frontiers | Frontiers in Marine Science

TYPE Review
PUBLISHED 27 September 2023
DOI 10.3389/fmars.2023.1252969

OPEN ACCESS

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RECEIVED 04 July 2023
ACCEPTED 30 August 2023
PUBLISHED 27 September 2023

CITATION
Di Camillo CG, Ponti M, Storari A, Scarpa C, Roveta C, Pulido Mantas T, Coppari M and Cerrano C (2023) Review of the indexes to assess the ecological quality of coralligenous reefs: towards a unified approach. *Front. Mar. Sci.* 10:1252969. doi: 10.3389/fmars.2023.1252969

Review of the indexes to assess the ecological quality of coralligenous reefs: towards a unified approach

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There is an urgent need to better understand the stressors, namely heatwaves, changes in thermohaline circulation and mucilage events, that are rapidly re-shaping bioconstructions, such as coralligenous assemblages. This calls for increased monitoring efforts in these invaluable habitats that will improve our understanding of the resistance and resilience of bioconstructions. Since 2009, 16 indexes have been designed to assess the ecological quality of Mediterranean coralligenous reefs. The main objective of this work is to propose a framework to support the development of a shared, cost-effective, and practical index to assess the status of the coralligenous biocenosis. To achieve this, studies conceiving these 16 indexes were reviewed: comparing their objectives, metrics, and applied methodologies. A standardized nomenclature of anthropogenic pressures is supplied, using, when possible, definitions from the European Habitat Directive, Marine Strategy Framework Directive and Water Framework Directive. Additionally, given the unprecedented climatic conditions, we highlight that a common index should give particular attention to the response of the coralligenous to thermal stress and mucilage. A list of priority anthropogenic pressures/environmental stressors and relative indicators and metrics are suggested. This review stresses the urgency to align the methodologies at basin scale and highlights the pros and cons of the preexisting indexes that must be considered in the design of a new, shared procedure to evaluate the status of coralligenous assemblages.

KEYWORDS

mesophotic, temperate seas, bioconstructions, biogenic reefs, environmental status, Mediterranean

1 Introduction

Coralligenous reefs are one of the most diversified biogenic habitat typologies in the Mediterranean Sea that depend on a fragile equilibrium between bioconstruction and bioerosion and other physical processes (UNE/MAP, 2017). They create a mosaic of unique seascapes supporting over 1600 species (Ballesteros, 2006; Bertolino et al., 2013), providing valuable ecosystem services such as food and bioactive compounds, and an attraction for scuba diving (Ballesteros, 2006; Chimienti et al., 2017). Coralligenous concretions are produced by the slow accumulation of encrusting algal thalli and by calcareous animal skeletons (Ingrosso et al., 2018; Casoli et al., 2020). They reach the highest degree of complexity when covered with large, long-living organisms such as gorgonians (Gómez-Gras et al., 2021) which allow the consolidation of a rich and diversified understorey (Ponti et al., 2018) and the establishment of coevolutionary relationships among organisms (Ponti et al., 2016; Cerrano et al., 2019).

The synergistic effects of mechanical damage (e.g., fishing activities, lost fishing gear, anchoring, scuba diving; Di Franco et al., 2009; Linares et al., 2012; Ferrigno et al., 2018), heatwaves and consequent mass mortality events (Cerrano et al., 2000; Garrabou et al., 2009; Garrabou et al., 2022a), pollution and eutrophication (Danovaro et al., 2009), are leading to the depletion of habitat-formers and to a general over-simplification of the coralligenous three-dimensional architecture (Rossi, 2013; Cerrano et al., 2019), with consequent loss in biodiversity, ecosystem functions and aesthetic value (Gómez-Gras et al., 2021).

According to the Marine Strategy Framework Directive (MSFD, 2008/56/EC) and the Action Plan for the conservation of the coralligenous and other calcareous bio-concretions in the Mediterranean Sea (UNEP-MAP-RAC/SPA, 2017), the scientific community has been developing biotic indexes to assess the coralligenous environmental quality status (Bavestrello et al., 2016). These will help verify to what extent the habitat is providing its services, and to identify the need to take action to limit a shift in habitat functional identity (Gómez-Gras et al., 2021).

Since 2009, at least 16 indexes have been designed (Table 1), but none of them have been officially adopted by the Regional Activity Centre for Specially Protected Areas (RAC/SPA) to estimate the quality of the coralligenous habitats. The main objective of this work is to propose a framework to orient the scientific community towards the development of a shared, cost-effective and practical index to assess the status of the coralligenous biocenosis.

We reviewed the studies conceiving these indexes, comparing their objectives, metrics and applied methodologies to:

- detect the most suitable sampling methodologies for data collection on the repercussions of pressures/stressors on the three-dimensional architecture of the coralligenous habitats;
- highlight major issues hindering the creation of a common approach to assess the ecological quality of coralligenous habitats;
- supply a list of priority anthropic pressures/environmental stressors, indicators, and metrics as a starting point to forge a common index;
- standardize nomenclature of anthropogenic pressures using, when possible, definitions from main European Directives on marine conservation;
- supply a process flow summarizing steps towards the consolidation of a multimetric biotic index to assess the quality of coralligenous in the Mediterranean Sea.

2 Methods

To retrieve papers about indexes designed to estimate the quality of coralligenous habitats, a literature search was conducted on the Web of Science (WoS) platform. The search was carried out using the string "Mediterranean AND coralligenous AND (index OR indexes OR indices)" in all the fields of the WoS Core Collection (last search 20/04/2023). In the first web-search, 60 documents were found. After screening the retrieved documents, by reading titles and abstracts, 23 papers were retained and considered relevant for this review. Five more articles (Di Franco et al., 2009; David et al., 2014; Rastorgueff et al., 2015; Paoli et al., 2016; Gennaro et al., 2020) were added after checking reference lists within the retrieved articles. The papers cover the development and implementation of 16 distinct indexes. For comparative purposes, the objectives, methodologies, considered pressures, and main characteristics of each analyzed index are detailed in Table 1 and summarized in Table 2.

TABLE 1 Summary of indexes (in chronological order) to assess the ecological status of coralligenous reefs.

