Ecological Indicators 122 (2021) 107296

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

MedSens index: The bridge between marine citizen science and coastal management

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A R T I C L E I N F O

Keywords:
Community-based ecosystem monitoring
Coralligenous habitats
Climate change
Impact assessment
Species sensitivity
Temperate reefs

A B S T R A C T

Citizen science (CS) projects may provide community-based ecosystem monitoring, expanding our ability to collect data across space and time. However, the data from CS are often not effectively integrated into institutional monitoring programs and decision-making processes, especially in marine conservation. This limitation is partially due to difficulties in accessing the data and the lack of tools and indices for proper management at intended spatial and temporal scales. *MedSens* is a biotic index specifically developed to provide information on the environmental status of subtidal rocky coastal habitats, filling a gap between marine CS and coastal management in the Mediterranean Sea. The *MedSens* index is based on 25 selected species, incorporating their sensitivities to the pressures indicated by the European Union's Marine Strategy Framework Directive (MSFD) and open data on their distributions and abundances, collected by trained volunteers (scuba divers, free divers and snorkelers) using the Reef Check Mediterranean Underwater Coastal Environment Monitoring (RCMed U-CEM) protocol. The species sensitivities were assessed relative to their resistance and resilience against physical, chemical, and biological pressures, according to benchmark levels and a literature review. The *MedSens* index was calibrated on a dataset of 33,021 observations from 569 volunteers (2001–2019), along six countries' coasts. A free and user-friendly QGIS plugin allows easy index calculation for areas and time frames of interest. The *MedSens* index was applied to Mediterranean marine protected areas (MPAs) and the management and monitoring zones within Italian MPAs. In the studied cases, the *MedSens* index responds well to the local pressures documented by previous investigations.

MedSens converts the data collected by trained volunteers into an effective monitoring tool for the Mediterranean subtidal rocky coastal habitats. *MedSens* can help conservationists and decision-makers identify the main pressures acting in these habitats, as required by the MSFD, supporting them in the implementation of appropriate marine biodiversity conservation measures and better communicate the results of their actions. By directly involving stakeholders, this approach increases public awareness and the acceptability of management decisions, enabling more participatory conservation tactics.

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https://doi.org/10.1016/j.ecolind.2020.107296
Received 31 August 2020; Received in revised form 11 December 2020; Accepted 17 December 2020
1470-160X/

1. Introduction

Community-based environmental monitoring (CBM) is a participatory approach to engage citizen volunteers, through citizen science (CS) programs, to enhance the ability of decision-makers and non-government organisations to monitor and manage natural resources, track at-risk species, and protect biodiversity (Chandler et al., 2017; Conrad and Hilchey, 2011). Thus, CBM involves citizens and other stakeholders in the ecosystem-based management (EBM) of natural heritage, aiming to conserve ecological goods and services by recognising their interactions within an ecosystem (Alexander et al., 2019; Freiwald et al., 2018; Keough and Blahna, 2006). Marine citizen science (MCS) may represent a valuable contribution to CBM in marine environments, given the vastness of the oceans and the world's coastlines and the diversity of their habitats, communities, and species (Garcia-Soto et al., 2017; Thiel et al., 2014). By engaging millions of people around the world, MCS programs are becoming increasingly important to conservation science by influencing and improving the management of marine protected areas (MPAs) and fishery resources (Freiwald et al., 2018). MCS programs also increase observation capacities (Hodgson, 2001; Pattengill-Semmens and Semmens, 2003; Sully et al., 2019). Despite a worldwide increase in the number and extent of MCS programs (Thiel et al., 2014), the collected information is rarely used for institutional monitoring programs or to inform decision-making processes in marine conservation (Conrad and Hilchey, 2011). This disconnect is partially due to persisting scepticism of the reliability of data collected from volunteers (Burgess et al., 2017) and to a co-creation approach that is still not well-integrated in CS processes (Bonney et al., 2015). If the results of a CS project answer research questions that are of low interest to decision-makers, it will inevitably be difficult to integrate the CS data into management strategies. However, many studies demonstrate that well-trained citizens can provide valuable data on marine environmental issues and that suitable protocols for volunteer projects can provide results that are consistent with the methods used by professional researchers (e.g. Done et al., 2017; Forrester et al., 2015; Holt et al., 2013). Still, there are limits to accessing the data, which are not always well-organised and readily available according to the FAIR (findable, accessible, interoperable, and reusable) data principles (Wilkinson et al., 2016). Also, there is a lack of simple analysis tools and indices to summarise the data and extract relevant information for management purposes at the proper spatial and temporal scales.

This study aims to provide a biotic index to environmental managers and decision-makers – the RCMed species sensitivity (*MedSens*) index, based on open data collected under the Reef Check Mediterranean Underwater Coastal Environment Monitoring (RCMed U-CEM) protocol (www.reefcheckmed.org; Cerrano et al., 2017). The *MedSens* index is not purport to replace detailed studies and the indices applied by professional researchers, such as the Coralligenous Assemblage Index (CAI; Deter et al., 2012), the Coralligenous Assessment by Reef Scape Estimate index (COARSE; Gatti et al., 2015), the Ecological Status of Coralligenous Assemblages index (ESCA; Piazzi et al., 2017), the Index Coralligenous approach (INDEX-COR; Sartoretto et al., 2017), the Standardized Coralligenous Evaluation procedure (STAR; Piazzi et al., 2019), and the 3D-complexity index (Valisano et al., 2019). The *MedSens* index is intended to integrate the assessment of the environmental status of coastal Mediterranean areas threatened by multiple stressors (Micheli et al., 2013) while considering the protected and sensitive species and adhering to the requests of the European Union's Habitat Directive (92/43/EEC) and Marine Strategy Framework Directive (MSFD, 2008/56/EC; Borja et al., 2010). A plugin has been specifically developed for the open-source geographic information system QGIS (QGIS Development Team, 2019), allowing index calculations for the areas and time frames of interest.

