterranean sensitive habitats; www.mareaproject.net/medviewer) Project. These layers are available as dummy indicator of presence/absence (P/A).

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280 The CEA model implements 15 MSFD pressures out of 18 provided by the MSFD (EC, 2008). In the description of Table 2, pressures are grouped into three pressure themes, according to MSFD amended version (EC, 2017, Annex 4, Table 2): biological (2 pressures), physical (5 pressures) and a mixed substances-litter-energy (8 pressures) theme. The three pressures related to significant changes in salinity regime, introduction of radio-nuclides and introduction of microbial pathogens were omitted from the pressure dataset due to lack of reference and expert judgement.

285 The marine ecosystem services component necessary for the MES-Threat analysis is based on a MES capacity matrix (Appendix 3) rescaled for the NA Sea according to an initial assessment by Depellegrin et al. (2017). The MES capacity matrix adopts a qualitative indicator of the potential ES supply of the habitat ranging from 0 (neglectable capacity) to 2 (high capacity) adopted from a methodology proposed by Galparsoro et al. (2014) and Salomidi et al. (2012). In the NA the matrix implements 12 MES (x-axes) and 15 EUNIS habitats (y-axes) grouped into four MES categories (provisioning, regulating, cultural and supporting).

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2.3.3. Case study strategy development

In order to provide meaningful assessment for environmental management and planning in the NA Sea, the webtools were applied by operating seven distinct dataset configurations resulting into three webtool base runs (CEA/MUC/MES-Threat), three CEA/MUC sector-specific runs (maritime traffic,

295 commercial fishery and coastal and maritime tourism), three MSFD pressure themes driven CEA runs (biological, physical and substance-litter-energy pressures) and four MES-Threat model runs, one for each MES category (provisioning, regulating, cultural and supporting). In Table 2 a summary of the dataset requirements and setup for each model run is presented.

300 Table 2. Overview of webtools, dataset selection & requirements for model runs and outputs based on case study configuration strategy. Note: U - human uses; E - environmental components; P - MSFD pressures; MES - marine ecosystem services.

Webtool	Dataset selection	Outputs	Description
CEA	All U, P and E	CEA base run	Overall CEA model run includes all 13 human uses, 15 MSFD pressures and 20 environmental components
	Sectorial U, all P and E	Maritime traffic Commercial fishery (small scale fishery, bottom and pelagic trawling) Coastal and maritime tourism	Sectorial model run includes 3 human uses, 15 MSFD-Pressures and 20 environmental components
	MSFD themes, all U and E	CEA - biological	CEA model run for two pressure composing the biological theme: (1) Introduction of non-indigenous species and translocation; (2) Selective extraction of species, including incidental non-target catches
		CEA - physical	CEA model run for five pressures composing the physical theme: (1) Smothering; (2) sealing; (3) changes in siltation; (4) selective extraction; (5) abrasion
		CEA - substances-litter-energies	CEA model run for eight pressures composing the substances-litter-energies theme: (1) underwater noise; (2) marine litter; (3) inputs of fertilisers and other nitrogen and phosphorus-rich substances; (4) introduction of non-synthetic substances and compounds; (5) introduction of other substances; (6) introduction of synthetic compounds; (7) significant changes in thermal regime; (8) organic matter

MUC	All U	MUC base run	Overall MUC model run output includes a conflict analysis on 13 human uses.
	Sectorial U	MUC - Maritime traffic MUC - Commercial fishery (small scale fishery, bottom and pelagic trawling), MUC - Coastal and maritime tourism	Sectorial MUC model run for three distinct human uses.
MES-Threat	All U, P and MES categories (EUNIS habitats)	MES-Threat Base run	Overall MES-Threat model run for 12 MESs provided by 15 EUNIS habitats, 13 human uses and 15 MSFD-Pressures
	Specific MES categories, all U and P	MES-Threat provisioning MES-Threat regulating MES-Threat cultural MES-Threat supporting	MES category driven model output includes four MES-Threat maps, one for each MES categories identified in the MES capacity matrix (Appendix 3)

2.5. Step 3: Geospatial and statistical outputs

The Tools4MSP Geoplatform provides to the user a full range of geospatial and statistical results that
305 can be used for further deepening of the analysis. In Fig. 5 a GUI example of the multiple outputs are
provided including exploration of geospatial and statistical results (Fig.5 a and d), the view layer
functionality to share and download modelling results (geotiff format) with the user community (Fig.5
b) and the complete metadata functionality to compile metadata information on the modelling results
(Fig.5 c). In particular the downloaded results can be used for further investigation or re-analysis
310 using dedicated GIS software. In the following Section geospatial visualizations were presented using
Quantum-GIS (QGIS Development Team, 2018) and statistical results were presented with Python
numeric and scientific libraries including Numpy, Scipy, Pandas, Matplotlib and Seaborn (van der
Walt, 2011; McKinney, 2010).
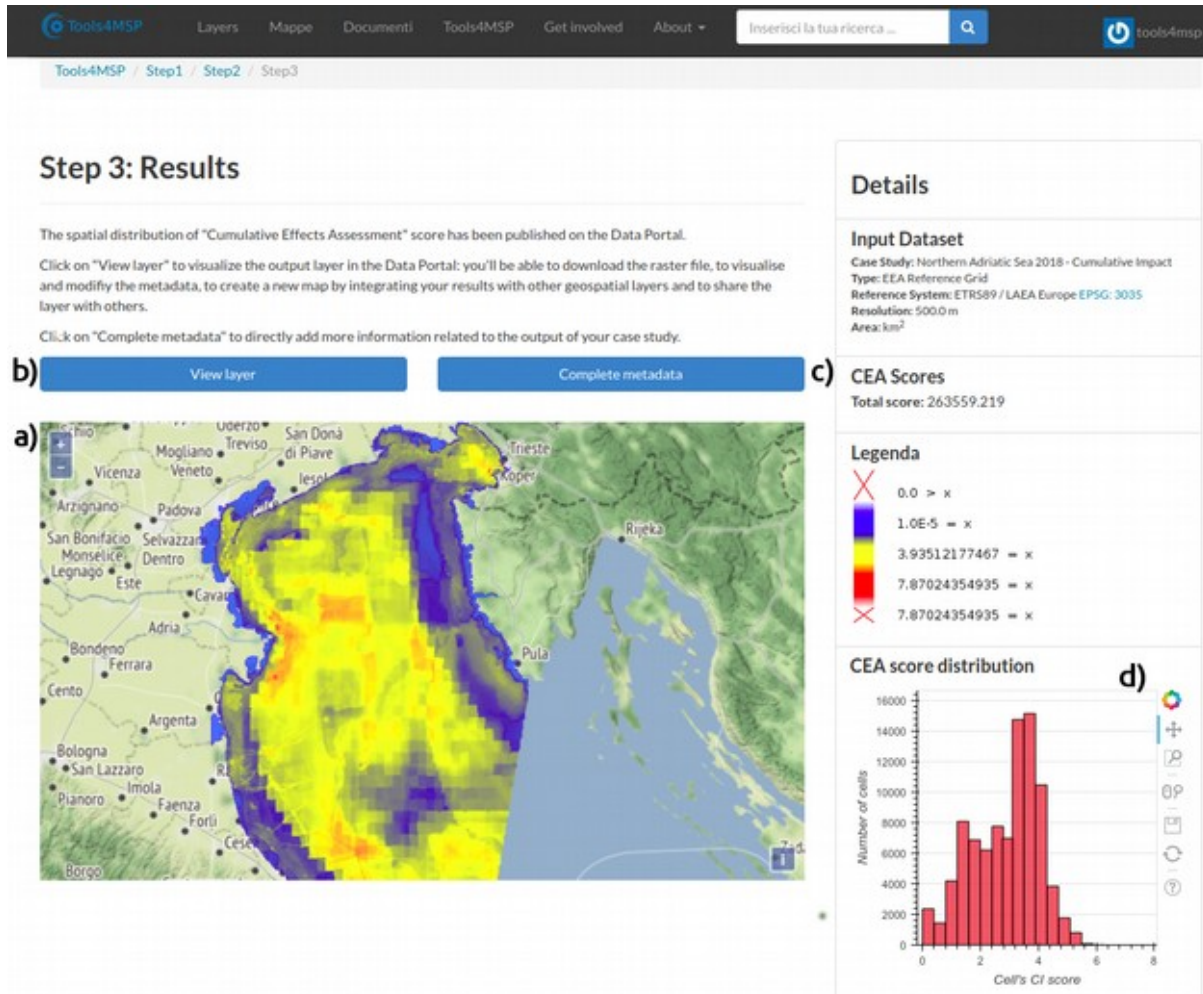
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Fig. 5. Example of GUI presenting geospatial and statistical results: (a) the geospatial results of CEA run for the NA, (b) view layer button enabling users to download geospatial results, (c) complete metadata button for describing metadata relevant for the understanding of the result and (d) statistical result in terms of CEA score distributions by number of cells per CEA score.