Index and references	Aim	Targets	Metrics	Sampling method and study area	Pressures/ Stressors
STVI (Scuba Trail Vulnerability Index) (Di Franco et al., 2009)	Definition of an index of vulnerability for dive trails within a Mediterranean MPA, considering benthic assemblages and environmental features of the area	Porifera (*Phorbas tenacior*, *Spirastrella cunctractix*), Bryozoa (*Myriapora truncata*, *Pentapora fascialis*, *Sertella* spp.), Cnidaria (*Astroides calycularis*, *Paramuricea clavata*, *Eunicella* spp., *Parazoanthus*	Percent cover of vulnerable taxa, consideration of biological traits (height from the substrate, organism shape, exposure), rock type, presence of suspended sediment, breakage resistance, growth rate, presence of permanent fish. Five vulnerability classes established.	Visual census in 1m x 1m quadrats along 100m transects (subdivided in 20 subtransects 5 m long). Interviews to owners of diving centers	PF05 (Diving activity)

(Continued)

TABLE 1 Continued

Index and references	Aim	Targets	Metrics	Sampling method and study area	Pressures/ Stressors
		axinellae), Fish (*Ephinephelus*)			
CAI (Coralligenous Assemblage Index) (Deter et al., 2012; Marre et al., 2020)	Assessment of the ecological quality of coralligenous communities. The index is linked to anthropic pressure affecting water quality.	Builders (bryozoans, scleractinians, *Miniacina miniacea* and coralline species), bryozoans	Percent cover of sludge, builders and bryozoans. (Tested but not used: density and height of gorgonians)	*Percent cover*: photographic quadrats (50×50 cm), n. 30 photoquadrats per site along a 40 m-long transect	PA17 (Agriculture), PF15 (Infrastructures), PK02 (water pollution), PF10 (Plastic pollution), PG19 (Aquaculture)
CavEBQI (Cave Ecosystem-Based Quality Index) (Rastorgueff et al., 2015; Boudouresque et al., 2020)	Assessment of the ecological quality of undersea caves considering the ecological status of each component (targets 1-7) of the cave ecosystem (very bad (0), bad (1), moderate (2), good (3), very good (4)) together with the component's weight (i.e., its importance in determining the structure and functioning of the cave ecosystem)	1.Passive filter-feeders, 2. large and 3. small active filter-feeders, 1,2,3. sessile filter feeders, 4. detritus feeders and omnivores, 5. cave-dwelling mysids, 6. characteristic carnivores, 7. associated carnivores	1-3. percent cover; 1,2,3. volumetric stratification (from 0 to 4); 4. α-diversity, density, 5. semi-quantitative abundance; 6. teleost and decapod species richness; 7. teleost and decapod species richness, anemone semi-quantitative abundance	*Percent cover:* Photo sampling in an area of 1-4 m^2; *Volume* stratification: visual assessment in an area of 1-4 m^2; *α-diversity and semi-quantitative abundance*: visual census in the entire cave (or at the entrance for anemones); Density: n. ind. in a 5 min survey;	Not specified
ESCA (Ecological Status of Coralligenous Assemblages) (Cecchi et al., 2014; Piazzi et al., 2015; 2017a, b, 2021a, 2022; Penna et al., 2018)	Assessment of the ecological status of coralligenous assemblages through the analysis of deep macroalgae in relation to water quality	Macroalgae (*Halimeda tuna, Flabellia petiolata, Palmophyllum crissum, Pseudochlodesmis furcellata, Peyssonnelia* spp., *Zanardinia typus*). morphological groups: Algal turf, Erect corticated terete algae, Flattened Rhodophyta with cortication, encrusting Corallinales	Overall Sensitivity Level (SL) of a sample (the SL of each taxon/ group is obtained by multiplying its sensitivity value per its class of abundance (percent cover)), n. of species per sample (α-diversity), heterogeneity of assemblages (β-diversity)	Photographic sampling (30 photos taken in each area with a 50 cm × 37.5 cm frame) to calculate percentage cover of macroalgae	PA17 (Agriculture), PK02 (Water pollution), PF10 (Plastic pollution), PI02 (Invasive species), SED (Sedimentation)
ESCA-TA (ESCA Total Assemblage) (Piazzi et al., 2017a, b; 2021a)	Assessment of the ecological status of coralligenous assemblages through the analysis of deep macroalgae and sessile invertebrates in relation to water quality	36 targets among specific taxa and morphological groups including both macroalgae and macroinvertebrates	Overall Sensitivity Level (SL) of a sample (the SL of each taxon/ group is obtained by multiplying its sensitivity value per its class of abundance (percent cover)), n. of species per sample (α-diversity), heterogeneity of assemblages (β-diversity)	Photographic samplings: 10 photo samples of 0.2 m^2 conducted in each of three areas of 4 m^2 included in two areas of about 100 m^2	PA17 (Agriculture), PK02 (Water pollution), PF10 (Plastic pollution), PI02 (Invasive species), ALDFG (Fishing gears), PE02 (Shipping, anchoring), PF05 (Diving activity), SED (Sedimentation), PJ01 (Thermal stress)
COARSE index (COralligenous Assessment by ReefScape Estimate) (Gatti et al., 2015; Piazzi et al., 2017b)	Characterization and evaluation of the integrity of the coralligenous stratified structure composed of three layers (basal, intermediate, lower)	Taxa present in the *basal* (encrusting organisms), *intermediate* (organisms with a moderate vertical growth) and *upper* (organisms with considerable vertical growth) layers of the	**Geomorphologic characterization** to individuate shoals, outcrops, cliffs, landslide deposits, and detritic bottoms; **Mesologic characterization:** depth, elevation from the bottom, slope, exposure; **Bionomic characterization.** *Basal layer*: Percent cover of benthic categories, semi-	*Rapid Visual Assessment* (RVA for a total of 63 replicates of about 1.5m^2 each); visual estimation of percent cover of benthic organisms; six photographs randomly collected without a frame to identify species of the intermediate level; measurement of the height of	PF15 (Infrastructures), PK02 (Water pollution), PF10 (Plastic pollution), PF05 (Diving activity), SED (Sedimentation)