2. Materials and methods

2.1. The Reef Check Mediterranean U-CEM protocol

The RCMed volunteers (mainly scuba divers, but also free divers and snorkelers; EcoDivers hereafter) collect data on the abundances of selected taxa according to the U-CEM protocol (Cerrano et al., 2017). After a short training course and the verification of their learning and abilities, EcoDivers can make independent observations along random swim (Hill and Wilkinson, 2004). The taxa were selected from a combination of criteria, including ease of identification and being a key indicator of shifts in the Mediterranean subtidal habitats. Before starting the data recording, each EcoDiver have to choose some of the 43 taxa included in the protocol as search targets, according to the expected habitat typology and personal motivations. This freedom of choice ensures greater attention and accuracy by the participants. The EcoDivers select species based on confidence (thereby reducing identification errors), personal interest (increasing satisfaction), and the number of species they feel able to handle (to reduce psychological stress during dive). However, this generates skewed distribution efforts among the taxa. The most-searched taxa are attractive and iconic species, such as the red coral *Corallium rubrum* and sea fans *Paramuricea clavata* and *Eunicella cavolini*. Less conspicuous but highly concerning species, such as invasive algae in the genus *Caulerpa*, are also frequently surveyed (Cerrano et al., 2017).

EcoDivers record the abundance (using numerical or descriptive classes according to the countability of organisms) and observed depth ranges of the searched taxa, along with the prevalent habitat type. Not encountered but actively searched taxa are recorded as absent. The diving sites are localised by global positioning system (GPS) receivers, nautical charts, or known points (e.g. mooring buoys at MPAs). Geographical coordinates (WGS84) are recorded with ± 6 arc-seconds (i.e. 185 m in latitude) accuracy, the usual distance range explored by EcoDivers.

Recorded observations, including absence, site name, geographic coordinates, date and time, underwater visibility, survey depth range (min and max), and observation effort in terms of time dedicated are uploaded to the online database through an internet form[2] or a dedicated app for Android smartphones ('Reef Check Med' app).

Recorded data are subjected to quality assurance and control (QA/QC) procedures, based on automatic filters (e.g. consistency among survey and observation depth ranges) and on manual checks (e.g. matching between the site name and geographic coordinates), and made freely available on a web-based GIS[3].

2.2. Species sensitivity assessment

The marine evidence-based sensitivity assessment (MarESA; Tyler-Walters et al., 2018) has been conducted for 25 taxa inhabiting the Mediterranean subtidal rocky bottoms, especially the coralligenous habitats (Ingrosso et al., 2018), and included in the RCMed U-CEM protocol (Supporting Information S1: Table S1.1). The species assessment is based on evidence from a literature review, complemented by expert judgement, for the possible effects of physical, chemical, and biological pressures listed in the MSFD Annex III (Supporting Information S1: Table S1.2). For each taxon and pressure, resistance (none, low, medium, high, or not relevant) and resilience ranks (very low, low, medium, high, or not relevant) were assigned according to the MarESA standard benchmarks. The quality and applicability of the evidences were also assessed according to the MarESA principles. The species

[2] https://www.reefcheckmed.org/english/underwater-monitoring-protocol/upload-your-data/

[3] https://www.reefcheckmed.org/english/underwater-monitoring-protocol/webgis-map/

Table 1
Abundance classes and their converted scores (*Sc*).

Numerical class	Descriptive class	*Sc*
0	absent	0
1	isolated specimen	1
2	some scattered specimens	2
3–5	several scattered specimens	3
6–10	a crowded area	4
11–50	some crowded areas	5
>50	several crowded areas	6

sensitivity ranks (not sensitive, low, medium, high) to each pressure were established by combining the resistance and resilience ranks using the MarESA combination table. Species sensitivity ranks were converted to numerical scores (0–3), and the mean sensitivity values toward physical (MSV_{phy}), chemical (MSV_{chem}), and biological (MSV_{bio}) pressures and the overall mean (MSV_{tot}) were calculated.

2.3. Territorial units and time frames

The RCMed U-CEM data are unevenly distributed across space and time because of the preferences and behaviour of the volunteers. To reduce conscious and unconscious bias, the data from several EcoDivers within a defined territorial unit (TU) and time frame (TF) were pooled and analysed together. TUs and TFs should be designed according to the aims of the monitoring and management purposes. For instance, TUs may be the cells of a regular grid over the area of interest, a set of management and monitoring zones within MPAs, or the areas surrounding single dive sites. The minimum TU size depends by the exploration ability of the divers and the positioning accuracy they can achieve (Meidinger et al., 2013). Therefore, the recommended minimum TU size is 0.08 km^2 (e.g. within a 6 arc-second radius). TF may span several months or multiple years, depending on the intensity and scale of the monitoring program.