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3. Results

3.1. Cumulative Effects Assessment

In Fig. 6 a-d results from CEA case study development are presented. The CEA base run show that highly impacted sea areas are located mainly in Italian coastal areas such as the Gulf of Trieste and

325   along a coastal segment in front of the Po river outlet (Fig. 6a). On overall the NA Sea reaches a mean CEA score of 3.06. The maximum CEA score of 8.3 is located in proximity of the port of Trieste, in the North-Eastern NA.

The sectorial CEA application for maritime transport is presented in Fig. 6b. CEA scores reach a maximum score of 2.73. Areas of highest CEA score are located mainly offshore, and correspond to

330   high density shipping lanes (up to 400-500 vessels per year) connecting the main Adriatic ports (e.g. Venice, Trieste and Koper) to the Mediterranean Sea potentially affecting valuable hotspots of marine

mammals (mainly *T. truncatus*) and loggerhead turtles (*C. caretta*). The sectorial CEA application for coastal and maritime tourism is presented in Fig. 6c. Areas of highest CEA score are located in the Gulf of Trieste (score 1.5) and Venice Lagoon and the Malamocco outlet. The Gulf of Trieste is

335 particularly densely populated with 26 marinas on the Italian coastal areas and 3 on the Slovenian coastal areas. To notice is that on overall the the Italian coastal regions of Friuli-Venezia-Giulia and Veneto have higher CEA scores distributed along the entire coast, compared to Slovenian and Croatian coastal segments. The sectorial CEA score from the commercial fishery is represented in Fig. 6d. The maximum CEA score is 4.9 in proximity of Riccione (Emilia-Romagna Region). Other

340 sea areas of high CEA score (3.8) are located in front of the Po Delta inlet. Both areas are subjected to intense fishery activities along Italian coasts, especially trawling (e.g. bottom otter trawl, pair pelagic trawl), which greatly affects both biological resources and seafloor integrity. Areas of lower intensity CEA scores can be attributed to the 3 nm boundary, where trawling activities are forbidden (EC Regulation 1967/2006).
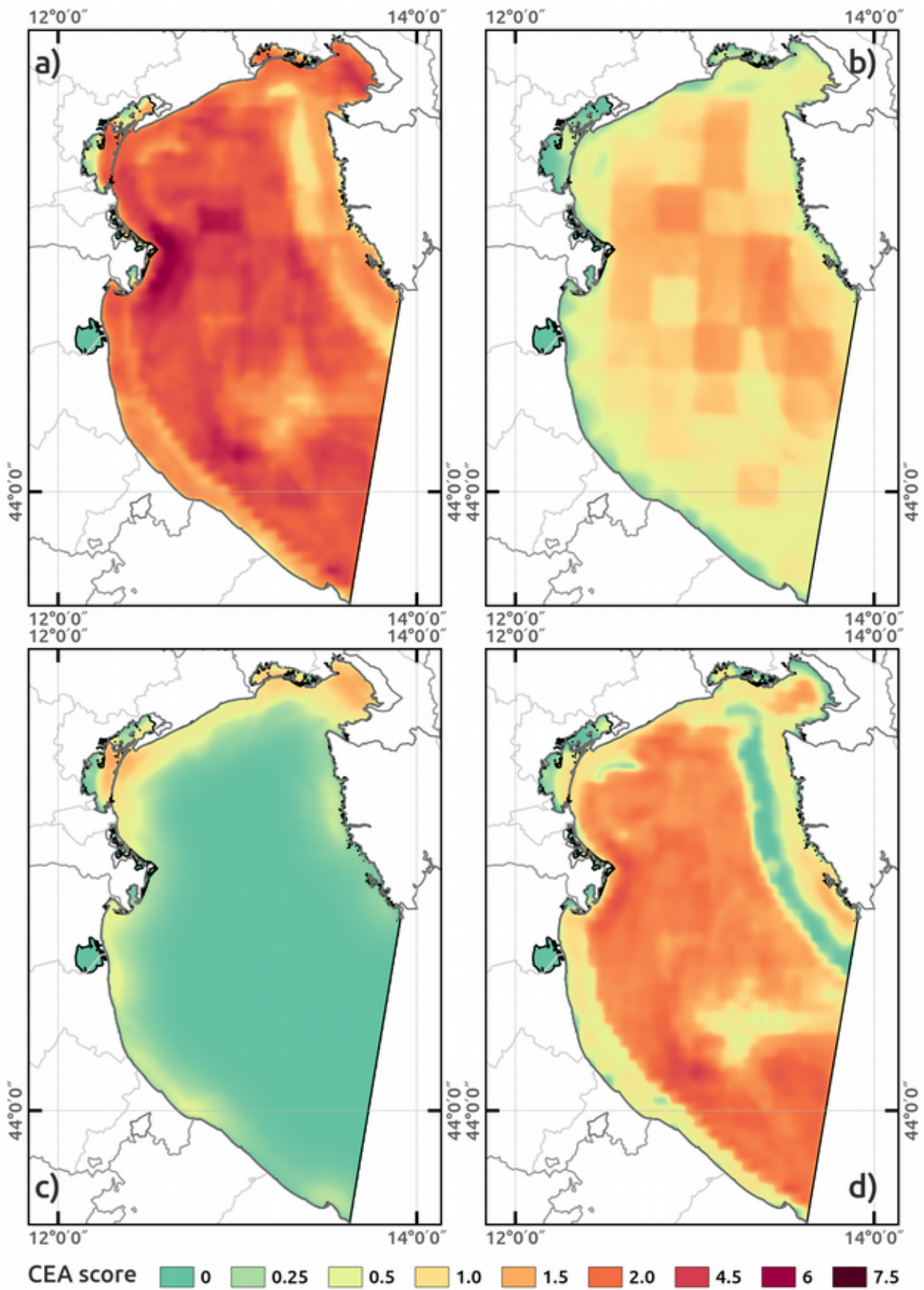
345

Fig. 6. CEA model outputs: (a) CEA base run; CEA sectorial runs for (b) maritime transport; (c) coastal and maritime tourism and (d) commercial fishery.