(Continued)

TABLE 1 Continued

Index and references	Aim	Targets	Metrics	Sampling method and study area	Pressures/ Stressors
		coralligenous concretions	quantitative assessment of boring species (common, occasional, absent), thickness and consistency of the calcareous layer; *intermediate layer:* list of species; *upper layer:* species coverage, height of tallest specimens, percentage of necrosis	taller organisms and determination of the thickness (mm) of the calcareous layer with a penetrometer.	
MAES (Mesophotic Assemblages Ecological Status) and q-MAES (quick MAES) (Cánovas-Molina et al., 2016)	Assessment of the ecological status of mesophotic megabenthic assemblages to test its sensitivity to different levels of human disturbance over a wide geographic area	Several taxa (both encrusting and erect species)	1. Community structure: number of taxa, percent of the biotic cover in the basal layer, density of erect megabenthic species; 2. dominant erect species condition: average height, percent of colonies with epibiosis/necrosis; 3. human impacts: density of litter/lost fishing gear (species height and necrosis were not considered in q-MAES)	Remotely Operated Vehicles (ROV) surveys, 500 m long video-transects; ROV was kept at 1 m height from the seabed	ALDFG (Fishing gears), PF10 (Plastic pollution), PH08 (Macro litter)
OCI (Overall Complexity Index) (Paoli et al., 2016)	Development of a synthetic measure of ecosystem complexity that includes four complexity indices (Structural-, functional-, extensive- and intensive complexity)	*Posidonia* meadows, facies of: *Posidonia* dead matte, large bryozoan, *Paramuricea clavata*; associations: *Cymodocea*, *Jania-Laurencia*, *Stypocaulon*, sciaphilic algae; biocenosis of: terrigenous muds, biodetrics, coralligenous, fine sands, sand-gravel, pebbles	Structural complexity is measured as the thermodynamic distance from the equilibrium in genetic and evolutionary terms (thermodynamic metrics: exergy and specific exergy); Functional complexity is evaluated as quantity and efficiency of energy exchanges among different compartments (intensive metrics: throughput and information)	Structural complexity is measured by means of exergy and specific exergy; functional complexity by means of throughput and information. Information regarding biomass per unit area of each taxonomic group has been obtained from the literature	Not specified
CBQI (Coralligenous Bioconstructions Quality Index) (Ferrigno et al., 2017; Apolloni et al., 2020; Piazzi et al., 2022)	Evaluation of the quality status of different types of coralligenous bioconstructions through an easily and rapidly applicable method	32 morphological groups (including fish)	Coralligenous structuring (coralligenous percent cover, % morphological groups, fan coral density); coralligenous stress (% necrosis/epibiosis, entanglement, Lost Fishing Gear (LFG)); bottom abiotic factors (depth, slope, substrate type)	Remotely Operated Vehicles (ROV) surveys	ALDFG (Fishing gears), PG11 (Illegal collection)
INDEX-COR (David et al., 2014; Sartoretto et al., 2017)	Evaluation of the ecological status of coralligenous habitats, through an easily and rapidly applicable method	160 sessile and vagile species (algae, foraminifera, sponges, bryozoans, cnidarians, platyhelminth, annelid polychaeta, echiurans, mollusks, echinoderms, crustaceans and ascidians)	**Metrics**: Ratio between Sensitive and Tolerant Species (RSTS); Observable Taxonomic Richness (OTR); (Structural Complexity (SC). **SC sub-metrics:** (i) percentage of species belonging to the basal layer, (ii) number of species belonging to the intermediate layer and (iii) observations on the species belonging to the upper layer with a classification within 5 classes of density.	Photographic sampling (15 photos per transect along two transects (15 m) with a 60x40cm quadrat frame, video survey, *in situ* observation	PK02 (Water pollution), PF10 (Plastic pollution), PG11 (Illegal collection), PE02 (Shipping, anchoring), PF05 (Diving activity)
ISLA - Integrated Sensitivity Level of coralligenous	Integration of the Disturbance Sensitivity Level (DSL) and Stress Sensitivity Level (SSL)	51 taxa/morphological groups	Biological traits (growth forms, growth rates, bioconstruction potential…) to determine sensitivity to disturbance; stress	Photographic sampling. Determination of percent cover of conspicuous taxa/ morphological groups	ALDFG (Fishing gears), PH08

(Continued)