2.4. RCMed species sensitivity (MedSens) index

The *MedSens* index provides the mean sensitivity of the species assemblages recorded by EcoDivers within a TU and TF. It can be calculated for the physical ($MedSens_{phy}$), chemical ($MedSens_{che}$), biological ($MedSens_{bio}$), and overall pressures ($MedSens_{tot}$) on the species, based on the corresponding mean sensitivity values (*MSV*), weighted for the abundance classes of the taxa. For each observation, the abundance class was converted to an abundance score (*Sc*) of 0 to 6 (Table 1). The index is calculated as:

$$MedSens_x = \Sigma(Sc_i \times MSV_{(x)i})/\Sigma Sc_i$$

where *x* is the chosen pressure typology (*phy*, *che*, *bio*, or *tot*), and $MSV_{(x)i}$ refers to the taxon in the *i*th observation having an abundance score Sc_i in the selected TU and TF. The minimum requirements for the index calculation are: TU size ≥ 0.08 km^2, EcoDivers ≥ 3, number of observations (including absences) ≥ 20, and searched taxa ≥ 10. The index values increase with increasing sensitivity means of the species recorded and, to a lesser extent, with their abundance.

2.5. MedSens index classification

The distribution of values assumed by the index was explored by applying the formula through a 15 arc-second grid (i.e. 1/4 of a nautical mile in latitude) covering the coasts of the Mediterranean Sea and the entire time frame of the available data (2001–2019; last access May 18, 2019). The index values distributions ($MedSens_{phy}$, $MedSens_{che}$, $MedSens_{bio}$, and $MedSens_{tot}$) were compared for homogeneity of variances and differences in the means using Bartlett's test and the analysis of variance (ANOVA), respectively (in both cases, α = 0.05). The index values were classified into 5 classes, from very low to very high sensitivity, via quintiles.

Table 2
Mean sensitivity values of the physical (MSV_{phy}), chemical (MSV_{che}), and biological (MSV_{bio}) pressures, and the overall mean (MSV_{tot}) of the selected taxa.

Taxa	*MSVphy*	*MSVche*	*MSVbio*	*MSVtot*
Caulerpa cylindracea	0.643	0.571	0.333	0.583
Caulerpa taxifolia	0.643	0.571	0.333	0.583
Axinella spp.	1.231	0.714	1.333	1.087
Aplysina spp.	1.538	0.714	1.333	1.261
Geodia cydonium	1.769	1.571	1.667	1.696
Corallium rubrum	2.308	2.333	3.000	2.409
Paramuricea clavata	2.462	2.667	2.750	2.565
Eunicella cavolini	2.462	2.500	2.750	2.522
Eunicella singularis	2.231	2.500	2.500	2.348
Eunicella verrucosa	1.692	2.333	2.750	2.043
Parazoanthus axinellae	1.769	1.833	0.667	1.636
Savalia savaglia	2.385	2.000	2.000	2.217
Cladocora caespitosa	2.154	2.500	2.333	2.273
Astroides calycularis	1.769	2.500	1.000	1.826
Balanophyllia europaea	1.769	2.333	1.333	1.864
Leptopsammia pruvoti	1.692	2.000	1.000	1.682
Pinna nobilis	1.923	1.500	2.750	1.957
Arca noae	1.308	2.167	2.250	1.696
Palinurus elephas	1.214	1.857	2.500	1.600
Homarus gammarus	1.214	1.857	2.750	1.640
Scyllarides latus	1.231	1.857	2.500	1.625
Paracentrotus lividus	1.462	1.429	2.250	1.583
Hippocampus spp.	1.933	1.143	2.250	1.769
Diplodus spp.	1.133	0.714	2.250	1.192
Sciaena umbra	1.267	1.286	2.000	1.385

2.6. MedSens index calculator

To facilitate the application of the *MedSens* index, a plugin for QGIS was developed in Python language and made freely available in the QGIS plugin repository (also linked at the '*MedSens* index' web page[4]). The plugin requires two input datasets in shapefile format (ESRI, 1998), one containing a subset of the data collected using the RCMed U-CEM protocol with the abundances of the 25 assessed taxa (i.e. the open access 'MedSens data' shapefile; Ponti et al., 2020), and a second with polygons representing the TUs of interest. The polygons shapefile may be any file containing one or more enclosed areas ≥ 0.08 km^2. The desired TF can be defined as the starting and ending dates. The output is a new polygons shapefile reporting in the attribute table the values of $MedSens_{phy}$, $MedSens_{che}$, $MedSens_{bio}$, $MedSens_{tot}$, observers, observations, searched taxa and area (km^2) for each assessed area. Colour legends are also provided.

2.7. Case studies

As case studies, the *MedSens* index was calculated for the Mediterranean MPAs reported in the World Database on Protected Areas (WDPA) from UNEP-WCMC and IUCN (2019), and the management and monitoring zones within Italian MPAs, wherever sufficient *MedSens* data were available in the time frame 2001 – 2019. In particular, Italian MPAs are usually organised into management zones with different levels of protection enforcement, as indicated in their management plans and coast guard directives. With some exceptions, A zones (no-entry/no-take areas) allow only scientific activities, B zones (partial protection) allow recreational dives under some circumstances (e.g. a limited number of participants, only guided tours), and C zones (buffer zones) allow dives with no restrictions (Villa et al., 2002).

