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Risk-based analysis of recreational ecosystem services supply and demand in beach areas of the Adriatic Sea

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ABSTRACT

Beaches are important suppliers of recreational services to human beings, through bathing water resources, marine biodiversity and scenic values of coastal seascapes. This study presents a conceptual model for risk-based analysis of multiple anthropogenic stressors (e.g. nutrient load, marine litter, pollutants or pathogens) on recreational ecosystem services supply-demand patterns in beaches for seven regions of the Italian Adriatic Sea. Results of the supply-demand analysis show that the beaches in Puglia region have highest recreational supply, while demand for coastal recreation is highest in the beaches of Emilia-Romagna region, which is a region prone to mass recreational activities. Based on the supply-demand analysis we performed a risk assessment on recreational ecosystem services provision by analysing the exposure of beaches ecosystems to multiple stressors generated by different maritime (e.g. shipping, aquaculture) and land-based activities (e.g. agriculture). Beaches of the Northern Adriatic region suffer from high exposure to pollutants due to port activities, aquaculture industry, shipping, and riverine discharge. The presented study advances knowledge on the integration of ecosystem-services-based recreational supply-demand analysis in coastal areas and discusses its application potentials for sustainable management of coastal resources and the investigation of tourism flow to coastal recreational areas for large geospatial settings.

1. Introduction

As part of the ecosystem, human derive benefits from biotic and abiotic components. These benefits are defined as ecosystem services (ES). Human health is a central concept in ES assessment, and the way anthropogenic impacts cumulatively effect ecosystems, is integral to their evaluation. The Millennium Ecosystem Assessment (MEA, 2005) defines components of human health as physical and mental health, including a clean and supporting physical environment, employment and adequate income, personal and community security or access to education. The World Health Organization (WHO) defines human health as "*the complete physical, mental and social well-being and not merely the absence of disease or infirmity*". Within the Sustainable Development Goals (SDG) 3 refer to "*Ensure healthy lives and promote wellbeing for all at all ages*" (SDG, 2021). In particular, target 3.9 refers to "*By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination*". An aspiration of the European Green Deal (EGD, 2020) is to "*protect the health and well-being of citizens from environment-related risks and impacts*" and establish a toxic-free environment, deliver healthy and sustainable diets, and protect biodiversity. In this context, growing evidence of the benefits of marine blue spaces to human physical and mental health, and associated ES is relevant (Evers and Phoenix, 2022; Georgiou et al., 2021; Gascon et al., 2017; Grellier et al., 2017).

Ecological and human health risks in marine environment, are deeply intertwined and can be affected by multiple anthropogenic stressors, such as pollutants, pathogens, invasive species, or harmful algal blooms. Coastal recreational areas, such as beaches, are

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particularly vulnerable, because they are biomes in the land-sea interface that can be subjected to terrestrial- and sea-based sources of stressors like agricultural activities, port development or aquaculture (ESPON, 2020a & 2013). Moreover, Mediterranean coastal recreational areas like beaches are important economic assets for the livelihood and subsistence of coastal economies and therefore management is particularly important to ensure recreational quality for beach users.

Conceptual models to address the inter-linkages among human health and ecosystem change were developed by the international scientific community (Pires de Souza Araujo et al., 2021). For example, the World Health Organization (WHO; Corvalán et al., 1996) developed a Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework to address the exposure to environmental change by human populations, Atkins et al. (2011) used Driver-Pressure-State-Impact-Response (DPSIR) framework for integrating ES and social benefits into marine management, Turner and Schaafsma (2015) used Economic Assessment process of ES for analysing the impact of ES provision changes on human wellbeing, and Scharin et al. (2016) suggested a DAPSI(W)R(M) and Balance Sheets Approach (BSA) as important frameworks for achieving sustainable stewardship of ecosystem-based marine management. Also, Cooper, (2013) developed a human well-being enhanced Driving Force-Pressure-State-Welfare-Response (DPSWR) model including ES assessment into the analysis. This progress is coupled with an extending global literature in coastal and marine ES assessment within Maritime Spatial Planning (MSP) (Depellegrin et al., 2020; Farella et al., 2020; Samhouri and Levin, 2012; Herbst et al., 2020). Furthermore, human health improvement and its connection to wellbeing through access to the marine environment is increasingly recognized through literature discussing the importance of blue spaces (White et al., 2020; Pouso et al., 2021; Georgiou et al., 2021). For example, recreation in blue spaces, can support spirituality, embodied sensual pleasures; creativity and resilience, relief from suffering, problem solving, positive, imaginative, and emotional experiences, eudomonia, mindfulness, contentment and trancendence (Evers and Phoenix, 2022).While there are several studies addressing the anthropogenic threats to ES (Vanbergen and the Insect Pollinators Initiative, 2013; Keyes et al., 2021; Egarter Vigl et al., 2021a), their application integrating ES supply-demand pathways is to a large extent unexplored. Separating the ES supply-side, defined as the components of a ecosystem based on biophysical, ecological functions, and social properties from the ES demand-side referring to the usage of ecosystems providing a certain ES (Wei et al., 2017) has the dual advantage that enables to address ecosystem and potential human health effects in a ES providing unit.

With the aid of an analytical framework, this research aims to analyse coastal recreational ES supply and demand from beaches, and to propose a risk-based stressor methodology, to assess the threats to recreational supply and demand from land- and sea-based anthropogenic stressors. For this purpose, the framework provides a database for coastal recreational ES supply indicators, based on seven socio-ecological features surrounding a beach environment (e.g., Hemeroby Index, protection status, landscape diversity, accessibility in terms of street density, recreational capacity of land uses, recreational capacity of marine habitats, Obstructed view). To reflect the recreational demand for beaches we use a common geo-spatially explicit social media dataset for cultural ES mapping (namely FLICKR and Panoramio; Sinclair et al., 2020; Erskine et al., 2021; Ciesielski and Stereńczak, 2021). Results were analysed for seven coastal regions subjected to different anthropogenic stressors in the Italian Adriatic Sea and characterize the supply and demand potential of beach environments. These were discussed to show the opportunities and challenges in the integration of ecosystem and human health risks into coastal and maritime spatial planning.

2. Methods and materials

2.1. A framework for marine recreational ecosystem service risk assessment

In Fig. 1 the analytical framework for the analysis of recreational ES and associated risks from multiple anthropogenic stressors is presented. In summary, the critical methodological steps can be described as follows: (1) Development of the dataset includes a set of indicators, for supply-demand pattern analysis. Also, with definition of land- and sea-based anthropogenic activities affecting recreational supply-demand. (2) Modelling of recreational supply-demand and application of the Tools4MSP modelling framework, to perform a generic risk-based stressor propagation, using a convolution function (Menegon et al., 2018). This is integrated by a hydrodynamic modelling mainly for nutrient (Nitrogen and Phosphorus) propagation using SHYFEM (Umgiesser et al., 2004). In addition, based on a literature review we cross-reference the stressors with the risk for recreational supply and demand (Table 2). (3) Geospatial and statistical analysis of regional ES recreational supply-demand and exposure to anthropogenic stressors. (4) As a final step we perform a compounded analysis of recreational supply-demand patterns, and analysis of risks to recreational supply-demand expressed as following: *i)* Supply-side of the risk assessment refers to the cumulative stressor risks to the beach units responsible for the provision of the recreational goods and services, *ii)* demand-side can be defined as the risks to human health, generated by multiple anthropogenic stressors to beach users. In the sections below a more detailed description of the methodological steps is provided.