350 Results for the MSFD pressure-specific CEA case study runs are presented in Fig. 7. Geospatial results for the biological theme (Fig. 7a) show that highest CEA score (1.2 - 1.5) have a patchy distribution, mostly corresponding with commercial fishing activities in offshore areas, in front of the Venice Lagoon, Po Delta outlet, Rimini Port (Emilia-Romagna Region), and in offshore areas in front of the coastal settlements of Rovinj (Istria Region) (CEA score = 1.4). The environmental components

355 with highest sensitivity to biological pressures refer to commercial fishes nursery habitats, marine mammals and turtles.

The geospatial distribution of the physical pressure theme (Fig. 7b) shows a more homogenous distribution. In particular the offshore areas (about 3-6 nautical miles) in front of the Italian coastal Regions of Veneto, Emilia-Romagna and Marche Region are areas of high CEA scores (2.5 - 2.8) in

360 front of the Po Delta outlet and between Port of Rimini and Pesaro, which clearly relate these pressures to intense trawling activities. The environmental components most affected by the physical pressures refer to infralittoral and circalittoral sand a mud habitats, *Cymodocea* beds and infralittoral rock and other hard substrata. The geospatial results for the substances-litter-energy pressure theme (Fig. 7c) has the highest relative score (3.97) among all three pressure themes. High CEA score are

365 concentrated in small area in front of the Po Delta outlet. Other high CEA score areas are located in offshore areas in proximity of hotspots of Species of Community Interest (*C. caretta* and *T. truncatus*).
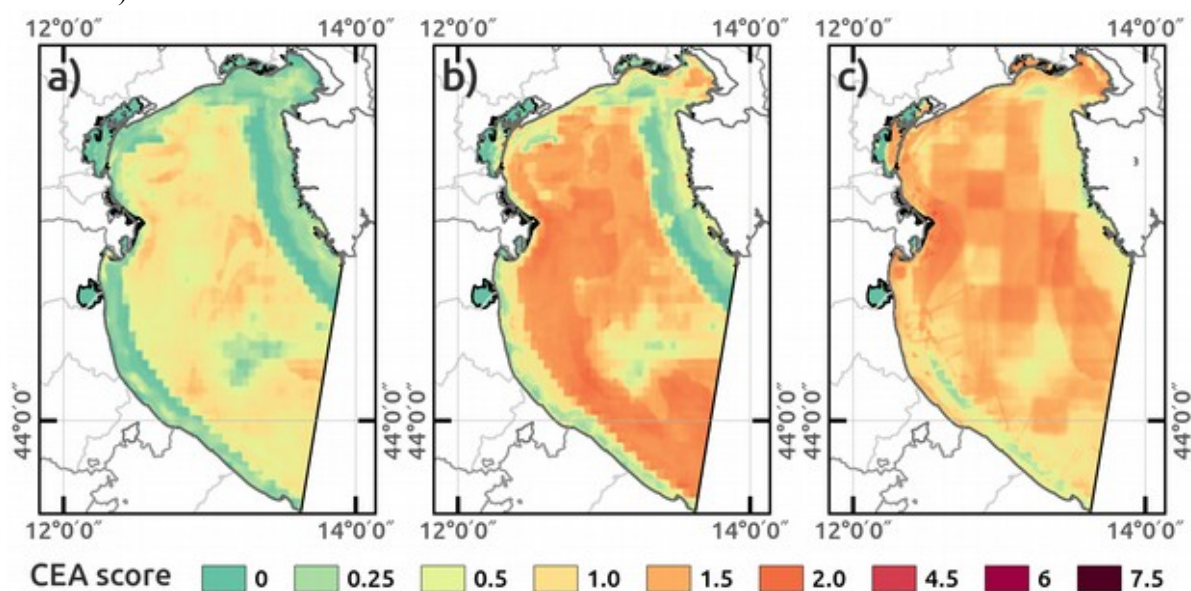
Fig. 8. CEA model outputs from MSFD pressures themes: (a) biological pressures, (b) physical pressures and (c) substances-litter-energies.

370

3.2. Maritime Use Conflict analysis

Results from MUC base run and sectoral conflict analysis are presented in Fig. 8a. Sea areas with MUC score > 20 (298 km^2) are located in proximity of the Ports of Trieste and Koper, in front of Venice lagoon and Chioggia. Other conflict areas are located in coastal areas of Emilia-Romagna

375 region (Porto Garibaldi and Ravenna) and in Marche region (Port of Ancona). Sea areas with MUC score ranging from 20 to 10 (1300 km^2) are located further outside Port of Trieste, Veneto Region (Jesolo and Caorle) in front of Venice Lagoon, Po Delta outlet, and other hotspots localized along the Emilia-Romagna and Marche Regions. Similarly to the CEA base run, the eastern coast of the NA Sea has lower conflict areas with exception of Koper Port in the Slovenian Coastal Karst Region and

380   coastal segment between the Croatian coastal settlements of Novigrad and Pula (MUC score between 5 and 8).

The analysis of sector-specific MUC runs are presented in Fig. 8b-d: Results for maritime transport (Fig. 8b) show that areas of highest MUC (>8; 580 km^2) are located in front of main port areas in the NA Sea (Trieste, Koper) and northern Po River Delta, Port of Ravenna and Ancona. Highest MUC

385   score (> 8; 612 km^2) for coastal and maritime tourism (Fig. 8c) show a similar pattern to the maritime transport. The MUC run for commercial fishery (Fig. 8d) evidences clear patterns of conflict between the different types of fishing and with maritime transport. Areas of highest MUC scores (>15; 179 km^2) are located in front of Chioggia and Venice lagoon , followed by port of Trieste and a narrow offshore area between 3 and 4 nm in front of Veneto, Emilia-Romagna and Marche region (MUC