Used testing polygons shapefiles and their resulting *MedSens*

[4] https://www.reefcheckmed.org/english/underwater-monitoring-protocol/medsens-index/

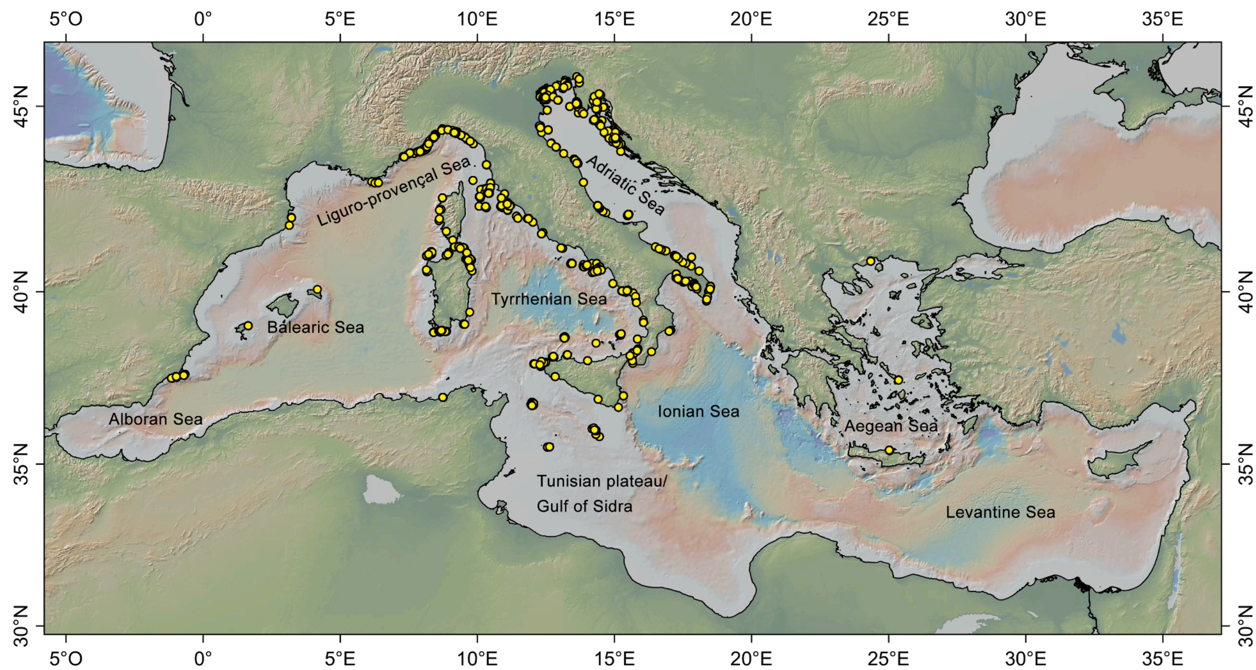

Fig. 1. Geographical distribution of the *MedSens* data points (Ponti et al., 2020). Map is in Mercator projection, datum WGS84.

Table 3
MedSens index classification of the physical, chemical, biological, and overall pressures.

Mean sensitivity	$MedSens_{phy}$	$MedSens_{che}$	$MedSens_{bio}$	$MedSens_{tot}$
Very low	≤1.5106	≤1.4381	≤1.5554	≤1.5305
Low	≤1.6275	≤1.6342	≤1.7908	≤1.6432
Moderate	≤1.7206	≤1.7806	≤1.9168	≤1.7431
High	≤1.8456	≤1.9621	≤2.0594	≤1.8921
Very high	>1.8456	>1.9621	>2.0594	>1.8921

classifications are available at the '*MedSens* index' web page[4].

Possible correlations among *MedSens* index, calculated for different pressure typologies, number of observations, observers, taxa considered, and the size of the investigated areas were analysed by the Pearson correlation coefficient (***r***). Differences of ***r***-values from zero were tested with a *t* distribution (α = 0.05).

3. Results

The details of the evidence-based sensitivity assessment (including references) for the 25 selected taxa are summarised in the Table S2 (Supporting Information S2). The mean sensitivity values are reported in Table 2.

The *MedSens* data shapefile used to classify the *MedSens* index contained 33,021 observations from 569 EcoDivers (Fig. 1; Ponti et al., 2020). The data came from the Croatian, French, Greek, Italian, Spanish, and Tunisian coasts. The *MedSens* index calculation for 15 arc-second grid cells along the Mediterranean coasts resulted in 137 TUs assessed. When calculated for the physical, chemical, biological, and overall pressures, the index value distributions significantly differed for the variances (Bartlett's test: $p = 1.475 \times 10^{-10}$) and means (ANOVA: $p = 2.347 \times 10^{-6}$). This suggests slightly different classification scales for the different pressure types; the 5-class scheme obtained by quintiles is reported in Table 3.

3.1. *MedSens index applied to Mediterranean MPAs*

In October 2019, WDPA reported 1504 MPAs (*sensu lato*) in the Mediterranean Sea. This included many coastal areas characterised by rocky bottoms, but also several wetlands, coastal lagoons, estuaries, and pelagic areas that are unsuitable for the *MedSens* index. Overall, 81 MPAs were assessed by the *MedSens* index, and the results are reported in Table S3.1 (Supporting Information S3). The assessed areas ranged from very small rocky outcrops (e.g. Scoglio dell'Argentarola, 0.15 km^2) to vast marine spaces (e.g. Tabarca-Cabo de Palos, 1262 km^2). The protected areas with the most sensitive species assemblages were located in the southern and central Tyrrhenian Sea (e.g. Isole Egadi, Scoglio dell'Argentarola, Isola di Ustica, Scilla, and Costa Viola) and Ligurian Sea (e.g. Punta Manara). The protected areas with the least sensitive species assemblages were characterised by artificial habitats, such as shipwrecks in Malta and the offshore platform wreck 'Paguro' in the northern Adriatic Sea, whose benthic assemblages are simplified compared to natural rocky bottoms (Ponti et al., 2002, 2015). Low to very low mean species sensitivities were also found at 'Tegnùe di Chioggia', a northern Adriatic no-take zone characterised by mesophotic coralligenous banks. These results are consistent with high anthropic disturbance in the area, including several dystrophic crises (Tomašových et al., 2017; Zuschin and Stachowitsch, 2009) and intense trawling (Melli et al., 2017; Ponti et al., 2011) that may limit the abundance of species sensitive to physical and chemical pressures.