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. 2). Its coastline spans from Friuli-Venezia Giulia Region to Puglia southern coast, which 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. In the Mediterranean, the Adriatic Sea is a semi-enclosed basin that communicates with the Ionian Sea through the Otranto Strait. The northern part of the Adriatic Sea has the most extended shelf area of the entire Mediterranean, with a very smooth coastal area, and a softly sloping bottom. Contrastingly, the Southern Adriatic Sea is characterized by the presence of the circular, South Adriatic Pit, bordering the Puglian continental shelf, with a maximum depth of 1200 m. Extremely diverse, coastal and seabed landscapes are featured in the Adriatic, with a wide heterogeneity of geomorphological features and bottom sediments (UNEP/MAP-RAC/-SPA, 2015). Sediments in the Northern and Central Adriatic seabed are predominantly composed by sandy muds, influenced by fluvial supply. In the Southern Adriatic Sea coarser sediments of rocky bottoms featuring bioconstructions (e.g., coralligenous assemblages), and *Posidonia oceanica* meadows are more frequent. The sea space is a recognized hotspot of biodiversity within the Mediterranean Sea, hosting a high diversity of invertebrate and fish species, resident marine mammals, turtles, and seabirds (SPA/RAC, 2021). This relatively small sea space is subjected to intense anthropogenic activities. Shipping, commercial fishing, oil and gas extraction, coastal tourism, aquaculture, or cabling that can exert multiple stressors on its valuable ecological resources and affect coastal recreational activities (WWF, 2021; Drius et al., 2019).

2.3. Dataset development and recreational supply-demand modelling

In Table 1 the geospatial datasets used for the analysis of ES supply-demand are presented. The geo-locations of beaches were extracted from OpenStreetMap (OSM, 2019), and resulted in 577 units, derived

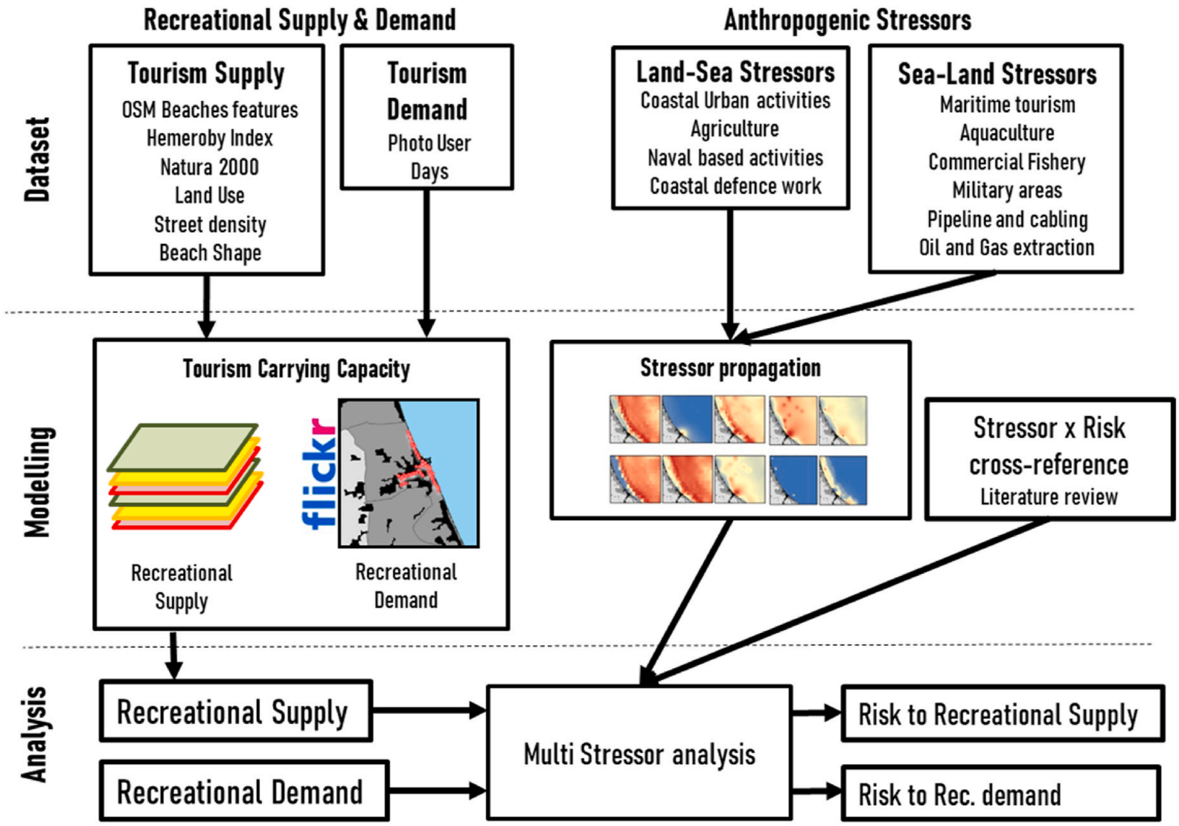

Fig. 1. Analytical framework for recreational ES accounting into cumulative effects assessment.

within the coastal municipalities of the study area. In order to incorporate more efficiently the supply-demand attributes for beach, we extended beach polygons with a buffer zone of 500 m. This buffer is considered as suitable distance because it is assumed that 500 m from beach is the area of highest impact of stressors and where most of beach tourism activity take place. Moreover, from a modelling point of view, this allows to spatially overlay more efficiently the attributes in the proximity of the beach that contribute to recreational ES provision. The recreational capacity of a beach is described by the properties and conditions of a beach and its adjacent sea space. To determine the recreational capacity of a beach we ensemble a set of spatially explicit indicators (see Table 1) from different studies in the terrestrial domain (e.g. Walz and Stein, 2014; Fischer et al., 2014; Stoll et al., 2015) and in marine/coastal domain (e.g. Menegon et al., 2018; Salomidi et al., 2012): Characteristics of recreational supply, were adapted from a set of studies, using geospatial investigation techniques to map recreational ES provision. The Hemeroby Index (*hi*) provides measure of level of human intervention on land use level, on a scale from 1 (*ahemerobic* - no human impact) to 7 (*metahemerobic* – excessively strong human impact). We used an inverted *hi* to represent natural land uses surrounding each beach (Walz and Stein, 2014). Natura 2000 sites (n_{2000}) were extracted from European Environmental Agency database for Natura 2000 sites (EEA, 2020) and included into the analysis to represent beaches that have particular high natural value. The sites were considered using a dummy indicator of presence (score 1) and absence (score 0). Accessibility (*acc*) to the beach was measured by calculating the street density in km of street per km^2 of buffered beach surrounding. Data on street network was obtained from OpenStreetMaps (OSM, 2019). To map the terrestrial recreational capacity (tr_{cap}) of land uses and the landscape diversity (*ld*), the LU dataset of CORINE Land use/cover (LULC) available from the Copernicus portal was used (Copernicus, 2018). The terrestrial recreational capacity was identified using an ES-land use (LU) matrix. The ES-LU matrix was developed using look-up score for ES capacity of LU to provide recreational goods and services, retrieved from Stoll et al. (2015). The matrix identifies the highest (score 5) to natural and semi-natural land uses and lower recreational (score 1) capacity of urban and semi-urban land uses in coastal areas (Burkhard et al., 2009; Stoll et al., 2015). To map the landscape diversity a Shannon Index was used as indicator for the number of different natural landscape types (Dušek and Popelková, 2017). The marine recreational capacity (mr_{cap}) was measured using an ES – marine habitats matrix for the Adriatic Sea (for more details see Depellegrin et al., 2017; Menegon et al., 2018a) that identifies the marine habitats in proximity of beaches with highest recreational capacity. Geospatial information on habitats distribution were extracted from the European Monitoring and Data Network – Seabed Habitats data portal (EMODnet, 2018). The recreational capacity of marine habitats scored between 3 (*high* – e.g. A3: Infralittoral rock and other hard substrata), 2 (*medium* – e.g. A5.23: Infralittoral fine sands) to (*low/negligible* - A5.35: Circalittoral sandy mud). Obstructed view (o_{view}) is a spatial indicator based on a cumulative viewshed analysis (Depellegrin, 2016). Obstructed view is important to calculate because recreational beach users aesthetically value a natural, uninterrupted panorama. Beaches from where no infrastructure is visible will have the highest o_{view} score close to 1 (no obstruction). The following algorithm was applied to calculated o_{view}:

$$o_{view}(b) = \sum_{i=1}^{nb} s_i(b)$$

Where, s_i (*b*) is the viewshed performed for the *i-th* infrastructure that impacts the coastal territory of the *b-th* beach and *nb* the number of visible infrastructures from the *b-th* beach. o_{view} was modelled using *r. viewshed*, a GRASS (Geographic Resources Analysis Support System), GIS tool that computes the viewshed of a point on an elevation raster map (GRASS, 2021).