390   score 10-15; 983 km^2) and a widespread offshore area along the main maritime traffic corridors (MUC score 5-10; 6254 km^2).
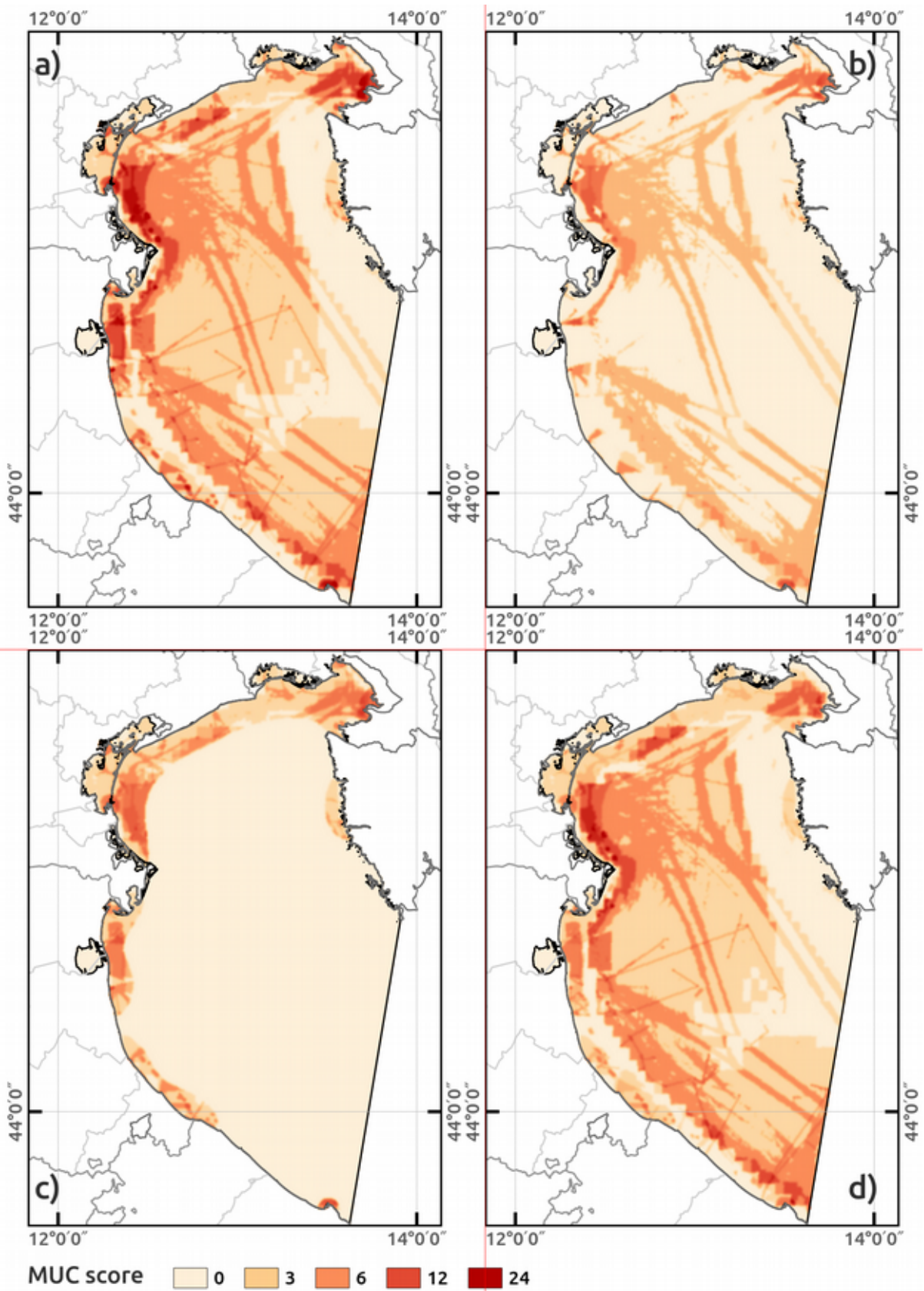
395   Fig. 8. MUC analysis model outputs: (a) MUC base run; sectorial MUC analysis runs for (b) maritime transport; (c) coastal and maritime tourism and (d) commercial fishery.

3.3. Comparison of CEA/MUC outputs

400 In Fig. 9a the CEA (by MSFD pressure themes) and MUC contribution as function of distance from coast in nautical miles (nm) is illustrated. In terms of pressure-specific CEA, the cumulative effects coming from input of substances, litter and other forms of energies contributes to 41.1% to the total CEA score, followed by the cumulative effects from physical pressures with 40.9% and the cumulative effects from biological pressures with 18%. Within the 0-3 nm the the CEA Substances-
405 litter-energies contributes to 60.9% to the total CEA, followed by physical pressures with 29.3% and biological pressures with 9.8%. Beyond the 12 nm, the CEA from physical pressures contributes to 41.7%, followed by CEA from Substances-litter-energies (38.3%) and from biological (20%) pressures.

The MUC analysis evidences that 50% of the conflict relies within the 9 nm. Peak of conflict is
410 located within the 3-9 nm with contribution of 21% of the total MUC score. On the contrary, about the 70% of the CEA score is almost uniformly distributed between the 3 and 24 nm. Highest CEA score is located between 15-18 nm.
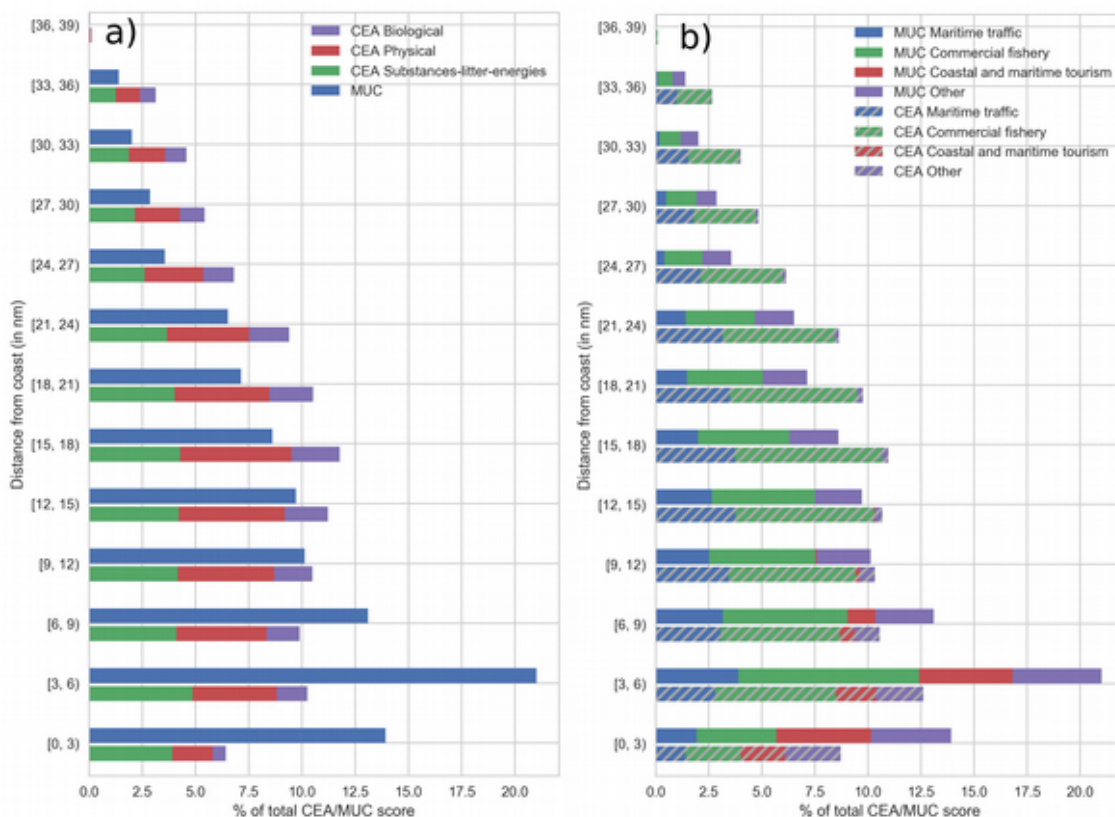
415 Fig. 9. (a) Percent contribution of total CEA (divided into MSFD pressure themes) and MUC scores from base run, according to distance intervals of 3 nautical miles (nm) from coastline. (b) Percent contribution of sectorial CEA/MUC score (commercial fishery, maritime transport, coastal and maritime tourism and other uses) to total CEA/MUC score according to distance intervals of 3 nautical miles (nm) from coastline.

420

Sector-specific CEA/MUC as a function of distance (nm) are presented in Fig. 9b. The overall contribution of maritime traffic, commercial fishery and coastal maritime tourism represents the 95% ot the total CEA score and the 74% of the MUC score. Commercial fishery has the highest

425 contribution to CEA (55.4%) and MUC (44%) overall score, followed by maritime transport (CEA = 31.3% and MUC = 20.2%) and coastal and maritime tourism (CEA = 5% and MUC = 10.2%). To notice is that 94 % of CEA score derived from coastal and maritime tourism is concentrated within 0-9 nm, similarly 99% of MUC score contribution comes from this segment.