TABLE 1 Continued

Index and references	Aim	Targets	Metrics	Sampling method and study area	Pressures/ Stressors
Assemblages (Montefalcone et al., 2017)	indexes to measure changes in the coralligenous assemblages in both space and time		sensitivity level; abundance of target taxa (percent cover)		
Index of 3D - Structural Complexity (Valisano et al., 2019)	Definition of different levels of architectural complexity for the coralligenous and evaluation of its 3D architectural complexity	28 phytobenthic and 97 zoobenthic taxa aggregated in 6 Structural Descriptors (SD): α: Nude Substratum (NS), β: non-Crustose Coralline Algae (nCCA), γ: Crustose Coralline Algae (CCA), δ: Encrusting/basal fauna (EPI I), ϵ: Massive Epibenthic fauna (EPI II), ζ: Branching Epibenthic fauna (EPI III).	Percent cover of Structural Descriptors (d=sum of covering of each taxon of the SD/total covering of the community). A score was attributed to 6 classes of abundance. Also considered: nature of the substratum, frequency of anthropic damage (fishing lines/nets), entity of damage on colonies (percentage of necrosis/epibiosis).	10-meter long and 1m width video – transect	ALDFG (Fishing gears), PE02 (Shipping), PJ01 (Thermal stress)
STAR - STAndaRdized coralligenous evaluation procedure (Piazzi et al., 2019a, b, Gennaro et al., 2020)	Approach using existing indexes in a standardized method to assess the ecological quality of the coralligenous habitat	36 taxa/morphological groups	Stress sensitivity level attributed to each taxon/group; abundance of target taxa (percent cover), α-diversity, β-diversity, thickness of the calcareous layer, size (mean height) and percentage of damaged colonies, necrosis and epibiosis, percentage cover of sediment	Photo survey (three areas of 4 m^2 surface tens of meters apart with a minimum of 10 replicated samples of 0.2 m^2 at each area, for a total sampling surface of 6 m^2), RVA	Not specified
MACS - Mesophotic Assemblages Conservation Status (Enrichetti et al., 2019; Moccia et al., 2021)	Integration of Index of Status (I_s) and Index of Impact (I_i) to evaluate and monitor the environmental status of mesophotic temperate reefs	13 taxa	**Index of Status (I_s):** species richness, basal bio-cover, coralline algae cover, dominance, structuring species density, structuring species height. **Index of Impact (I_i):** sedimentation, entanglement, necrosis, epibiosis, litter density, litter type	Remotely Operated Vehicles (ROV) surveys, at least 200 m long x 0.5 m wide video-transects, 100 m^2 covered for each transect, 42 transects in total	PE02 (Shipping), PK02 (Water pollution), PF10, (Plastic pollution), PG01, PH08, ALDFG (Fishing gears), SED (Sedimentation)
MedSens sensitivity index (Turicchia et al., 2021a, b)	Mean sensitivity of the species assemblages from subtidal rocky coastal habitats in defined territorial units and time frames by analyzing data recorded through Citizen Science	25 taxa	Sensitivity level of target taxa towards Physical, chemical, biological pressures	Data collected by trained volunteers following the RCMed U-CEM Protocol (data on the abundance, and geographical and bathymetric distribution of selected taxa)	ALDFG (Fishing gears), PA17 (Agriculture), PK02 (Water pollution), PF10 (Plastic pollution), PG01 (Overexploitation), PG11 (Illegal collection), PG19 (Aquaculture), PK02 (Water pollution)
NAMBER (Piazzi et al., 2023)	Assessment of the ecological quality of mesophotic biogenic reefs in the northern Adriatic Sea	macrobenthic sessile species groped in 31 morpho-ecological groups	Combination of: percentage cover of crustose coralline algae degree of bioconstruction, α-diversity, mean sensitivity level of macrobenthic sessile species groped in 31 morpho-ecological groups; α-diversity	Photo survey (10 replicated samples of 0.06 m^2, for a total sampling surface of 0.6 m^2)	Not specified

Besides the study first proposing the index, relative publications from the same Authors were mentioned. Acronyms of anthropic pressures/environmental stressors were attributed accordingly to European environmental Directives and detailed in Table 3.
Bold text has been used to emphasize relevant terms and to facilitate their search in the text.

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TABLE 2 Comparison of the underwater scientific methodologies applied by the considered studies to collect data and the components (i. e., metrics and parameters useful to obtain metrics, such as abundance) to compute each index.

Underwater methodologies	CAI	ESCA/ ESCA TA	ISLA	STVI	MedSens	3D - SC	CBQI	CavEBQI	MAES	INDEX-COR	MACS	COARSE	STAR	NAMBER	OCI
SCUBA/CCUBA*	■	■	■	■	■	■		■		■		■	■	■	
ROV							■		■		■				
Visual census/RVA				■	■			■		■		■	■		
Photo surveys	■	■	■					■	■	■	■	■	■	■	
Video surveys						■	■		■	■	■				
in situ measurements/estimations								■				■	■		
Components	**CAI**	**ESCA/ ESCA TA**	**ISLA**	**STVI**	**MedSens**	**3D - SC**	**CBQI**	**CavEBQI**	**MAES**	**INDEX-COR**	**MACS**	**COARSE**	**STAR**	**NAMBER**	**OCI**
% cover	■	■	■			■	■	■	■	■	■	■	■	■	
α-diversity/species richness		■					■	■	■	■	■	■	■	■	
% epibiosis/ necrosis/entanglement						■	■		■		■	■	■		
Stratification/3D complexity			■			■		■		■		■	■		
Colony height				■					■		■	■	■		
% sediment	■			■		■					■		■		
Density								■	■	■	■				
Bottom abiotic factors (depth, slope, substrate)				■		■	■					■			
Litter/fishing gears						■	■		■		■				
Biological traits (growth forms, growth rates, bioconstruction potential)			■	■								■			
Sensitivity level			■		■								■	■	
Semi-quantitative abundance					■			■				■			
β-diversity		■											■		
Breakage resistance				■											
Sensitivity		■													
RSTS**										■					
% damaged colonies													■		
Dominance											■				
Extensive metrics															■
Intensive metrics															■

*Self-contained (SCUBA) and closed-circuit underwater breathing apparatus (CCUBA).

TABLE 3 List of main anthropogenic pressures/environmental stressors on the coralligenous habitat and eventual corresponding descriptions/codes from the main environmental EU Directives according to the Article 17 report formats of the Habitats Directive (https://cdr.eionet.europa.eu/help/habitats_art17 last updated: 24/01/2023).