As proxy for the demand of recreational ES, we used photo-user-days

Table 1
Recreational supply and demand datasets applied in the study area. Note: P/A – presence/absence.

Indicators	Description	Unit	Reference
Beaches	Area along the edge of the sea that is used as access to sea for recreational purposes	P/A	OSM (2019)
Recreational supply			
Hemeroby Index (*hi*)	Indicator (1–10) of the naturalness of 1 km buffer surrounding OSM beaches	Index	Walz and Stein (2014)
Natura 2000 (n_{2000})	Coastal areas of high natural environment and value	P/A	EEA (2020)
Landscape Diversity (*ld*)	Attractive recreational areas have diverse landscapes.	Shannon Index	Fischer et al. (2018)
Accessibility (*acc*)	Accessibility to beach area within 1 km buffer surrounding OSM beaches. Higher scores of *acc* indicate better opportunity to reach a recreational areas and benefit from its services.	km/km^2	OSM, 2019; Liu et al. (2021)
Terrestrial Recreational Capacity (tr_{cap})	Recreational capacity of LULC (1–5 score) within 1 km buffer surrounding OSM beaches	1 (very low) to 5 (very high)	Burkhard et al., 2009; Stoll et al. (2015)
Marine recreational capacity (mr_{cap})	The capacity of coastal marine habitats to provide recreational value	*very low (score 1)*: A5.26: Circalittoral muddy sand A5.35: Circalittoral sandy mud A5.33: Infralittoral sandy mud *Medium (score 2)*: A5.23: Infralittoral fine sands A5.13: Infralittoral coarse sediment *High (score 3)*: A3: Infralittoral rock and other hard substrata A5.535: [Posidonia] beds	Menegon et al., 2018; Salomidi et al. (2012)
Obstructed view (o_{view})	Viewshed occupied by static infrastructure (e.g., oil and gas infrastructure) calculated in square radians.	0 (high occupancy) to 1 (no occupancy)	
Recreational demand			
Photo-user-Days (*PUD*)	Are defined as the total number of days, across all users, that each person took at least one photograph within each site.	Index	Wood et al. (2013)
Anthropogenic stressors			
Stressors	Stressors adapted from MSFD Annex III for 2017 including visual blight exerted by marine infrastructure. The propagation of each stressor is modelled using the Tools4MSP Modelling Framework (Menegon et al., 2018b)	*0 (low to absent stressor effect) to 1 (high stressor effect)* *Definition of stressors and their propagation distance in km:* *Land-based*: Inputs of fertilisers and other nitrogen and phosphorus-rich substances (depending on hydrodynamic model) *Sea-based*: Abrasion (surface, light, heavy); Underwater noise (50 km); Changes in siltation (<1 km or local); Introduction of non-indigenous species and translocations (5 km); Selective extraction of species (<1 km or local), including incidental non-target catches (<1 km or local); Introduction of synthetic compounds; Introduction of non-synthetic substances and compounds; Introduction of other substances; Visual blight from infrastructure (depending on the structure height) *Land- and sea-based*: Marine litter; Introduction of microbial pathogens; Inputs of organic matter (depending on hydrodynamic model)	Depellegrin et al. (2017); Menegon et al., 2018; MSFD 2008 & 2017

(*PUD*) based on geotags retrieved from Flickr (Retka et al., 2019; Depellegrin et al., 2012). The bounding box for the beaches included the coastal municipalities of the study area. PUD are the total number of days, across all Flickr users, that each person took at least one photograph within a coastal site. The Python FLICKR API (Version 2.3; Python FLICKR API, 2021) was used to extract geotags for coastal municipalities (n = 132) and then were filtered according to the beach buffer of 500 m beaches identified through OSM (2019). All indicators were rescaled using $x/x_{\max}$.

Recreational ES were assessed and mapped using a supply-demand mapping approach. ES-supply is defined as the components of a

Table 2
a list associating stressors to risks to recreational supply and demand.Cross-referenced risks to recreational supply and recreational demand as function of the stressors identified. Note: Supplementary material, Annex 1 provides the list of stressors associated to the risks to recreational supply and demand.

	Stressors												References
Risks to Rec_Supply	Abrasion	Change in siltation	Underwater noise	Marine litter	Synth compounds	non-synth compound	Input of fertilizers & N & P	Pathogens	Non-indigenous species	Selective extraction	Inputs of organic matter	Infrastructure	
Decreased Water Quality		X		X	X	X	X	X	X		X		Landrigan et al., 2020; O'Hara et al., 2021; Depellegrin 2016; Kreitler et al., 2013; Barnett et al., 2018
Loss of Space	X	X											
Reduced Species Richness	X						X			X			
Visual Blight												X	
Risks to Rec_Dem													Landrigan et al., 2020; Stewart et al., 2008; Bienfang et al., 2011; Griffin et al., 2015
Decreased Naturalness		X		X			X		X		X		
Exposure to Diseases							X	X	X		X		
Impairment of Recreational Use	X			X	X	X	X						
Intoxication					X	X	X						
Reduced natural seascape				X								X	

Kreitler et al., 2013: https://doi.org/10.1371/journal.pone.0056670; Stewart et al., 2008: https://doi.org/10.1186/1476-069X-7-S2 -S3; Bienfang et al., 2011: https://doi.org/10.1155/2011/152815; Barnett et al., 2018: https://doi.org/10.1016/j.jort.2017.12.003.

coastal ecosystem based on biophysical, ecological functions, and social properties (Wei et al., 2017). The coastal ES supply (Rec_{Supp}) is expressed as the capacity of ecosystems to provide recreational services appreciated by humans, and is calculated as follows (eq. (1)):

$$Rec_{Supp} = \left(h_i + n_{2000} + acc + tr_{cap} + ld + mr_{cap} + \frac{1}{o_{view}}\right)' \quad \text{eq.1}$$

Whereas $'$ indicates the normalized Rec_{Supply} score on a value from from 0 to 1.

Demand for recreational services (Rec_{Dem}) is defined as the usage of ecosystems providing recreational services (Wei et al., 2017). Useful in assessing this are Geotags, which are an emerging tool for assessing human-nature interaction in coastal environments in relation to the analysis of recreational hot-spots (ESPON, 2020b; Retka et al., 2019; Sinclair et al., 2020), or the assessment of landscape aesthetic values (Depellegrin et al., 2014; Griffin et al., 2015).

Thus, the mapping and identification of recreational ES demand, was developed based on a geotag dataset from FLICKR, using about 1.2 million geotags of the coastal municipalities of the study area. Geotag harvesting was performed using a python library named Python FLICKR API (2021). The extraction of the geotag metadata was enabled through a FLICKR Application Programming Interface (API). The archived metadata information included user-ID, geographic coordinates (*lon/lat*), and the time stamp (*dd/mm/yy*). This information was incorporated into Geographic Information Systems, to map the recreational demand. Based on extracted data we defined the recreational demand (Rec_{Dem}) as follows (eq. (2)):

$$Rec_{Dem}(b) = PUD(b) = \sum_{i=1}^{d}\sum_{j=1}^{u} P_{ij}(b) \text{ where } P = \begin{Bmatrix} 1 & ifp > 0 \\ 0 & otherwise \end{Bmatrix} \quad \text{eq.2}$$

Whereas *P* is the number of photos taken by the *j-th* user at *i-th* day at beach *b*, *u* are the number of Flickr user and *d* is the number of days. PUD (Photo-User-Days) is the sum over the period 2014–2018 of the daily users. The daily users are the number of users that took at least one photo per day.