The indices for the different pressures were correlated (Table S3.2, Supporting Information S3). However, there were instances where the classifications differed greatly, particularly between assessments of the chemical and biological pressures. The number of taxa considered was correlated to the number of observations and observers, and the number of observations was correlated to the number of observers, but these parameters did not correlate with the size of the area or the sensitivity of their assemblages.

3.2. *MedSens index applied to Italian MPA management zones*

The *MedSens* index was calculated for 22 management zones belonging to 12 Italian MPAs (Table S3.3, Supporting Information S3). The management zones with the most sensitive species assemblages were in the MPAs Isole Egadi, Tavolara – Punta Coda Cavallo, Isola di Ustica, Punta Campanella, and Portofino. Many A zones were not assessed due to the lack of data; the exceptions being the Cinque Terre,

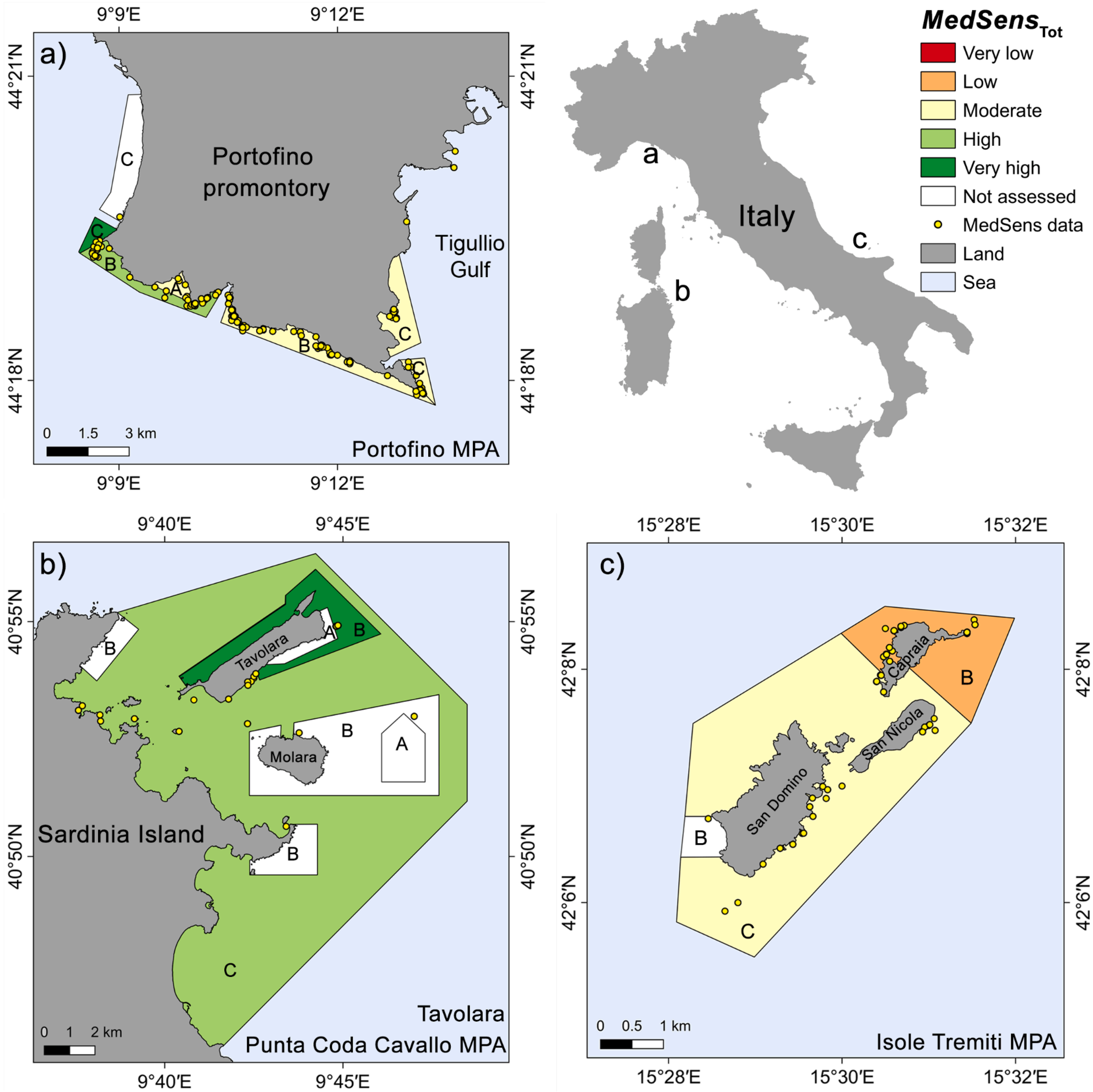

Fig. 2. Examples of sensitivity assessments (*MedSens$_{tot}$* index) applied to MPAs management zones: a) Portofino, b) Tavolara – Punta Coda Cavallo, and c) Isole Tremiti. Yellow dots display *MedSens* data points. Letters indicate protection levels (Mercator projection, WGS84). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Miramare, Isole Egadi, and Portofino MPAs, where data were collected during authorised dives. However, the *MedSens* index did not detect very sensitive assemblages into these A zones. The A zones of Miramare and Isole Egadi are characterised by seagrass meadows and the *MedSens* index may not provide reliable results in these habitats. At Cinque Terre, the non-indigenous algae *Caulerpa cylindracea* has invaded (Bianchi et al., 2019; Montefalcone et al., 2015) and reduced the sensitivity of the assemblages, especially towards biological pressures.