3.4. MES threats analysis

430 In Fig. 10a results from MES-Threat base run are presented. The areas of highest threat (MES-Threat score >25; 165 km^2) are located in front of Grado-Marano Lagoon coastal area referring and smaller patchy areas in proximity of the Venice Lagoon. Threatened habitats refer to *Cymodocea* beds (A5.531), habitats providing a multitude of MES (e.g. providing nursery, biodiversity, food provisioning, nutrient cycling, water quality; Appendix 3) associated with areas of high cumulative

435 pressures. CEA applied on provisioning MES (Fig. 10b) shows potential threats (MES-Threat score > 10) located in the Gulf Trieste for coastal habitats responsible for food provisioning capacity, such as circalittoral sandy (A5.35), circalittoral fine mud (A5.36) and circalittoral muddy sand (A5.26). CEA applied on regulating MES (Fig. 10c) has a more patchy distribution of high threat areas (MES-Threat score > 3) localized in the Gulf of Trieste, coastal areas of Grado-Marano and the segment from

440 Venice Lagoon to Po Delta. CEA applied on cultural MES (Fig. 10d) shows high threats in nearshore areas along Friuli-Venezia-Giulia Region (MES-Threat score >10), Veneto Region (MES-Threat score > 4) and southern Emilia-Romagna and Marche Region (MES-Threat score > 2). To notice is that in the Eastern NA more extended threat areas occur, but with lower threat score (MES-Threat score > 2). Threats are particular relevant for infralittoral habitats and *Cymodocea* beds.

445 Threat analysis for supporting MES (Fig. 10e) responsible for sustaining biodiversity and nursery provision show a threat distribution compared to the MES-Threat base run, with highest threat scores (>12) in proximity of Grado-Marano, Venice lagoon and Conero Promontory.
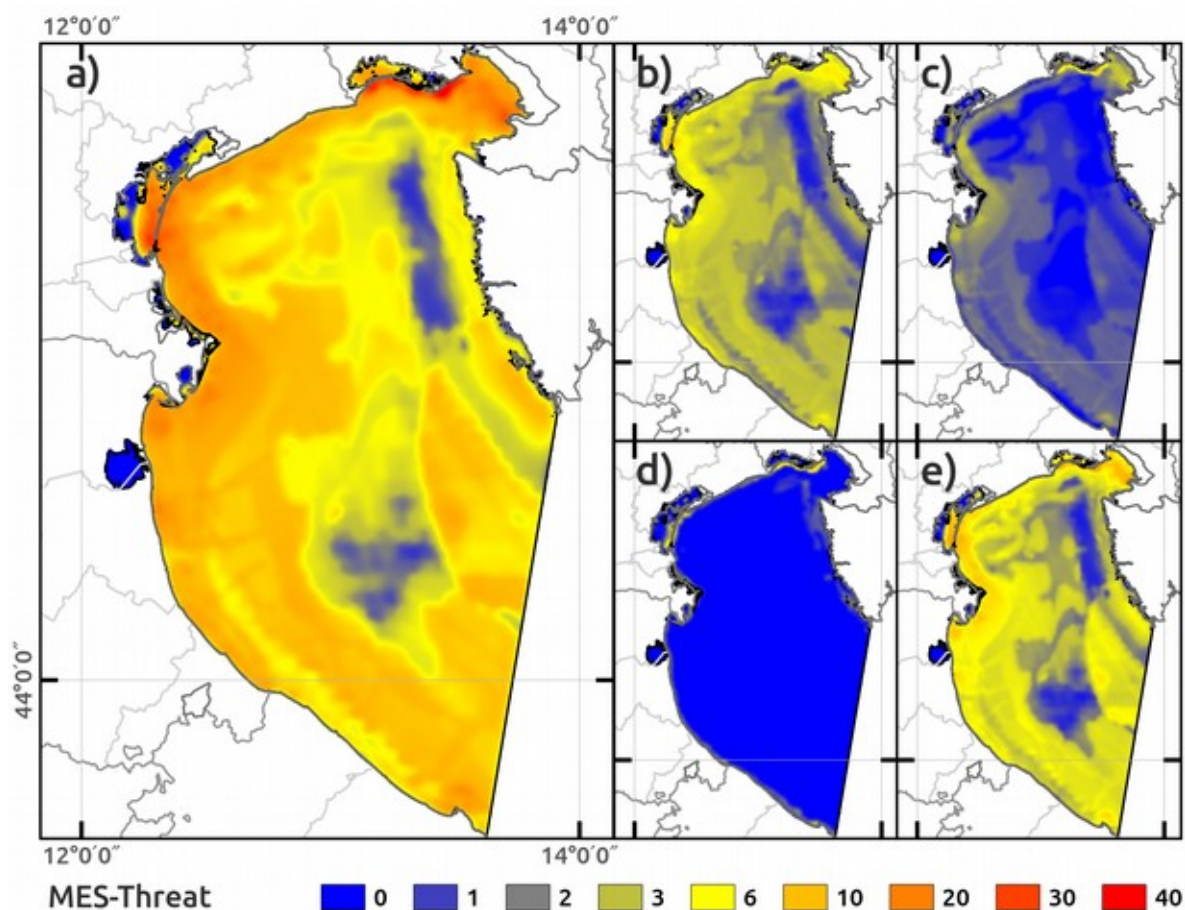
Fig. 10. MES-Threat analysis outputs for: a) Base run, b) provisioning, c) regulating, d) cultural and e) supporting MES.

450

In Fig. 11 the MES-Threat score contribution in percentage as function of distance (in nm) from coastline were presented. On overall results show that highest threat scores from MES-Threat are located within 3-6 nm (18.7 % of total contribution), where about 50% of the contribution is due threats to provisioning MES, 14% to regulating MES, 4% cultural MES and 33 % to supporting MES.

455　To notice is that threat areas for MES cultural capacity are entirely located within the 0-9 nm from coastline with a 65% contribution within 0-3 nm, 28 % within 3-6 nm and 7% within the 6-9 nm.
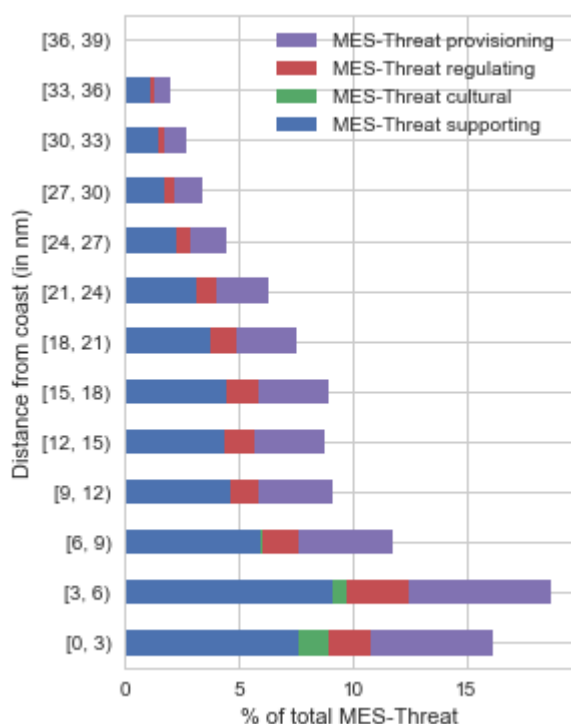
Fig. 11. Percent contribution of MES-Threat base run (divided into four MES categories) to total MES-Threat score according to distance
460   intervals of 3 nautical miles (nm) from coastline.