2.4. Risk-based multiple stressor model

Multiple stressors can reduce the quantity, quality, and stability of ES, and increase variability in their delivery (Armoškaitė et al., 2020; Farella et al., 2020). To model multiple risks to beaches, we applied a multi-stressor, risk-based Cumulative Effects Assessment model (Depellegrin et al., 2020; Menegon et al., 2018). CEA are geospatial models to evaluate the potential impact of maritime activities on the marine environments (MSP-EC, 2017). To model this, we used recreational ES supply, namely the beaches and their interactions with a set of land- and sea-based stressors (Table 1), that can affect beaches recreational supply-demand. The stressors relevant for the coastal recreation are defined in Table 1 and this includes as well visual impacts to seascapes exerted by static infrastructure such as oil and gas platforms installations (Samhouri and Levin, 2012).

The risk (*R*) to recreational supply or demand of a beach *b*, is defined as the product of the exposure (*E*) of the beach *b* to the stressor *j* and the supply of recreational ES Rec_{Supp} or the demand of recreational ES Rec_{Dem} (eq. (3)):

$$R(b) = \sum_{j=1}^{k} E_j(b) \times Rec_{Supp|Dem}(b) \quad \text{eq.3}$$

The exposure (E_j) of a beach *b* can be calculated as follows (eq. (4)):

$$E_j(b) = \sum_{i=0}^{a} \left(A_i(b) * G\left(d_{ij}\right)\right) \quad \text{eq.4}$$

Where A_i = anthropogenic activity *i* that can refer to maritime traffic,

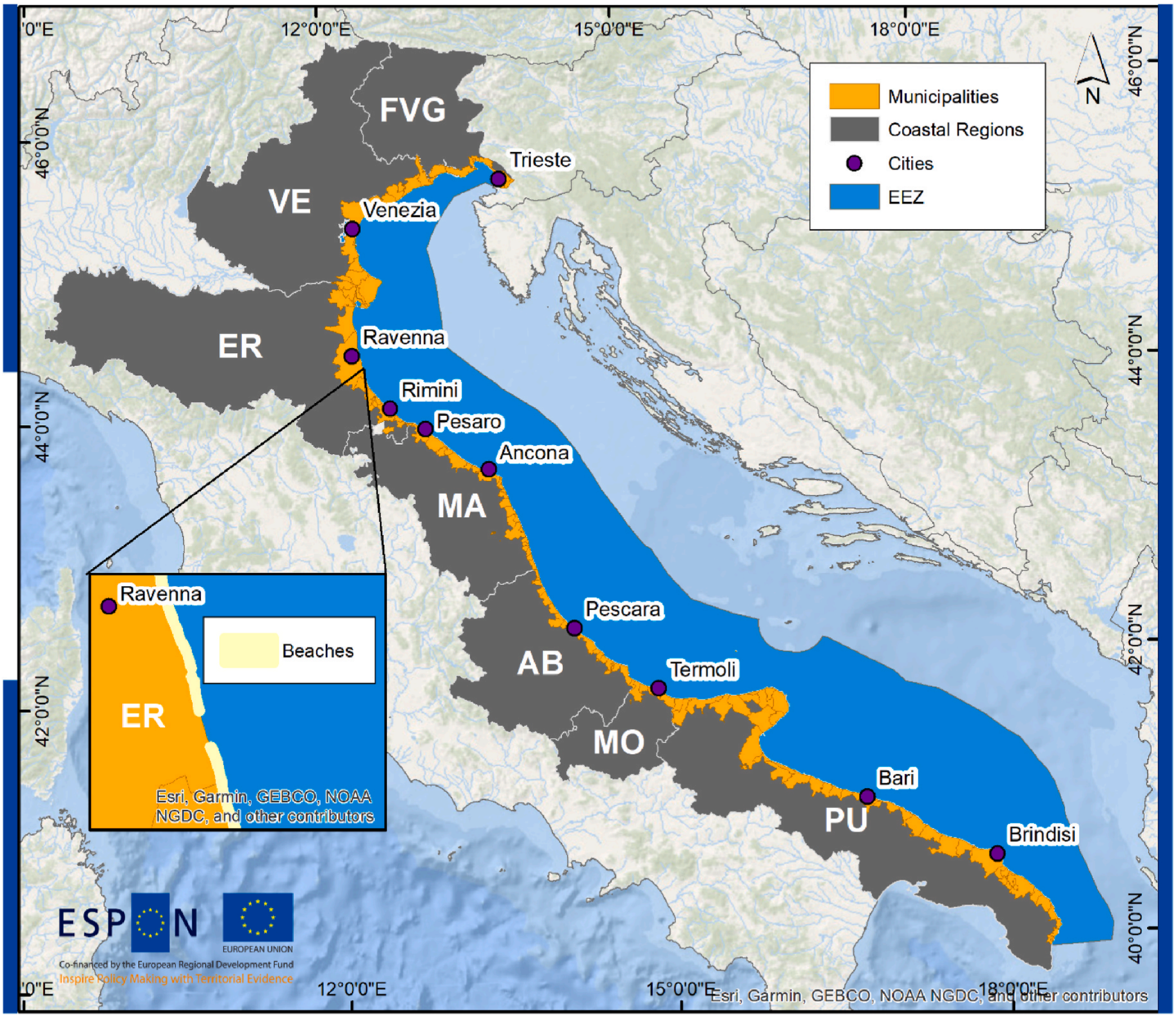

Fig. 2. The study area: Italian Adriatic Sea including seven coastal regions and 132 municipalities. Note: FVG-Friuli Venezia Giulia; VE-Venezia, ER-Emilia Romagna, MA-Marche, AB-Abruzzo, MO-Molise and PU-Puglia.

aquaculture, commercial fishery, coastal tourism etc. A_i refers to the geographic location of the maritime activity in the study area either in form of line, point or polygon shapefile. G is the Gaussian convolution with standard deviation to d_{ij}, and d_{ij} is the propagation distance (in km; see Table 1 for proposed propagation distances) of stressor j generated, by the *i-th* anthropogenic activity. For further definition of maritime activities and application of algorithm parameters we refer to Depellegrin et al. (2017) and Menegon et al. (2018a).

The rationale of the risk-based analysis $R(b)$ of eq. (3) can be graphically outlined in Fig. 3: Fig. 3A presents the supply-side of the risk-based analysis (Rec_{Supp}) of multiple land- and sea-based stressors affecting the beach. Fig. 3B describes the demand-side of the risk-based analysis (Rec_{Dem}) of multiple land-and sea-based stressors, expressed by the presence of beach visitors through PUD. Each stressor is exerted by a specific stressor source (the human activity) and propagates within a specific distance from 0 km (< 1 km *to local* stressor) to 50 km (e.g., underwater noise).

The effects on recreational supply and demand were defined through a structured literature review, focused on identifying stressors affecting recreational quality in coastal sites. In Table 2 we provide a cross-referenced table of the risks to recreational supply and recreational demand as a function of the stressors defined in the multi-stressor model. The presence or absence of specific risk is determined through a literature review aimed at identifying some of the most important risks to the marine environment (the supply-side) and to user of marine environment (the ES demand-side). The four risks for the recreational supply are defined as follows: decreased water quality from riverine inputs and coastal activities such as aquaculture (Landrigan et al., 2020), loss of recreational space, reduced species richness (O'Hara et al., 2021, Menegon et al., 2018) and visual blight (Depellegrin, 2016).