Anthropogenic pressures on the coralligenous habitat		Pressure definitions according to EU Directives			
Pressure	Code	Code	Habitat Directive	Marine Strategy Framework Directive	Water Framework Directive
Illegal species collection (corals, bivalves)	PG11	**PG11**	Illegal shooting/killing	Impaction of living resources, or mortality/injury to, wild species (by commercial and recreational fishing and other activities (**PresBioExtractSps**)	–
Overexploitation of wild species	PG01	**PG01**	Marine fish and shellfish harvesting causing reduction of species/prey populations and disturbance of species (professional)	Impaction of living resources, or mortality/injury to, wild species (by commercial and recreational fishing and other activities (**PresBioExtractSps**)	–
Invasive alien/native species	PI02	**PI02**	Other invasive alien species (other than species of Union concern)	Input or spread of non-indigenous species (**PresBioIntroNIS**);	5.1 – Introduced species and diseases (Transport, Fisheries and aquaculture, Tourism and recreation)
Abandoned, lost or otherwise discarded fishing gear	ALDFG*	**PG13**	Bycatch and incidental killing (due to fishing and hunting activities)	Physical disturbance to seabed (temporary or reversible) (**PresPhyDisturbSeabed**); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate) (**PresPhyLoss**); Changes to hydrological conditions (**PresPhyHydroCond**)	–
Other macro seafloor litter due to illegal sea dumping or accidental loss of boat equipment	PH08	**PH08**	Other human intrusions and disturbance not mentioned above	–	5.3 – Litter or fly tipping (Transport, Urban development)
Plastic pollution	PF10	**PF10**	Residential, commercial and industrial activities and structures generating marine pollution	Substances, litter and energy: Input of litter (solid waste matter, including micro-sized litter) (**PresInputLitter**)	5.3 – Litter or fly tipping (Urban development)
Pollution (excluded plastic pollution)	PA17, PK02, PG19	**PA17**	Agricultural activities generating pollution to surface or ground waters (including marine)	Substances, litter and energy: Input of nutrients – diffuse sources, point sources, atmospheric deposition (**PresInputNut**); Input of other substances (e.g., synthetic substances, non-synthetic substances, radionuclides) — diffuse sources, point sources, atmospheric deposition, acute events (**PresInputCont**)	–
		PG19	Marine aquaculture generating marine pollution	**PresInputNut**; **PresInputOM**; **PresInputCont**	–
		PK02	Mixed source marine water pollution (marine and coastal)	**PresInputNut**; Input of organic matter — diffuse sources and point sources (**PresInputOM**); **PresInputCont; PresInputLitter**	any pressure from categories '1 Point' and '2 Diffuse'
Shipping	PE02	**PE02**	Shipping lanes and ferry lanes transport operations	**PresBioIntroNIS;** Disturbance of species (e.g., where they breed, rest and feed) due to human presence (**PresBioDisturbSps**); **PresBioExtractSps; PresInputNut;** **PresInputCont;** Input of anthropogenic sound (impulsive, continuous) (**PresInputSound**)	2.4 – Diffuse – Transport (Transport) 2.7 – Diffuse – Atmospheric deposition (Transport) 4.3.2 – Hydrological alteration – Transport 5.1 – Introduced species and diseases (Transport) 5.3 – Litter or fly tipping (Transport)

(Continued)

TABLE 3 Continued

Anthropogenic pressures on the coralligenous habitat		Pressure definitions according to EU Directives			
Pressure	Code	Code	Habitat Directive	Marine Strategy Framework Directive	Water Framework Directive
Infrastructures	PF15	**PF15**	Modification of coastline, estuary and coastal conditions for built-up areas	**PresBioDisturbSps**; **PresPhyDisturbSeabed**; **PresPhyLoss**; **PresPhyHydroCond**; **PresInputSound**	4.1.4 – Physical alteration of channel/bed/riparian area/shore – Other
Diving activity (recreational and technical)	PF05	**PF05**	Vaguely related to PF05 (Sports, tourism and leisure activities)	**PresPhyDisturbSeabed**; **PresPhyLoss**	–
Destructive research/ educational activities	PH07	**PH07**	Intrusive and destructive research and monitoring activities	Research, survey and educational activities (**ActivResearch**)	
Anchoring	PE02	**PE02**	Shipping lanes and ferry lanes transport operations	**PresPhyDisturbSeabed**; **PresPhyLoss**	–
Environmental stressors					
Stressor	**Code**				
Thermal stress/climate change	PJ01	**PJ01**	Temperature changes and extremes due to climate change	–	–
Benthic mucilage	BM	-	–	–	–
Sedimentation	SED	-	–	–	–

New acronyms were used to define pressures/stressors not considered by the EU Directives.
*Macfadyen et al. (2009).
Bold text has been used to emphasize relevant terms and to facilitate their search in the text.

3 Results and discussions

3.1 Overview

The STVI (Scuba Trail Vulnerability Index, Di Franco et al., 2009) is based on a census of vulnerable benthic species populations that can potentially be affected by the direct (mechanical) or indirect (sediment resuspension) impacts of diving activity on the coralligenous. The suggested protocol is easy to be applied, however its usefulness is limited to narrow scuba trails where divers are in close proximity to walls/ceiling/substrates (i.e., submerged caves, tunnels, arcs, or canyons) and the damage caused can be reliably attributed to divers.

The CAI (Coralligenous Assemblage Index, (Deter et al., 2012)) was designed considering three metrics (i.e., the percentage coverage of sludge, builder taxa and bryozoans) correlated with anthropogenic pressures affecting water quality. The 'builders' of the coralligenous framework considered include coralline algae, bryozoans, scleractinians, and the foraminifera *Miniacina miniacea* (Pallas, 1766). Other animal builders such as serpulids polychaetas or sponges (Ballesteros, 2006) are not considered. Metrics referring to gorgonian demography (colony height and necrosis) are discarded because injuries to these long-living organisms may be related to ancient stress, such as heat waves (Garrabou et al., 2022a), and not to more recent anthropogenic pressures. Other indexes (i.e., MAES, CBQI, 3D complexity, STAR, MACS, see ahead) addressed this issue by linking the level of epibiosis to the age of the impact.

Biocenosis of semi-dark caves (at least at the entrance) can overlap with those of the coralligenous (Bellan-Santini et al., 2015), therefore the CavEBQI (Cave Ecosystem-Based Quality Index, Rastorgueff et al., 2015) was considered in this review. The index aims to evaluate the ecological quality of marine submerged caves by adapting the approach used to gauge the ecological quality of *Posidonia oceanica* meadows (Personnic et al., 2014). The data collection combines photo sampling, underwater estimations (volume stratification) and visual census to evaluate the status of seven ecological cave components (see details in Table 1). However, there is inherent risk associated with applying these complex protocols in an entire (accessible) underwater cave. Moreover, occurrence, abundance, and spatial distribution of vagile components (for example, cave-dwelling mysids) inside a cave may vary in relation to season, abiotic factors and reproductive behavior (Ribes et al., 1996), leading to inaccuracies when applying the index. Passive filter feeders are considered as the most valuable target given their sensitivity to pressures, but this component includes taxa that differ greatly in morphology, tolerance to disturbance and lifespan (e.g., hydrozoans and gorgonians). In these dark habitats, the geological structure of the caves, their rock composition and the possible occurrence of freshwater springs or hydrothermal emissions can greatly affect the composition of the benthic assemblage, which influences the outcomes of the index and how they are interpreted.