At Portofino MPA (Ligurian Sea, Fig. 2a), the assemblage sensitivities ranged from moderate to very high. Overall, the mean species sensitivities increased in the west and consistently with distance from the Tigullio Gulf, located upstream of the dominant currents (Doglioli et al., 2004). This is the source of the main local physical and chemical pressures due to increasing urbanisation (Mangialajo et al., 2007) and the fluvial transport of sediments and pollutants (Mateos-Molina et al., 2015).

At Tavolara – Punta Coda Cavallo MPA (northern Tyrrhenian Sea, Fig. 2b), the assemblage sensitivities ranged from high to very high. This is consistent with limited anthropic impacts in a well-managed MPA (Bianchi et al., 2012). Pressure gradients cannot be uniquely defined in this area, but the B zone performed better than the C zone in terms of assemblage sensitivity, as expected from the management and conservation plan.

At the Isole Tremiti MPA (central Adriatic Sea, Fig. 2c), the assemblage sensitivities ranged from low to moderate. The B zone had the lowest mean species sensitivity, especially for biological pressures. This may be related to a decline in the algal assemblages due to increasing pollution (Cormaci and Furnari, 1999) and the growing number of non-indigenous species, such the invasive algae *Womersleyella setacea* (Cormaci et al., 2000) and *C. cylindracea* (Pierucci et al., 2019).

The *MedSens* index may allow even more detailed analysis. The Portofino MPA can be further subdivided into 19 monitoring zones, as designated by the MPA authority. The *MedSens* index revealed that some zones have less-sensitive assemblages than others, which may help to

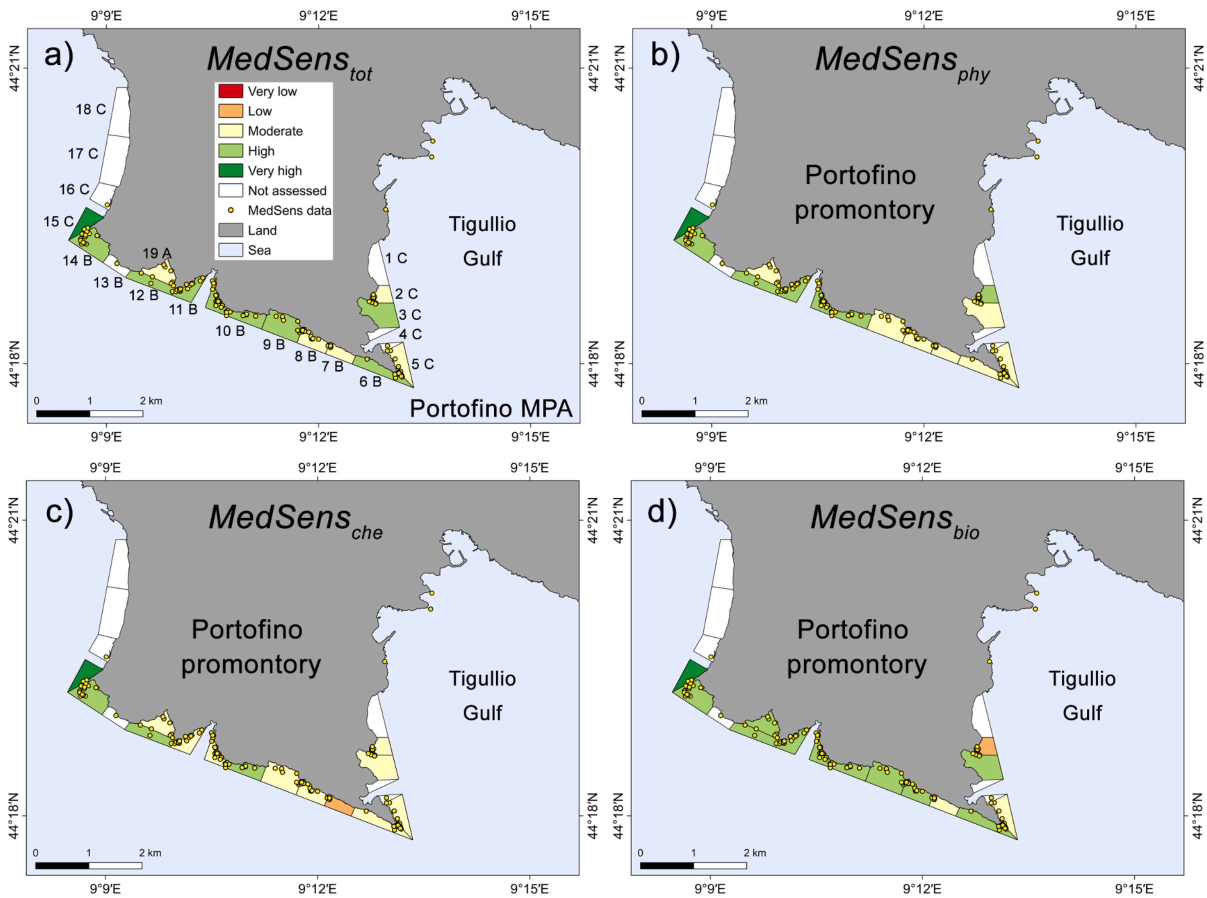

Fig. 3. Sensitivity assessments in the Portofino MPA monitoring zones (from 1 to 19) for the: a) overall assessment (*MedSens*$_{tot}$), b) physical pressures (*MedSens*$_{phy}$), c) chemical pressures (*MedSens*$_{che}$), and d) biological pressures (*MedSens*$_{bio}$). Yellow dots display *MedSens* data points. Letters indicate protection levels (Mercator projection, WGS84). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