The following five risks to recreational demand are: decreased naturalness, exposure to diseases (An et al., 2020; Gyraite et al., 2019), impairment of recreational use due to the presence of pollutants or hazardous substances (Landrigan et al., 2020), intoxication (Bédry et al., 2021) and reduced natural seascapes due to visual blight from marine and coastal infrastructure (Depellegrin, 2016; Griffin et al., 2015). Bathing water can be a vector for a series of diseases, bacterial pathogens (e.g., E. coli or Salmonella), including antibiotic resistant strains of bacteria (Bonadonna et al., 2002; Schippmann et al., 2013), viruses (Wyn-Jones et al., 2011) or toxic algal blooms (Zingone et al., 2021; Pistocchi et al., 2012), that can impact human health severely. Bacterial pathogens can be particularly harmful because they can cause septicaemia, gastroenteritis, or other illnesses (EPA, 2021). Some viruses found in bathing sea water have infectious capacity. For example, adenoviruses are associated with gastroenteritis in children, some respiratory infections, ear infections, and conjunctivitis. Impairment of recreational use refers to the deterioration of beaches due to marine litter, eutrophication, through nutrients (N and P), and the consequent decrease of the quality of bathing waters (Wyn-Jones et al., 2011; Depellegrin et al., 2020), through synthetic/non-synthetic compounds

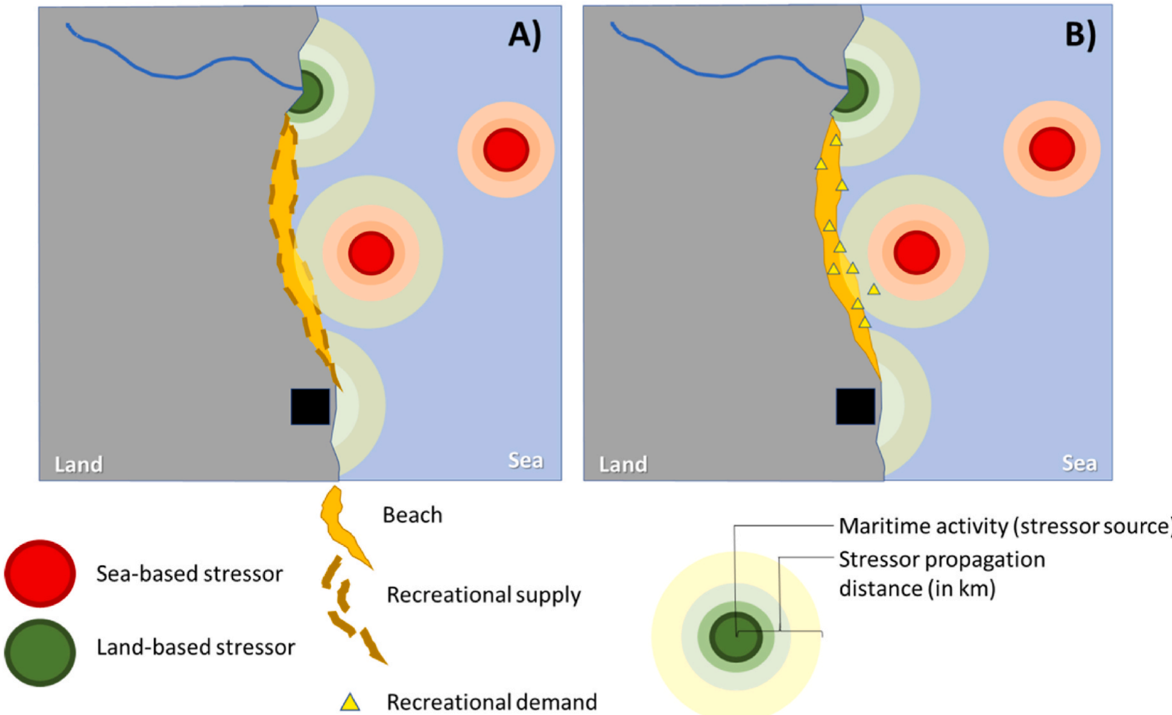

Fig. 3. Conceptual integration of recreational supply-demand analysis into multiple stressor risk analysis. A) Supply-side of risks to beach as recreational supply unit; B) demand-side of risks to visitors of the beach as recreational demand unit. Note: Sea-based stressors are originated for example by aquaculture activities, oil and gas installations, fishery etc; Land-based stressors are originated for example by ports or riverine inputs. Based on Menegon et al. (2018a) there are 12 maritime activities in the study area: aquaculture, cables & pipielines, coastal tourism; coastal defence work, commercial fishery (flying, trawling); LNGs, maritime transport/shipping, military areas, naval/port based activities, oil & gas extraction, small scale fishery.

and pollution phenomena. Intoxication can be caused by chemical substances in the marine environment, such as hydrocarbons or heavy metals (Weinstein et al., 2010). The presence of infrastructure, such as oil and gas platforms, and aquaculture can reduced natural seascape attractiveness and lead to the decline of tourism (Falconer et al., 2013; Smythe et al., 2020).

3. Results

3.1. Recreational supply and demand

Geospatial results from recreational supply-demand analysis are presented in Fig. 4a and b. Beaches with highest recreational supply index are located in Marche and Puglia region ($max = 0.9$ and $\max = 1$). Puglia region has very high scores, due to the presence of Natura (2000) sites and habitats attractive for recreational activities (e.g., seagrass beds such as *Posidonia oceanica*). The coastal regions with the highest median are Veneto and Friuli-Venezia-Giulia ($\widetilde{x} = 0.68$ and $\widetilde{x} = 0.7$). A noticeable result is that Marche and Emilia-Romagna regions have the lowest median recreational supply index, with scores around 0.62 and 0.64. In terms of geospatial results, beaches in proximity to Pesaro, Ancona, and Termoli show the highest recreational supply scores. Beaches in Puglia and Marche have the highest recreational demand index ($\max = 0.88$; $\max = 0.86$). The beaches of Emilia-Romagna, Marche, and Friuli-Venezia-Giulia regions have the highest median recreational demand index, with scores of $\widetilde{x} = 0.65$, $\widetilde{x} = 0.64$, and $\widetilde{x} = 0.55$ respectively. Further, it can be noticed that Molise region in central Italy, has the lowest median demand score ($\widetilde{x} = 0.31$), among the studied regions. In terms of geospatial distribution, beaches with highest recreational demand are in the eastern segment of Veneto region and in the proximity of the city of Trieste, in Friuli-Venezia-Giulia region.

3.2. Risks to ES supply

Fig. 5a presents the alluvial diagram representing the risk assessment framework used to identify the risks to recreational supply from multiple stressors. In total four risks to recreational supply were defined: decreased water quality, loss of space, reduced species richness and viual blight. Water quality for bathing activity for example, is a major contributor to coastal recreation and human well-being. Loss of space for coastal recreation can be caused by land use change. However, considering maritime impacts, it is mainly exerted by changes in siltation and abrasion from commercial fishing activities, or port dredging, that can reduce the space for recreational activities. The reduction of species richness, is one of the most important risks to coastal recreation. Several sectors of marine recreation industries, such as scuba diving and snorkelling depend on the availability of a healthy marine ecosystem. Visual blight caused by marine infrastructure, including oil and gas platforms, aquaculture and ports in the proximity of recreational sites, can reduce the natural seascape characteristics, making amenity activities less attractive. In Fig. 5b, the regional exposure (E) of beaches to the four recreational supply risks is presented. Emilia-Romagna region has the highest median score for poor water quality ($\widetilde{x} = 0.15$), loss of space ($\widetilde{x} = 0.52$), reduced species richness ($\widetilde{x} = 0.59$). In Fig. 5c results show that the three regions of the Northern Adriatic Sea, namely Friuli-Venezia-Giulia ($\widetilde{x} = 0.56$), Veneto ($\widetilde{x} = 0.45$) and Emilia-Romagna ($\widetilde{x} = 0.56$) region are subjected to the highest risks for recreational supply.