The ESCA (Ecological Status of Coralligenous Assemblages, Cecchi et al., 2014) index considers deep macroalgae (ten taxa/ morphological groups) and three metrics to evaluate coralligenous status. The index is expressed as Ecological Quality Ratio (EQR) i.e., the ratio between the measured value for each metric (or Ecology Quality Value, EQV) and its expected value in the absence of major human disturbance (Reference Condition (RC), Water Frame Directive (WFD), 2000/60/EC).

Sessile macroinvertebrates are considered along with seaweeds to compute the ESCA-TA (Piazzi et al., 2017a) and to evaluate the response to disturbance of the "Total Assemblage". The application of this last index highlighted that macroalgae are more suitable to detect pressures such as, the increase in nutrients or water turbidity, while the macroinvertebrates are more sensitive to the effects of water warming or mechanical damage, as reported previously (see Coma et al., 2006; Cerrano and Bavestrello., 2009; de la Nuez-Hernández et al., 2014). In general, the methodology is simple to apply and easy to replicate. However, reference conditions are not available for all sites (Ponti et al., 2009; Piazzi et al., 2021a) and may be difficult to define (Bouleau and Pont, 2015), especially if there is scarce knowledge of the possible exploitation of the study area.

The COARSE (COralligenous Assessment by ReefScape Estimate) index, (Gatti et al., 2015) evaluates the coralligenous integrity as a descriptor of the marine environmental status (as required by the MSFD) rather than water quality (as per WFD). Here, the vulnerability towards physical stress and mechanical damage of the multi-layer architecture of this habitat is considered. The COARSE index is based in part on a Rapid Visual Assessment (RVA), providing a time and cost-effective methodology, which allows for the direct collection of a sufficient amount of data with a congruent diving effort (Gatti et al., 2012). However, visual estimations of percentage cover (Meese and Tomich, 1992) and species identification (Thompson and Mapstone, 1997) may be inaccurate at 30 m or deeper, given the limited dive time and need to collect other underwater measurements.

The combination of two indexes (COARSE and ESCA) was tested in the same area obtaining different but complementary information (Piazzi et al., 2017b) given the different objectives of the two indexes. However, the implementation of two or more underwater protocols is more demanding in terms of time and cost.

The INDEX-COR (Sartoretto et al., 2017) is based on *in situ* observation/estimations, combined with photographic sampling. The metrics Ratio between Sensitive and Tolerant Species (RSTS), Observable Taxonomic Richness (OTR), and Structural Complexity (SC) seems to be related to human pressures defined by expert judgment; however, the authors themselves stated that a more objective impact index is needed to correlate the structural complexity with anthropogenic pressures at a lower scale.

The Index of 3D - Structural Complexity (Valisano et al., 2019) aims to assess the status of coralligenous assemblages by aggregating taxa according to their morpho-functional role in the multi-layer structure of the habitat. A different weight is assigned to each cluster reflecting its relevance in the bioconstruction/bioerosion equilibrium and as ecosystem engineers building animal forests (Cerrano et al., 2019). The index assesses the 3D architectural complexity of coralligenous assemblages.

The STAR (STAndaRdized coralligenous evaluation procedure, Piazzi et al., 2019a) is the first attempt to standardize metrics and protocols to collect and to interpret data on the status of the coralligenous. Findings of a literature review revealed April-June to be the best period to carry out sampling activities according to seasonal dynamics of native and invasive macroalgae; while 35 m and 85–90 m were considered as optimal depth and slope, respectively to carry out photo-surveys. The authors also suggested carrying out sampling with high replication at small scales (i.e., tens of meters) and less replicates at intermediate or large scales (i.e., hundreds of meters to kilometers). The ideal sampling design should consider three areas of 4 m^2, tens of meters apart, with at least 10 replicates of 0.2 m^2 at each area, for a total sampling surface of 6 m^2.

The ISLA Index (Integrated Sensitivity Level of coralligenous Assemblages, Montefalcone et al., 2017), allows for the change experienced by the coralligenous assemblages to be estimated in both space and time by multiplying abundance (i.e., percentage cover) of several target taxa/morphological groups per an integrated index that considers both sensitivity to disturbance and sensitivity to stress. Disturbance causing mortality or physical damage (subtraction of biomass) is evaluated considering the biological traits of the target taxa. Stress causing physiological alteration (reduction in productivity) and sensitivity to stress is estimated based on expert judgment.

The MedSens sensitivity index (Turicchia et al., 2021a) is a biotic index developed to provide information on the environmental status of subtidal rocky coastal habitats, and above all, coralligenous reefs. It uses data collected by trained volunteers (scuba divers, free divers, snorkelers) which record the abundance and depth ranges of the searched taxa through a protocol of simple application (The Reef Check Med Underwater Coastal Environment Monitoring (RCMed U-CEM) Protocol, Turicchia et al., 2021b). Despite the need for rigorous participant training (subject to learning tests) and steps to assure data quality, the protocol is easy to learn and provides a large amount of timely, up to date geo referenced data (Turicchia et al., 2021b, c) which is the greatest benefit of this approach. The sensitivity level to physical, chemical, and biological pressures is attributed to selected taxa according to the Marine Evidence-based Sensitivity Assessment (MarESA, Tyler-Walters et al., 2018). The index calculates the mean sensitivity of the various taxa considered weighted for the abundance class of the taxa.

Three indexes were based on photography and video footage collected by Remotely Operated Vehicle (ROV): the CBQI (Coralligenous Bioconstructions Quality Index, Ferrigno et al., 2017) focused on fishing pressure, the MAES (Mesophotic Assemblages Ecological Status, Cánovas-Molina et al., 2016), and the MACS (Mesophotic Assemblages Conservation Status, Enrichetti et al., 2019) to monitor the environmental status of mesophotic temperate reefs. ROVs allow exploration of deep reefs (Jones et al., 2007; Enrichetti et al., 2019) providing sufficient levels of detail and a large amount of recorded information (Smith and Rumohr, 2005).