4. Discussion

4.1. Overall results

The presented webtools embedded into the Tools4MSP Geoplatform in combination with a clearly
465   defined case study modelling strategy exemplified how meaningful geospatial and statistical results
can be obtained in support of planning and environmental management considerations. The geospatial
webtools in support of planning and environmental management provide set of advantages as largely
discussed in literature (Atkinson and Canter, 2011; González Del Campo, 2017; Palomino et al.,
2017) such as transparency, objectivity and replicability of model outputs, all considered fundamental
470   within a pragmatic planning process. Particularly relevant are the dynamic functionalities coupled to
the Spatial Data Infrastructure (SDI) enabling data pre-processing (normalization and aggregation,
rescaling, filtering), access to existing and novel datasets as they become available and republish of
spatial outputs for utilization within user communities and possibilities for model re-run.

The case study developed for the Northern Adriatic demonstrated the potentialities of the Tools4MSP
475   Geoplatform to be further developed towards an operational Decision Support System for a multitude
of marine and coastal environmental management and MSP-oriented planning tasks. In addition to the
presented modelling capabilities, the Geoplatform aggregates a multitude of geospatial dataset and
formats into already normalized datasets and therefore enhances its usability by reducing time and
manpower for extensive data preparation. The tool can be flexibly applied to different spatial scales
480   (from seabasin to regional level) by defining the study area and depending on the availability and
quality of dataset, also grid resolution can be customized. The case study for the NA Sea was
performed on a resolution 500 m x 500 m grid. A higher resolution of analysis can be considered in
combination with local datasets. In the NA, this is particularly required for inland waters such as
Venice Lagoon and Grado-Marano Lagoon and the Gulf of Trieste, where anthropogenic activities are
485   particularly intense (Gallmetzer et al., 2017; Malačič et al., 2008; Munaretto and Huitema, 2012).

The geospatial results outline the complexity of anthropogenic impacts and interactions in the study area. CEA and MUC outputs highlight the need for thorough planning measures in order to deal with the intense conflicts occurring in the area, especially in the western segment of study area along Italian nearshore areas.

490   The CEA analysis presented in Fig. 6a-d provides an overview of the spatial distribution of the cumulative and the sectorial effect scores in the study area. The CEA score exerted by commercial fishery has the most evident effects across the study area (Fig. 6d and 9b). The Northern Adriatic Sea is one of the most intensively fished area in Europe, where most of the harvested stocks are overexploited, especially in the western sector, due to intense non-selective fishing activities from
495   Italian fleets exerted on fish habitats (Colloca et al., 2013; Russo et al., 2015, Bastardie et al., 2017). In nearshore areas (about 3 nm) lower CEA scores refer to areas where towed gears are banned or unsuitable, usually in favour of small scale fisheries (mainly set gears and longlines). Maritime traffic effects are located mainly offshore (Fig 6b), in the central-eastern portion of the study area, where the north-south Adriatic traffic route connects to the Mediterranean. Those areas intersect with
500   biodiversity hotspots of valuable marine species, such as loggerhead turtles and marine mammals (Fortuna et al., 2015). The cumulative effects from coastal and maritime tourism sector generates main impact phenomena in proximity of coastal areas (Fig. 6c and 9b), where the necessary infrastructure and facility occur (Papageorgiou, 2016) and where the majority of vulnerable ecosystem are present. In the NA, summer recreational resorts from Friuli-Venezia-Giulia, Veneto Region and
505   Emilia-Romagna, belong to the top 20 most popular tourist destinations on EU level (Eurostat, 2017). The MSFD-driven CEA representation (Fig. 7) shows that the anthropogenic pressures within 0 to 3 nm derive from the MSFD pressure theme substances-litter-energies exerted mainly by land-based activities (Fig. 7c, 9a). The higher scores are linked to riverine discharge from Po and Adige rivers, that are the biggest contributors of freshwater, nutrients and pollutants of the Adriatic Sea (Chiogna et
510   al., 2016; Simonini et al., 2004), commercial traffic in proximity of ports (Venice, Chioggia, Ravenna), coastal tourism and leisure boating. In comparison, the MSFD pressure themes concerning biological and physical pressures close to the coast have lower effects intensity (Fig. 7a,b and 9a) and mainly derive from artisanal fisheries and maritime transport. High CEA scores are evidenced for valuable habitats such as *Cymodocea* beds and nursery areas. A major reason for lower CEA score by
515   physical pressures are related to limitations of towed gears ban within the 3nm off the coast, with the significant exception of those close to port and marinas or subjected to intense artisanal fisheries with bottom impacting tools. Beyond 3 nm limitations, physical pressures became the most intensive (Fig. 7b and 9a), due to the strong contribution of bottom trawling fisheries on the CEA score, determining high physical (e.g. abrasion) pressures on essential fish and seabed habitats (Pranovi et al., 2000).
520   Moreover, trawling fisheries are also highly responsible for biological pressures (e.g. extraction of species; Eigaard et al., 2016) and, together with maritime traffic, releases of marine litter and substances, potentially affecting seabed habitats and the populations of marine turtles and mammals. The application of the MUC and its setup for sectoral analysis of conflicts allowed to identify main areas of conflict to compare results among the most relevant sea uses in the Northern Adriatic Sea
525   (Fig. 8). According to Fig. 9b over 60% of the total MUC score is concentrated within the 12 nm boundary, mainly caused by intense interactions between coastal tourism, maritime transport, fisheries and other activities (e.g. aquaculture), especially close to ports (e.g. Trieste, Koper, Venice and Ravenna) and marinas, while in offshore areas spatial conflicts occur between traffic routes and trawling fishery grounds (Fig. 8). The distribution of conflicts evidences the high demand for sea
530   space in proximity of coastal areas in a relatively small sea space. Soft uses (e.g. fishery and coastal tourism) and hard uses (e.g. aquaculture, Oil & Gas exploitation or maritime transport) need to trade-

off especially in coastal areas that function as hub aggregating infrastructure and facilities necessary to support maritime economic activities.

The MES-Threat analysis demonstrated how CEA based modelling capabilities can be linked with
535 MES mapping based on the MES supply capacity of EUNIS habitats. Spatial results provided novel insights on the distribution of threats to MES and therefore to the risk of reduction, loss or impairment of the MES provisioning capacity of a particular habitat or combination of habitats. From a planning perspective, the produced results can be considered as highly integrative to the CEA and MUC outputs, as they incorporate societal values into the analysis (Maron et al., 2017), can more efficiently
540 delineate protection priorities (Werner et al., 2014) and support the design of restoration plans (Allan et al., 2013) for coastal areas or habitats (e.g. *Cymodocea* beds) subjected to highest threat from anthropogenic stressors (Fig. 10a). Similar to CEA/MUC results, the analysis showed that threats to MES are highest within the 0-6 nm, a critical area for MES provision (Fig. 11), but also for intensity, variability of pressures and conflict areas (Fig. 9). Particularly affected categories are provisioning
545 and supporting MES, which are responsible for the provision of fundamental goods and services sustaining various components of coastal economies such as commercial fishery, aquaculture and tourism.