3.3. Risk to recreational demand

In Fig. 6a we provide the risk assessment framework to recreational demand. The following five risks to recreational demand are: decreased naturalness, exposure to diseases, pathogens, algal blooms, impairment of recreational use, intoxication and reduced natural sea space.

In Fig. 6b, the exposure of coastal regions to the five recreational

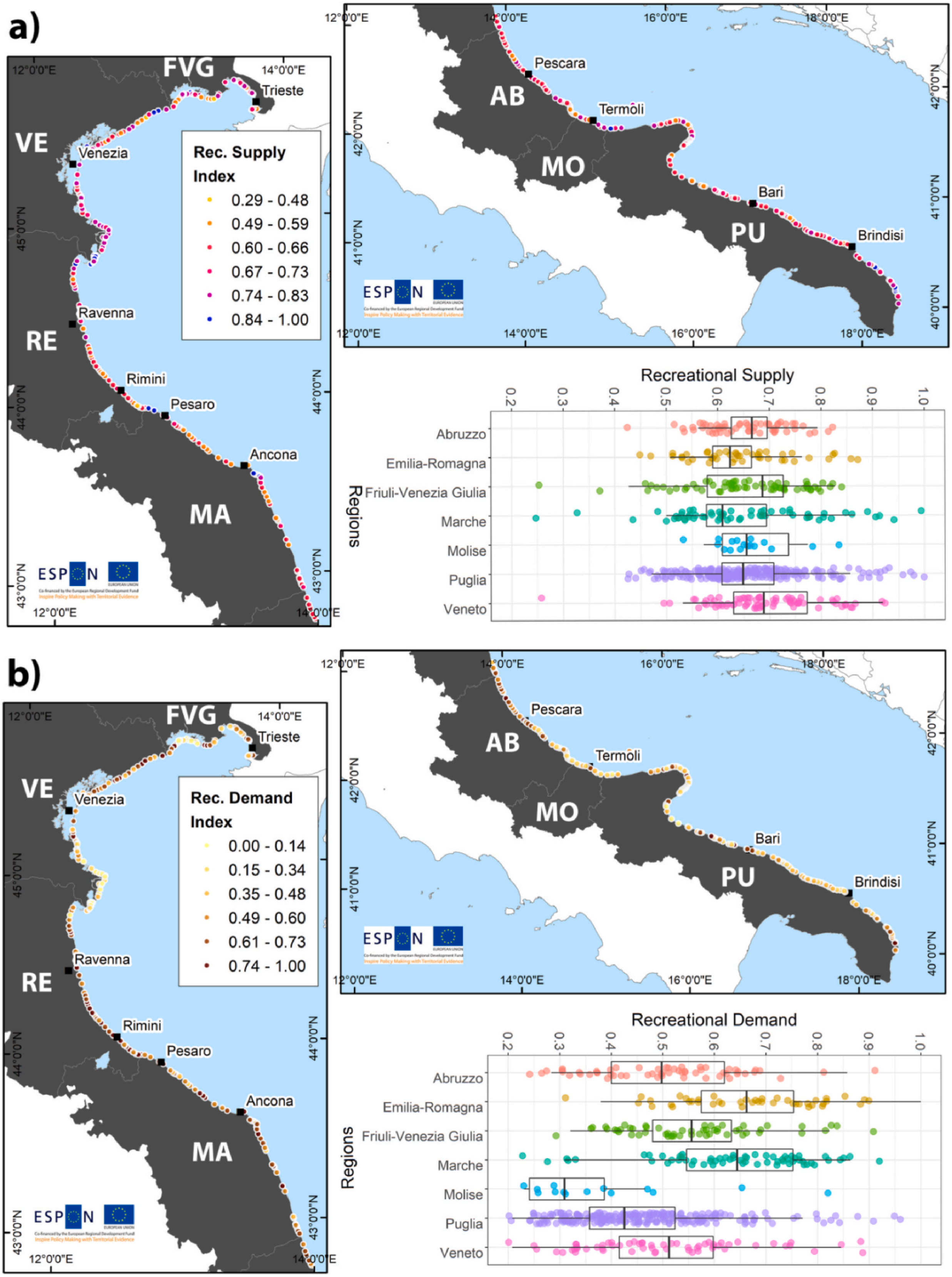

Fig. 4. Geospatial results from (a) recreational supply and (b) recreational demand. The box plots summarize the respective regional scores of supply and demand for beaches in the seven coastal regions of the study area. FVG-Friuli Venezia Giulia; VE-Venezia, RE-Emilia Romagna, MA-Marche, AB-Abruzzo, MO-Molise, and PU-Puglia.