identify local pressures and fine-tune the adaptive management actions (Fig. 3). The south-east side (zones 3–9), in particular, appeared less sensitive to physical disturbances (Fig. 3b), possibly resulting from exposure to sedimentation and water turbidity from the Tigullio Gulf (Mateos-Molina et al., 2015). These zones are also most affected by the mass mortality of gorgonians and other organisms that have frequently occurred since 1999 (Cerrano et al., 2000) and by recreational and artisanal fishing activities (Markantonatou et al., 2014). The results from zones 7 and 2 suggest that the management authorities should develop tailored strategies for their species assemblages that are less sensitive to chemical and biological pressures, respectively (Fig. 3c and d).

3.3. Changes in the MedSens index over time

The *MedSens* index can be calculated for specific time frames (TF). As an example, changes in the mean assemblage sensitivity at Gallinara Island (Ligurian Sea; 44° 1.400′ N 8° 13.700′ E) were analysed annually from 2006 to 2018 (except 2011 due to a lack of data). The assemblages showed very low to moderate sensitivity along the whole study period (Fig. 4a). This result is consistent with the impoverishment of benthic assemblages that occurred after increases in human disturbance since the 1990s and the failure to establish a planned MPA (Bianchi et al., 2018). The mean sensitivity to biological pressures was very low due to the invasion of *C. cylindracea* in 2005 (Cerrano et al., 2017). In 2016, there was an increase in species mean sensitivity, especially to the chemical and physical pressures. However, in the following two years, there was a new decline, likely due to the heatwaves of 2017 and 2018 (Garrabou et al., 2019).

Another case study is represented by the mass mortality of the gorgonian *Paramuricea clavata* at Secca del Papa, Tavolara Island (northern Tyrrhenian Sea; 40° 54.910′ N 9° 44.840′ E) in the late summer 2008 heatwave (Huete-Stauffer et al., 2011). Data collected in 2007, before the crisis, showed a very high mean sensitivity of the assemblages, especially to the chemical and physical pressures (Fig. 4b). Data collected between 2015 and 2017 (after the crisis) indicated a drastic reduction in the sensitivity of the assemblages. Indeed, the loss of *P. clavata* may affect the structure of benthic communities (Ponti et al., 2014, 2018). However, the sensitivity to biological pressures was consistently moderate before and after the crisis.

4. Discussion

4.1. The success of MedSens

The United Nations Decade of Ocean Science for Sustainable Development Goals 2021–2030 (SDG 14, Life Below Water) asks for an urgent improvement of the capacity of marine conservation actions worldwide, and MCS is a promising and powerful tool to enhance engagement in marine conservation worldwide. Following the ten principles of the Citizen Science (Kelly et al., 2020), the RCMed U-CEM open access dataset allows for various uses, e.g. to complement scientific papers on species distribution and abundance, aid distribution modelling, and compare historical series (Lucrezi et al., 2018 and references therein). The *MedSens* index, being based on this dataset, represents a bridge between MCS and coastal management in the Mediterranean Sea,

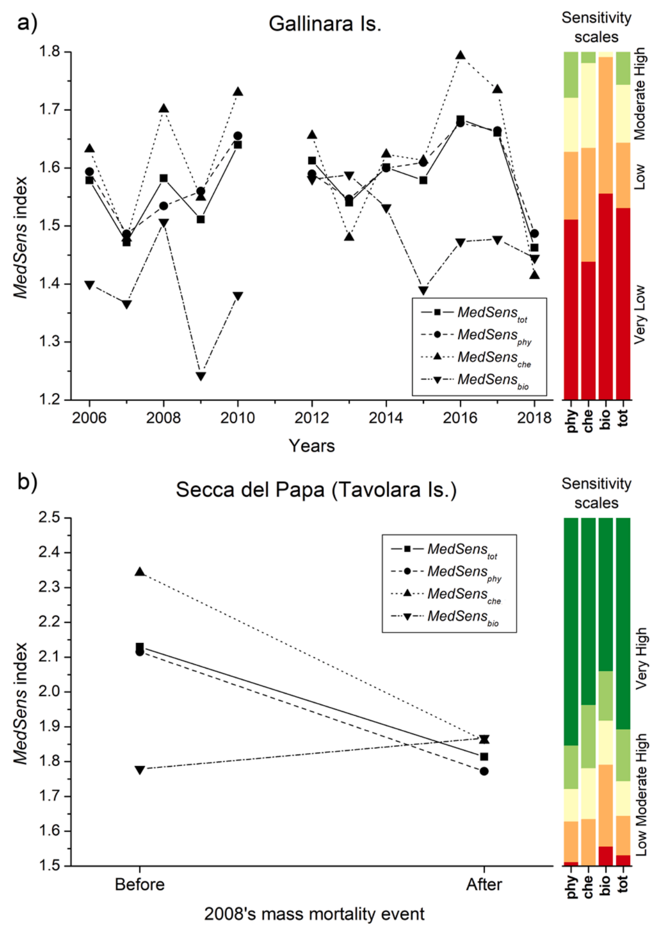

Fig. 4. Temporal change in the *MedSens* index at: a) Gallinara Island from 2006 to 2018 and b) Secca del Papa, Tavolara Island before and after the 2008 mass mortality of *Paramuricea clavata*.

allowing the effective integration of a consolidated community-based environmental monitoring into ecosystem-based management policies. It provides a proxy of the mean sensitivity of the rocky bottom assemblages to natural and anthropic pressures listed by MSFD. Higher average assemblage sensitivities are associated with lower levels of disturbance, thereby indicating good environmental conditions.