The use of a case study development strategy demonstrated a high degree of customization of the webtools by the user and a flexible adaptation to different MSP stages: First, the webtool can facilitate
550 data gathering through a community-based approach and interoperable access to EU-level and international SDIs, such as EmodNet, EEA, SeaDATANet or International Hydrographic Organization (IHO). Current datasets can be flexibly visualized and recombined through interoperable view services (i.e WMS, TMS, ArcGIS REST service) in order to create shareable online maps. Second, the webtools can be used for the identification of specific planning constraints and current
555 conditions of the sea space in terms of multiple and single pressure on environmental components and existing conflict among uses. Third, the model outputs can be used to evaluate different management actions or define alternative scenarios through the comparison of two case studies and understand variations of cumulative effects, consequences for sea use conflict and threats to ecosystem service supply capacity.

560

4.2. Webtools support to EIA and SEA

MSP, as an area-based management framework can represent plans, programs or policies that require environmental impact assessment (EIA) and strategic environmental assessment (EIA). Common aim for MSP, EIA and SEA is to promote sustainable development through the integration of
565 environmental considerations into the planning process and reduce spatial negatives (IUCN, 2013).

In the context of the EIA (2011/92/EC) and SEA (2001/41/EC) the presented webtools can deliver a promising support to address several requirements of both Directives: (1) The presented Geoplatform facilitates the access and usage of geospatial datasets that can be relevant to EIA and SEA (Vanderhaegen and Muro, 2005). (2) Although on different spatial and implementation scales the
570 CEA/MUC can be flexibly deployed on sectoral level (Fig. 6 and 8b-d) and MSFD pressure specific (Fig. 7) local project as required within EIA [Article 5(1), ANNEX IV], while as requested within SEA [Article 3(5) ANNEX II], the tool can flexibly address the cumulative nature of effects on a broader scale from regional to national and also transnational level. (3) The implemented CEA isotropic distance model (Eq.1) is capable to modulate propagation of pressures and can further
575 complement the analysis of spatial influence of the proposed project on local, regional, national or transboundary level. Although methods for ES-inclusive SEA are still lacking (Slootweg and van Beukering 2008; Söderman et al., 2012), the presented marine ES-inclusive threat analysis approach

based on EUNIS habitats MES supply scores can be a valid complement to SEA. In particular the ES-driven concept can be flexibly incorporated along a SEA activities and evidence sea areas of socio-
580   ecological importance, possible impacts of present and future plans on key ES and identify solutions and restoration measures to reduce anthropogenic effects (Geneletti, 2011).

4.3. Webtools support to MSP

The relevance of geospatial tools to support MSP implementation has been evidenced by many
585   academic, planning and decision-making communities around Europe (MSP Platform, 2018; JPI Ocean, 2017; WESTMED, 2017). In particular the tools for cumulative effects and associated processes (e.g. strategic environmental assessments) have found vivid development in the last decade, with application in various planning and spatial contexts (Andersen et al., 2013; Depellegrin et al., 2017; Stelzenmüller et al., 2013). At this stage the presented tool need to be seen as a test toolset, with
590   particular limitations related to data availability and model robustness. Depending on the modelling approach for uses, pressures and the environmental components, its over-simplifications do not allow to take decisions with high socio-economic relevance. Moreover, the connections with provisions from other policy instruments (e.g. MSFD, WFD, CFP, H&BD) are relevant and are only partially explored, while maritime plans have to carefully consider the coordination and compliance with all
595   relevant policies. Within a typical MSP methodology (Ehler and Douvere, 2009; Barbanti et al., 2015), these tools can be used both in the analysis phase, defining and analysing existing conditions, and in the planning phase, supporting the development of measures and scenarios and the evaluation of their effectiveness. Finally, the presented webtools are part of a wider ecosystem of analytical techniques supporting MSP. In fact CEA, MUC and MES-Threat can be combined with each other
600   ensuring a multi-functional approach or can play a complementary role in support of tool functionalities, such as Displace for use specific investigations (Bastardie et al., 2017), Marxan with Zones for scenario development (Ban et al., 2013) or Seasketch (2018) for incorporating participatory stakeholder engagement into spatial modelling.

605   ### 4.3. Datasets

Although the presented webtools benefit from a multitude of geospatial datasets (in total 65) composed by human uses, environmental components and pressures further extension can be considered. In particular, integration of novel datasets can be used for scenario analysis of emerging sectors of the marine economy in the Adriatic Sea, such as potential offshore wind energy farms off
610   the coastal settlement of Rimini (Emilia-Romagna Region; Schweizer et al., 2016) or in front of the coastal settlement of Pula (Istria Region; Hadžić et al., 2014), extensions of the ports of Ravenna (RER, 2015), Trieste (TMT, 2016) and Koper (Port of Koper, 2015) or increasing aquaculture development to meet fish food demand (Piante and Ody, 2015) should be incorporated and analysed for its environmental impacts and the creation of potential sea use conflicts. Moreover, our case study
615   shows high variability in CEA/MUC scores between western and eastern coastal areas, this is related to higher number and intensities of human activities along the Italian coasts compared to Slovenian and Croatian ones, but also due to a high heterogeneity in human activities (especially Oil and Gas extraction, aquaculture and shipping) and the number of datasets available from different countries. Concerning the environmental components, higher resolved geospatial datasets on habitats, benthic
620   communities and species (Certain et al., 2015; Marcotte et al., 2015) should be integrated considering their potential sensitivity towards specific anthropogenic pressures (Eno et al., 2013) and with proper classification schemes.

625 While the current dataset incorporates a multitude of endogenic pressures, generated within the system and that can be managed (Elliott, 2011), there is the need to incorporate as well exogenic pressures such as climate change in order to align the methodology to other CEA assessments around the globe (Halpern et al., 2015; Clarke Murray et al., 2015). This would support the analysis of climate change scenarios and its influence on coastal areas, marine ecosystems and interactions with human activities (Pinarbasi et al., 2017). In fact, ecological and geomorphological conditions of the Northern Adriatic Sea make it particularly sensitive to changing hydrological and oceanographic

630 conditions (Bosnjakovic and Haber, 2015), inducing harmful algal blooms (Barale et al., 2008), red tides (Socal et al., 2011) or different hydrodynamic impacts (e.g. inundations, storm surges or coastal erosion).

4.4. Limitations

635 The tested tools are not free of limitations. Difficulties in the parametrization of the model induced the implementation of an additive and linear model, while ongoing research in cumulative assessment demonstrate the need of integration of mitigative and antagonistic effects in the pressure - environmental components interaction. There is spatio-temporal inhomogeneity among dynamic environmental components (seabirds, mammals and turtle datasets) with coarser resolution datasets

640 compared to EUNIS marine habitats (100 m x 100 m) and differing nominal scales (e.g. individuals/km^2 versus presence-absence indicators).

Although an extensive sensitivity and uncertainty analysis has been performed for the Adriatic-Ionian Sea (Gissi et al., 2017), an implementation of uncertainty in the webtools is currently absent. Uncertainty analysis is an important component within CEA, as it supports realistic knowledge

645 aggregation optimised methodological procedures which are baseline for MSP (Judd et al., 2015). In particular an uncertainty analysis as part of model-based decision support, should be an integral part of the webtool results to better identify data gaps (Meyer, 2012), support effective risk assessment (Stelzenmüller et al., 2015), take into account the precautionary principle into planning considerations and communicate the uncertainty within a participative dialogue (Bijlsma et al., 2011).

650 A limitation of the presented MUC is the absence of representation of synergies in the sea space, as the MUC model only considers spatial conflicts focused only on use-use conflicts, without considering multiple interaction (within three or more sea uses) or dynamic interaction from highly mobile sea uses (e.g. maritime traffic, commercial fishery, coastal and maritime tourism).