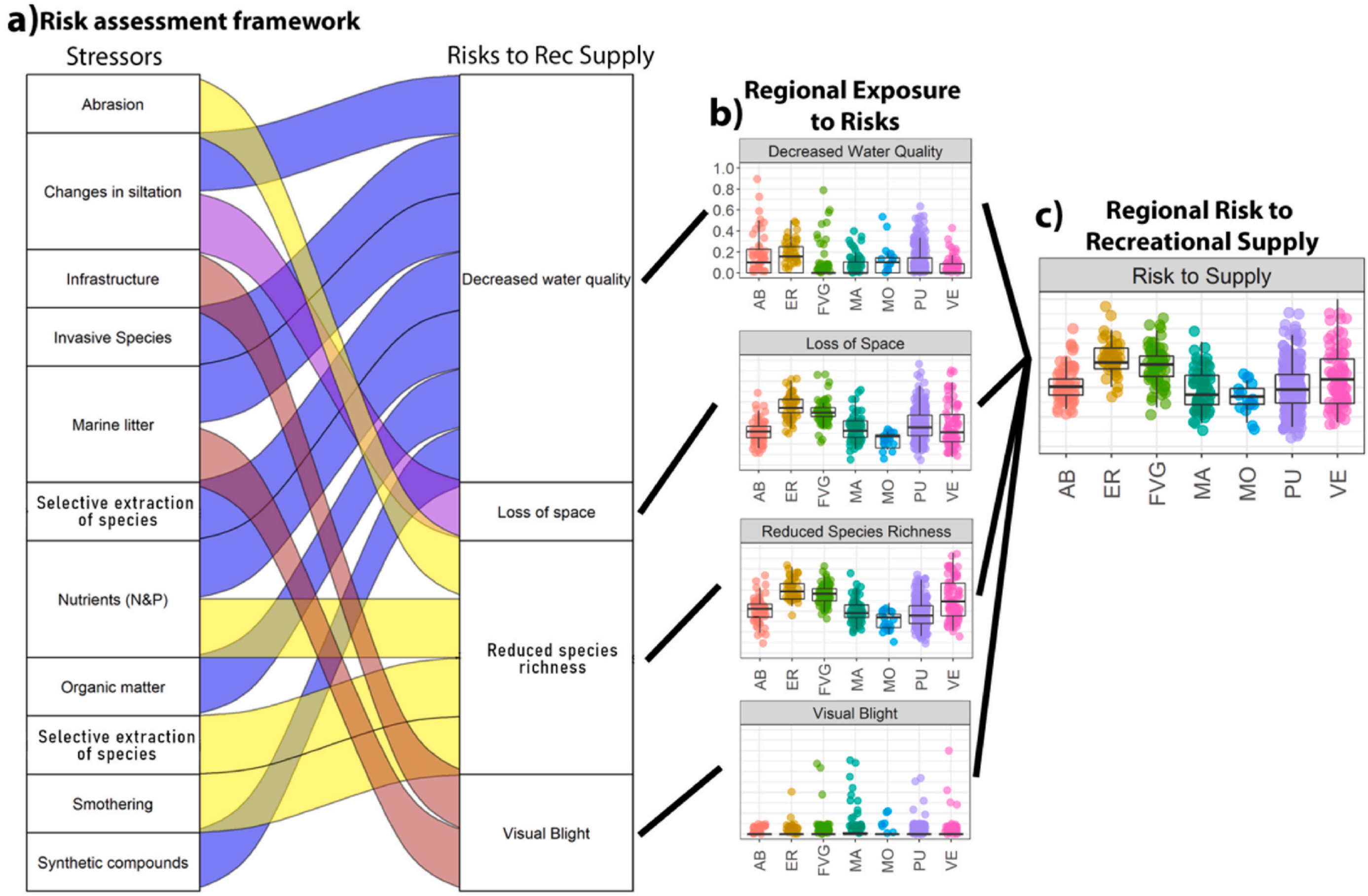

Fig. 5. a) Risk assessment framework defining type of stressors and type of risks to recreational supply, b) regional exposure to the recreational supply risks, and c) the regional risk for recreational supply. FVG-Friuli Venezia Giulia; VE-Venezia, ER-Emilia Romagna, MA-Marche, AB-Abruzzo, MO-Molise, and PU-Puglia.

demand risks is presented. Results show that Friuli-Venezia-Giulia has the highest median score ($\tilde{x}$) for decreased naturalness ($\tilde{x}$ = 0.63), impairment of recreational use ($\tilde{x}$ = 0.58) and reduced natural seascape ($\tilde{x}$ = 0.42). Emilia-Romagna region, on the other hand, has the highest median score for exposure to diseases/pathogens ($\tilde{x}$ = 0.15), and intoxication ($\tilde{x}$ = 0.61). In Fig. 6c, the regional risk to recreational demand shows that beaches of Emilia-Romagna, Friuli-Venezia-Giulia, and Veneto regions have the highest median risks to human health ($\tilde{x}$ = 0.51; $\tilde{x}$ = 0.4, and $\tilde{x}$ = 0.33). Beaches of Veneto, Emilia-Romagna, and Abruzzo regions show the highest risk scores (max = 0.9; max = 0.87, and max = 0.83).

4. Discussion

This research presents a new methodology for the analysis of recreational supply-demand in beaches. It links the analysis with a multi-stressor model, to address the regional risks to supply-demand from land and sea-based anthropogenic activities. The presented model is used in a case study for the Italian Adriatic Sea but has the flexibility to be applied in any geographic region across the globe. The framework developed, can be used by decision-makers and coastal planners to address the recreational potential of beaches, and characterize multiple sources of stressors, posing risks to recreational quality of the beaches, as well as to potential risks to human health, induced by the stressors. The presented study shows a methodological advancement in the domain of ES supply-demand analysis, and in the integration of risk assessment procedures. It also evidences that the human well-being component, that is implicit to the ES concept, can be explicitly modelled, as a separate component through ES demand analysis. In fact, the maritime anthropogenic activities, identified in the model, are potentially risky to human well-being/health. Five distinct risk groups were identified (Fig. 6a): decreased naturalness, exposure to diseases/pathogens, intoxication through contaminants in the bathing water, impairment of recreational use, and reduced natural seascapes. A Pearson correlation analysis (Supplementary material, Annex 1) shows that the demand for recreational activities, is positively correlated with coastal population density. This suggests that beaches in the proximity of coastal urban settlements, still belong to the most used, due the better accessibility (proximity) and infrastructure availability. In contrast, recreational supply is positively correlated with spatial features of naturalness, such as the presence of Natura (2000) sites or natural land uses of high recreational capacity, such as coastal forests or dunes. Also, worth noting is that there is a negative correlation, among the recreational supply-demand indexes, suggesting that there is mismatch among the visitor preferences and the naturalness of coastal features. The multi-stressor model adapts a cumulative effects assessment (CEA) that were applied across the globe for integrated maritime spatial planning (Farella et al., 2020; Clarke Murray et al., 2015) or for cumulative effects assessment of single sectors of the Blue Economy, such as offshore wind energy development (Gusatu et al., 2020). CEA models focus on the analysis of impacts on marine ecosystems, and are relevant for strategic environmental assessments (SEA) purposes. In this context, we have considered beaches at the land-sea interface as the receptor of the stressors. The result of the analysis shows that beaches located in geographic areas with highly industrialized maritime activities have higher exposure to health risks. Coastal management strategies require therefore, appropriate management of the land-sea interface activities, to reduce health risks. The multi-stressor model applied in this research, provided a

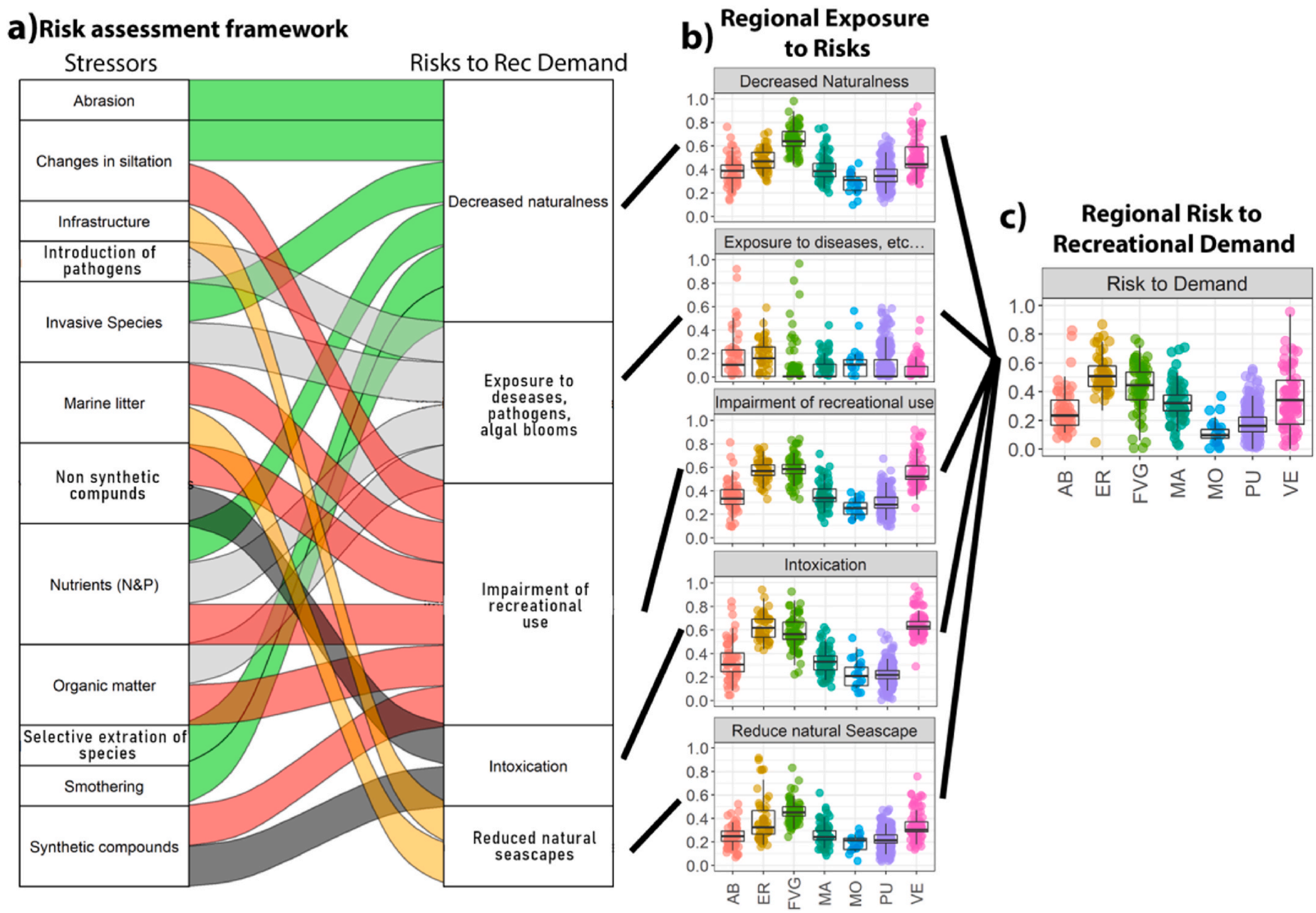

Fig. 6. a) Risk assessment framework defining type of stressors and type of risks to recreational demand; b) regional exposure to the recreational demand risks, and the c) the regional risk for recreational demand.