The *MedSens* index was calibrated on a large dataset of wide-ranging conditions occurring along the Mediterranean Sea coasts. Case studies showed that the index responds well to the local pressures documented by previous studies. The *MedSens* index may also be applied in a wide range of circumstances; it is particularly suitable for monitoring MPAs and can aid spatial gradients analysis, time series analysis, and before/after-control/impact studies. Moreover, the newly developed QGIS plugin provides an easy freeware tool to calculate the index whenever data are available.

MedSens is a biotic index based on the sensitivities and tolerances of the species to pollution and/or other disturbance sources (for a review see Ponti et al., 2009). Other indices based on a similar approach for the Mediterranean benthic communities include the AZTI' Marine Biotic Index, AMBI (Borja et al., 2000), for soft bottoms, and the Ecological Status of Coralligenous Assemblages index, ESCA (Piazzi et al., 2017), for rocky bottoms. These indices are based on the assumption that sensitive species decrease in abundance and number as the pressures increase, leaving space for the more tolerant species (Hilsenhoff, 1987). While the high abundance of a sensitive species is likely witness of reduced pressures, the high abundance of tolerant species is not necessarily related to poor environmental conditions – this should be considered when interpreting the results. The main strengths of the *MedSens* index are that the sensitivities of the selected species in a wide range of taxonomic groups and biological and ecological features are based on scientific evidence and that these sensitivities were assessed according to the different pressure types. This can help discriminate against local pressures that are likely to act in an area. Conversely, the main weaknesses lie in the reduced number of considered species, which could be increased in the future, and the need for large amounts of data from many well-trained volunteers.

The success of a CS project stems from simple and effective protocols (Bonney et al., 2009; Holt et al., 2013), developed by scientists to include particular aims, proper training and skills assessment of the participants, and timely feedbacks on the progress and efficacy of the participants' actions to keep high their involvement (Devictor et al., 2010). The RCMed U-CEM protocol is a simple but effective visual census, with easy-to-monitor species that encompass the key ecological aspects of the Mediterranean subtidal habitats (Cerrano et al., 2017). This protocol is easy to learn and may provide a large amount of timely, up-to-date geo-referred data, from the Mediterranean Sea coasts. Data quality is assured by rigours participant training (subject to learning tests), numerous surveys by independent observers, and quality control measures.

4.2. Future perspectives

The population of European divers is over 3 million people (data from the European Underwater Federation[5]), many of whom dive in the Mediterranean Sea. The Mediterranean Sea has about 23,000 km of rocky coasts (Furlani et al., 2014) and more than 7000 km^2 of subtidal rocks and biogenic reefs in the scuba diving depth range (EMODnet broad-scale seabed habitat map for Europe, v2019[6]). With the *MedSens* index, volunteers applying the RCMed U-CEM protocol can support researchers and managers to collect and interpret data over larger spatial and temporal scales than would otherwise be possible.

The *MedSens* index provides a free, complementary to professional investigations, and user-friendly tool to evaluate the ecological quality of the Mediterranean subtidal rocky habitats according to the Habitat Directive and the MSFD requirements. This will also help decision-makers as they plan and apply conservation strategies. The *MedSens* index offers a detailed picture of the vulnerability levels of different coasts, allowing tailored measures of conservation in an adaptive management framework. Moreover, this index can enable more opportunities for effective feedback to volunteers involved in the RCMed U-CEM protocol. The *MedSens* index application may represent a way to raise public awareness and enhance the collaboration between coastal management authorities, stakeholders, and researchers. By directly involving stakeholders, the *MedSens* index increases the acceptability of management decisions, including unpopular ones, as they may occur in MPAs where fragile sites and restoration areas are closed to the public.

The RCMed U-CEM protocol and *MedSens* index may also complement ocean observation systems and oceanographic forecast models, helping to develop an early-warning system for mass mortality events in benthic species along the Mediterranean Sea coasts (Turicchia et al., 2018). Thus, their combined application provides an effective strategy to achieve the habitat and species conservation objectives set by the European Union (Borja et al., 2010) and the Mediterranean Regional Activity Centre for Specially Protected Areas (UNEP-MAP-SPA/RAC, 2017).

The *MedSens* index was designed for the Mediterranean subtidal rocky bottoms, but its approach may be applied to other habitats, from temperate to tropical reefs, by including the relevant local species, with appropriate calibration and validation.

5 https://www.euf.eu

6 https://www.emodnet-seabedhabitats.eu

5. Authors' contributions

MP conceived the ideas and designed the methodology; ET conducted the evidence-based species sensitivity assessments; MG developed the *MedSens* plugin; ET and MP analysed the data; ET and MP wrote the manuscript. All authors contributed to earlier drafts and approved the final version.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank EcoDivers and their trainers. The following MPAs supported the training of EcoDivers and promoted data collection: Capo Gallo – Isola delle Femmine, Cinque Terre, Isola di Ustica, Isole Egadi, Isole Tremiti, Miramare, Porto Cesareo, Portofino, Tavolara – Capo Coda Cavallo. This study is part of ET's PhD. ET benefited from a EuroMarine Young Scientist Fellowship by OYSTER group. The authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2020.107296.

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