We consider the MES-Threat analysis a first methodological approach for integration of the socio-

655 ecological dimension into cumulative effects assessment. Major challenges remain identifying the suitable spatial extent and resolution for quantifying MES and models for taking into account their space-time variability. Further research is needed to aggregate other environmental components into MES datasets (e.g. marine mammals and turtles), develop pressure specific MES sensitivity charts (Hooper et al., 2017), deepen the link of biodiversity attributes with ecosystem services supply

660 (Harrison et al., 2014) and provide theoretical and methodological integrations of MES into environmental and socio-economic impact assessment also for specific pollution risks (Depellegrin and Blažauskas, 2013; Song et al., 2017) and emerging new uses, such as renewable energy (Papathanasopoulou et al., 2015).

665 **5. Conclusions**

The Tools4MSP Geoplatform provides a novel system in support of planning and environmental management, incorporating within a single geoplatform three operational webtools: the cumulative effects assessment, maritime use conflict analysis and marine ecosystem services threat analysis. This

670 is an added value for decision-makers and planners that seek for a rapid exploratory mapping of human-environment interactions. Modelling outputs were guided by a structured case study development strategy allowing overall analysis and context specific investigations, such as by marine sector, by MSFD pressure themes or by marine ecosystem services categories. The community-based Geoplatform demonstrated to be highly versatile instrument for the spatialization and geostatistical evaluation of MSP relevant knowledge applicable in several stages of an MSP process and potentially

675 also supporting EIA and SEA. In particular the Geoplatform can ensure notable support for transparent analysis that can engage a multitude of user communities into decision-making, ensure replicability of the modelling process and iterative data assimilation, as it becomes available. The tool can be used by a broad spectrum of stakeholders, including decision-makers, planners, academics, research institutions and the general public.

680

Declarations of interest: none

Author contributions
Conceived and designed the experiments: SM, DD.
Data curation: SM, DD, CV.
Performed the experiments: SM.
Analyzed the data: SM, DD, GF, AS.
Contributed reagents/materials/analysis tools: SM, DD, GF.
Founding acquisition: AB.
Wrote the paper: SM, DD, GF, AB.

Appendix 1. **Human use classification and rules for spatial conflicts according to COEXIST applied in the maritime use conflict (MUC) webtool methodology** (Gramolini, 2010).

Human uses can be classified according to five traits: vertical, spatial (horizontal), temporal scale, mobility, and location.

Rules for spatial conflicts: rule system to define conflict score for each pair of human uses.

- Rule 1: if vertical domain of activity 1 is different from vertical domain of activity 2 and no one of them interests the whole water column then conflict score is equal to 0;
- Rule 2: If both activities are "mobile" then conflict score is equal to the minimum of temporal domain plus the minimum of spatial domain.
- Rule 3: if Rule1 and Rule2 cannot be applied then the conflict score is equal to the maximum value of temporal domain plus the maximum value of spatial domain.

1	**Vertical scale**	
	● Pelagic	Value = 1
	● Benthic	Value = 2
	● Whole water column	Value = 3

2	**Spatial scale** ● Small ● Medium ● Large	 Value = 1 Value = 2 Value = 3
3	**Temporal scale** ● Short ● Medium ● Long/permanent	 Value = 1 Value = 2 Value = 3
4	**Mobility** ● Mobile ● Fixed	 Value = 1 Value = 2
5	**Location** ● Land ● Sea	 Value = 1 Value = 2

Appendix 2. MUC conflict matrix for the Northern Adriatic Sea
It's based on MUC base run, ranging from 5 (very high conflict) to 0 (non conflict).

	Aquaculture	Cables and Pipelines	Coastal Defence Work	Coastal and Maritime Tourism	Flying	LNGs	Maritime Transport	Military Areas	Military temporary	Naval base activities	Offshore sand deposits	Oil & Gas extraction	Small scale fishery	Trawling
Aquaculture														
Cables and Pipelines	5													
Coastal Defence Work	5	4												
Coastal and Maritime Tourism	5	0	5											
Flying	5	0	4	2										
LNGs	5	4	4	5	4									
Maritime Transport	5	0	5	4	2	5								
Military Areas	5	5	5	5	5	5	5							
Military temporary	5	5	5	4	3	5	4	5						
Naval base activities	5	4	4	5	4	4	5	5	5					
Offshore sand deposits	5	5	5	4	2	5	2	5	4	5				
Oil & Gas extraction	5	4	4	5	4	4	5	5	5	4	5			
Small scale fishery	5	4	4	2	2	4	2	5	3	4	2	4		
Trawling	5	4	4	2	2	4	2	5	3	4	2	4	2	

Appendix 3. Marine ecosystem services capacity matrix

The matrix is based on EUNIS Habitats extracted for the Northern Adriatic Sea (adopted from Depellegrin et al., 2017). The score ranges from 2 (high capacity) to 0 (no or neglectable capacity). In total 15 EUNIS habitats were extracted for the Northern Adriatic Sea.

				MES_{Prov}		MES_{Reg}			MES_{Cult}			MES_{Sup}				MES_{Cap}
Habitat code	Habitat name	km²	perc	Food provisioning	Raw material	Air quality	Disturbance protection	Water quality	Cognitive benefits	Leisure	Feel good/warm glove	Photosynthesis	Nutrient cycling	Nursery	Biodiversity	Σ
A3	Infralittoral rock and other hard substrata	24.2	0.1	2	2	2	2	2	2	2	2	2	1	2	2	**23**
A4	Circalittoral rock and other hard substrata	208.6	0.5	2	2	1	2	2	2	2	2	0	2	2	2	**21**
A5.13	Infralittoral coarse sediment	29.8	0.1	2	2	0	0	0	0	1	1	0	1	2	1	**10**
A5.14	Circalittoral coarse sediment	0.1	0.0	2	2	0	0	0	0	0	0	0	1	1	1	**7**
A5.23	Infralittoral fine sands	2148.5	5.0	2	1	0	0	0	0	1	1	0	1	2	1	**9**
A5.25	Circalittoral fine sand	5717.8	13.2	2	1	0	0	0	0	0	0	0	1	2	1	**7**
A5.26	Circalittoral muddy sand	9693.2	22.5	2	1	0	0	1	0	0	0	0	1	1	1	**7**
A5.33	Infralittoral sandy mud	12.2	0.0	2	0	0	0	1	0	0	0	0	1	1	1	**6**
A5.34	Infralittoral fine mud	62.9	0.1	1	0	0	0	1	0	0	0	0	1	0	1	**4**
A5.35	Circalittoral sandy mud	10379.6	24.0	2	0	0	0	1	0	0	0	0	1	1	1	**6**
A5.36	Circalittoral fine mud	9203.1	21.3	2	0	0	0	1	0	0	0	0	1	1	1	**6**
A5.38	Med. biocoenosis of muddy detritic bottoms	82.1	0.2	1	0	0	0	1	0	0	0	0	1	0	1	**4**
A5.39	Med. biocoenosis of coastal terrigenous muds	50.3	0.1	2	0	0	0	1	0	0	0	0	1	1	1	**6**
A5.46	Med. biocoenosis of coastal detritic bottoms	5442.0	12.6	2	0	0	0	1	0	0	0	0	1	1	2	**7**
A5.531	*Cymodocea* beds	106.3	0.2	2	1	2	2	2	2	2	2	2	2	2	2	**23**

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