flexible instrument to identify coastal areas at highest exposure to land-sea stressors. The dispersion of nutrients (N and P) and organic matter from riverine inputs responsible for a decrease of the quality of bathing waters was based on the 3-D hydrodynamic model named SHYFEM (Shallow water Hydrodynamic Finite Model; Umgiesser et al., 2004; for further information we refer to Depellegrin et al., 2017). The other stressors were modelled using the Tools4MSP Modelling Framework (Menegon et al., 2018b), an open-source software that can be used for ocean zoning challenges (Farella et al., 2020), environmental risk assessment (Depellegrin et al., 2020), and modelling cumulative environmental effects (Gusatu et al., 2020). This is in line with an emerging trend in empirical models for pathogens and pollutants, and their dispersion in coastal waters (e.g., Bruschi et al., 2021; Soto-Navarro et al., 2020). Additional stressors, such as pathogens (bacteria and virus) in coastal areas, marine litter, synthetic/non-synthetic compounds and harmful algal blooms (HABs), can be further integrated into hydrodynamic models, to increase the accuracy of the multi-stressor exposure model.

The presented study has substantial practical value in terms of technical implementation and for decision-making in the Land-Sea Interface: 1) the analysis shows flexibility in the representation of results, that can be visualized in statistical (Figs. 5 and 6) and or geospatial terms (Fig. 4). 2) In this study, the analysis was presented on a regional scale, but can be applied on macro-regional scale (e.g., Adriatic-Ionian Region or Mediterranean) or at local scale (e.g., municipality or single beach level). 3) Moreover, a local scale assessment offers opportunity for further validation of the model through the integration of in situ data on water quality and or through questionnaires to beach visitors. 4) Within a decision-making context the study enables decision-makers to address trade-offs among coastal vs offshore maritime activities by locating and if required forecast through a scenario-based approach how planning measures would affect recreational quality of beaches and potential effects to human health. This is of importance when harmonizing ICZM-MSP strategies on national and regional level.

The datasets involved in the recreational supply analysis were retrieved from EU and global data repositories, such as the Copernicus, EUNIS seabed habitats or OpenStreetMap. This suggests that the potential of the method is to provide at least EU-wide methodology for the recreational supply-demand assessment of coastal areas. Similarly, the demand-side of the analysis based on social media geo-tags retrieved from Flicker has shown to be applicable across the globe, e.g., in Brazil (Retka et al., 2019), India (Sinclair et al., 2018) or North America (Angradi et al., 2018). Although social media data is increasingly being used in the analysis of cultural ES (e.g., Egarter Vigl et al., 2021b; Retka et al., 2019; ESPON, 2020a), their application should be considered complementary to more traditional survey-based approaches of ES assessment. In this research, for instance, the geotags were applied to identify the frequency of visitation of recreational site by beach users, without providing any further details on the type of coastal recreational activity performed by the visitor (e.g., diving, swimming, sunbathing). Therefore, the use of social media derived data needs to be further extended, with local surveys and or the use of national statistical data on overnight stays, to validate the social media data and provide more comprehensive assessment. Moreover, geotags provide spatio-temporal information of recreational activity and can facilitate the application of crowed-sourced travel cost models, for the identification of the willingness to pay for recreation in protected areas and coastal areas (Lingua et al., 2022; Sinclair et al., 2020). Deployment of travel cost models are generally limited by the datasets restricted to localized survey area. This approach discloses opportunity for a wider spatial application of the dataset and make consideration on recreational demand on national or macro-regional level.

The presented study has several implications for coastal and maritime spatial planning. Fostering sustainable development in the marine space requires a holistic understanding of the anthropogenic impacts in the land-sea continuum. Although tested only for recreational activities, an ES approach, seems to be an effective methodology to conceptualize nature-society interactions, in the context of the carrying capacity of beaches (ESPON, 2020b). Supply and demand analysis can help explain the exposure of beach tourism to biological-, physical-, and energy-based anthropogenic stressors. Further stress phenomena such as climate change (e.g. sea level rise, coastal erosion and or marine heat waves) can extend existing risk and impact assessment framework used in MSP and also in this study.

The presented methodological framework is not free of limitations. In terms of conceptual design the study ensembles a set of models to better address social and ecological land-sea interactions processes. The applied datasets rely on the tourism demand based on social media datasets. While this data sources are promising from a geospatial point of view, because they could cover large scale areas their application requires constant validation in the study sites of application. The aggregation of datasets from different scales, such as for instance through a spatial buffer can have significant effects on the characterization of recreational supply-demand side of beaches. Results of the study indicate that recreational demand positively correlates with coastal population density and that factors such as infrastructure (e.g. access) are a good predictor for ES recreational demand. Although depending on the regional context, the research highlights that pristine environmental conditions through conservation not necessarliry attract higher number of beach users. The stressors implemented here were modelled using an isotropic propagation; however, many of the stressors relevant to human health, such as waterborne pathogens may be concreted according to current regimes and local hydrodynamic conditions, which are also subjected to various decay functions. Climate change phenomena can augment the intensity of stressors and therefore should be taken into considerations in future developments of the model.

5. Conclusions

We developed a methodological framework to investigate the recreational supply and demand of beaches by tourists and applied a risk model to address the exposure of beaches and beach users to multiple stressors exerted by anthropogenic activities at the sea-land interface. The study showed a high variability among northern and central-southern coastal regions in recreational supply and demand. The southern Italian coastal regions had the highest supply of recreational areas due to the presence of protected areas and lower levels of coastal urbanization and maritime activities. The demand for recreation at beaches is highest in northern Italian coastal regions, where there are more cities, more infrastructure and access to beaches enabled by a developed street network. The application of a multi-stressor model showed that beaches of coastal regions of Friuli-Venezia-Giulia, Veneto, and Emilia-Romagna are highly exposed to land-based stressors derived from riverine inputs, such as the Po and Adige rivers, and from high intensity of maritime activities, such as ports, shipping, cruising or aquaculture. In terms of risks to human health in those regions, intoxication from chemical compounds and visual effects to seascapes from oil and gas infrastructure and aquaculture installations are particularly persistent. The methods developed can be used by decision-makers and planners across regional and local scales to monitor the status of beaches and take measures to govern and monitor the maritime activities that have effects on the supply and demand of recreational ES.

Author contributions

DD: conceived the ideas, designed the methodology, and collected and analysed the data, procured the funding; **SM**: provided the cumulative stressor model, collected the data. **DD, SM and SR**: performed the formal analysis and realised the maps and graphs; **DD**: wrote the first draft; **SM, JAE, CML, LB, SR**: participated in the review and formulation of the final draft. All authors contributed to project administration, edited the manuscript and gave final approval for publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Daniel Depellegrin reports financial support was provided by European Observation Network for Territorial Development and Cohesion.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2023.106725.

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