The NAMBER Index (North Adriatic Mesophotic BiogEnic Reefs, Piazzi et al., 2023), draws inspiration from the STAR and ESCA-TA indices, by selecting the metrics and adapting the interpretation scales to the ecological and operational conditions encountered when investigating the mesophotic coralligenous banks in the northern Adriatic Sea. Starting with a close-up photographic sampling strategy, the degree of bioconstruction (expressed as percentage cover of crustose coralline algae), α diversity (expressed as the mean number of taxa), and the degree of sensitivity to human disturbances and climate changes (based on literature data and expert judgement) of the benthic assemblages are combined in the index, in terms of ecological quality ratios (*sensu* WFD) using as a reference the best values that the three metrics can currently achieve in the studied region.

Lastly, the OCI (Overall Complexity Index, Paoli et al., 2016) aims to measure habitat structural and functional complexity through a thermodynamic analysis, based on exergy and specific exergy, and a network analysis. The index was tested in an MPA where the most complex habitats were found to be the seagrass meadows and the coralligenous reefs. The information about environmental quality and natural capital was already available for the study area, but a larger scale application of this index would require considerable data collection and a sound baseline.

3.2 Comparative analysis of sampling methodologies: which is the best?

Table 2 summarizes and compares the underwater scientific methodologies applied in the studies considered to collect data and the components (i.e., metrics and parameters useful to obtain metrics, such as abundance) to calculate the indexes. All the proposed approaches (Tables 1, 2) are based on non-destructive methods but, when considered, the thickness of the calcareous layer is measured in a destructive way (insertion of a tool marked with a millimetric scale in the biogenic concretion, Piazzi et al., 2019a). However, the damage caused is limited.

Three indexes (CBQI, MAES, MACS), use ROV exploration, one (CAI) uses CCUBA (Closed Circuit Underwater Breathing Apparatus) to sample down to 84 m, while the others use SCUBA diving. According to Gennaro et al. (2020), sampling within a depth of 40 m should be carried out via SCUBA divers while, for safety reasons, below this depth the coralligenous should be explored using ROVs. However, trimix diving (either open or closed breathing circuits) by well-trained operators could be useful to conduct the surveys with high levels of safety down to 90-100 m depth.

Higher performing ROV systems, intended for > 80 m depth, are more expensive, and often require specialized operators to be maneuvered and large boats to be transported.

Photo surveys are the preferred method for underwater data collection (10 indexes), followed by *visual census* (6) and video surveys (5). Percent cover estimates from photo samples is the most applied procedure to estimate benthic species' abundance.

The same index could be calculated using more than one underwater sampling method, for example photo/video surveys could be carried out via SCUBA diving or an ROV.

Video-surveys and photo quadrats appear to be the best methods to collect data on the coralligenous. Video transects randomly conducted in georeferenced repeatable stations are the most efficient, fastest, and simplest method to detect general changes in the habitat architecture. Besides supplying permanent records about density and size of habitat-formers (i.e., gorgonians, *Savalia savaglia* (Bertoloni, 1819), erect sponges…), the videos contain information about the geomorphological features of the site, occurrence of macro-invasive species and lost fishing gears. Photo-surveys provide a better estimate of the percentage coverage of organisms with a low elevation from the substrate (e.g., encrusting, massive or little branched phyto/zoobenthos).

Despite their accuracy, the complexity of some approaches renders them unsuitable for the citizen science context (a helpful strategy fostering the continuous monitoring of the effects of thermal stress and anthropic pressures on a larger spatial and temporal scale (Krželj et al., 2020)).

Even if citizen science cannot override professional monitoring activities, with the number of target species often being lower than the taxa considered by scientists, an easy-to-apply citizen science-based index for the Mediterranean Sea, providing a community-based monitoring strategy, would be a valuable tool to gather a constant flux of data on benthic communities (Kelly et al., 2020). Examples of citizen science projects engaging divers in the study and monitoring of Mediterranean coralligenous assemblages are the CIGESMED SeasEra (ERAnet) (Gerovasileiou et al., 2016), the Reef Check Mediterranean Underwater Coastal Environment Monitoring Protocol (Ponti et al., 2021; Turicchia et al., 2021b; Turicchia et al., 2021c), and the derived MedSens index.

3.3 Standardization of the definitions of anthropic pressures and environmental stressors

Establishing an unambiguous list of anthropic pressure and environmental stressors on the coralligenous habitat is fundamental to assess its environmental and ecological quality. Given that different descriptions of pressures were used in the reviewed papers, here, a standardized nomenclature for 15 forms of pressure/stressors on the coralligenous has been devised (Table 3). Attempts were made to align the pressures with those defined by EU regulations (the Habitat Directive (Council Directive 92/43/EEC), the MSFD, and the EU Water Frame Directive (WFD, Directive 2000/60/EC), according to Article 17 report formats of the Habitats Directive (https://cdr.eionet.europa.eu/last updated: 24/01/2023)).

Pollution is the most considered pressure in the indexes (47%) reviewed, followed by abandoned, lost or discarded fishing gear (40%, ALDFG, Macfadyen et al., 2009).

Some pressures/stressors on coralligenous habitat are easy to detect and quantify due to the presence of long-lasting macroscopic signs (such as presence of marine litter, lost fishing gear, benthic mucilage, invasive and non-indigenous macrozoo- and phytobenthos, high sedimentation, collection of date mussels). On the contrary, it could be tough to attribute signs of damage (breakages, necrosis/epibiosis) to intangible and temporary pressures/stressors (liquid waste, contacts of divers, heatwaves, storms), above all in case of cumulative impacts. In the next paragraph we better analysed these issues and explored some solutions.

3.4 Major issues hindering the harmonization of the indexes and possible solutions

The indexes can produce inaccurate assessments of the environmental status where the low diversity is related to intrinsic traits of the site (water movements, light, geomorphology, food availability) rather than human disturbance (Enrichetti et al., 2019; Valisano et al., 2019; Pierdomenico et al., 2021), such as the assemblage of the coralligenous developed on granitic substrates (Canessa et al., 2020). Another issue detected in this review is how to define intermediate environmental status classes (i.e., good, moderate, poor) if historical data about biodiversity and pressures are unavailable and the pristine conditions are unknown (Ponti et al., 2009 and references therein). However, these obstacles will be overcome once periodic and continuous monitoring campaigns are established to detect the evolution of benthic communities and to differentiate among fluctuations, disease events and human pressure (Franz et al., 2019). As for other monitoring programs of the MSFD, the establishment of fixed stations (García-Gómez et al., 2020) will be indispensable for observing the dynamics of benthic communities and to assess their environmental status. These could be in known coralligenous hotspots (Martin et al., 2014; Di Camillo et al., 2018a), independent of their level of protection, within which random sampling could be conducted.

To establish the causes of biodiversity loss that are unrelated to mechanical damage, trends in physical and chemical parameters should be considered. Funding should be provided to increase the analysis of water/biota and to provide the fixed stations with benthic temperature loggers placed at different depths and multisensory buoys transmitting real-time data to a monitoring network. The analysis of the collected data would be valuable in helping link the transformation occurring in the coralligenous to atmospheric, oceanographic, and biogeochemical conditions (Bahamon et al., 2020; Garrabou et al., 2022b).

One of the major issues in designing an index to define the ecological status of a habitat is the attribution of a sensitivity level to taxa/morphological groups. The sensitivity level may be available in the literature, or expert judgement may be used (Piazzi et al., 2017a and references therein). However, sometimes it is unclear why some taxa are more sensitive than others; for example, *Eunicella cavolini* and *Cystoseira* spp. are considered more sensitive than *Paramuricea clavata* by the ESCA, while *P. clavata* was the most sensitive taxon for the MedSens index (Turicchia et al., 2021a) because of its sensitivity to physical, chemical, and biological pressures. According to Turicchia et al. (2021a), most sensitive taxa are long-living cnidarians. Since these species reflects the highest complexity level of the coralligenous, it would be crucial to assign one of the largest weights in the design of a new index.

To evaluate the status of coralligenous health, it is crucial to know its successional stages. The accretion rate of the coralligenous is very low (0.006–0.83 mm yr^{-1}) and variable depending on depth and period (Sartoretto, 1994; Turicchia et al., 2022), suggesting that dynamics of this environment are difficult to study on a short-term timescale (Garrabou and Harmelin, 2002). Mortality events drive a shift from ecosystem engineering (e.g., *Paramuricea clavata, Corallium rubrum*) to fast-growing and photophilous species (among which are encrusting organisms, serpulids, hydrozoans, turf-forming algae (Ponti et al., 2014; Cerrano et al., 2019; Gómez-Gras et al., 2021)). In some cases, bryozoans recolonize bare coralligenous after a severe impact in a few years (Cocito and Sgorbini, 2014; Casoli et al., 2020, and personal observations), but also other patterns are documented (Piazzi et al., 2021b). On the contrary, re-settlement and growth of gorgonians or red coral may be very slow (Garrabou and Harmelin, 2002; Cerrano et al., 2005; Cupido et al., 2009; Huete-Stauffer et al., 2013); in some cases, no signs of recovery have been registered even after a ten-year period (Ruffaldi Santori et al., 2021). Information about recovery of habitat-formers after mortality is scant and highlights a knowledge gap that needs to be filled urgently.

Heatwaves, changes in thermohaline circulation, and mucilage events are rapidly re-shaping bioconstructions in the Mediterranean basin (Cramer et al., 2018; Bevilacqua et al., 2021; Garrabou et al., 2022a); therefore, in these unprecedent critical conditions, the index design should focus first on the response of the coralligenous to these stressors.

Considering that heatwaves and mucilage events occur from late spring to late autumn (Garrabou et al., 2009), data collection should be carried out in early spring (April or May) and autumn (October) to have a better understanding of the effects of these pressures and the resistance and resilience of coralligenous bioconstructions (Ponti et al., 2014).

Based on these reflections, a list of priority anthropic pressures and environmental stressors and relative indicators are suggested below (Table 4).

4 Conclusion

This work highlights the urgent need to align the methodologies to assess the status of the coralligenous habitat at basin scale. The

TABLE 4 List of priority anthropic pressures/environmental stressors, indicators, and metrics as a starting point to define a shared index to assess the environmental quality of the coralligenous habitats.

	Anthropic Pressures/ Environmental stressors	Acronym	Indicators	Metrics
1	Thermal stress/Climate change	PJ01	*Eunicella singularis* if present in the study area	Density, % living specimens, % necrotic or bare areas in (<25%, 25%, 50%, 75%, >75%)
			Habitat-formers (non-zooxanthellate gorgonians, *Savalia savaglia*, massive and erect sponges); species of the canopy (small sponges, zoanthids, scleractinians, tunicates, crustose coralline algae); pioneer species (turf-forming algae, hydroids, fast-growing bryozoans/ serpulids)	Habitat-formers: density, height, % living specimens, % necrotic or bare areas in (<25%, 25%, 50%, 75%, >75%); canopy species: cover %; pioneer species: cover %
2	Benthic mucilage	BM	Mucilage, benthic organisms, substrate integrity	Cover % of mucilage, density of at least 3 habitat-formers typical of the study area (before and after summer), cover % of bare substrate (before and after summer)
3	Abandoned, lost or otherwise discarded fishing gear	ALDFG	Fishing gears, gorgonians, *Savalia savaglia*, erect bryozoans, solitary tunicates, erect sponges, crustose coralline algae	Density of fishing gears, specimens' height, % epibiosis/necrosis/entanglement, % damaged colonies/specimens
4	Other macro–seafloor Litter	PH08	Seafloor litter (non-plastic or mixed litter), gorgonians, *Savalia savaglia*, erect bryozoans, solitary tunicates, erect sponges, crustose coralline algae	Density of seafloor litter, specimens' height, % epibiosis/necrosis/entanglement, % damaged colonies/specimens
5	Illegal species collection	PG11	*Corallium rubrum*, date mussels, *Savalia savaglia*, substrate integrity	Variations in coral density, cover % of broken rocks, cover % of bare substrate
6	Plastic pollution	PF10	Seafloor plastic litter > 5cm	Density of seafloor litter
7	Invasive alien species	PI02	Invasive seaweeds, invertebrates, and fish	Variations in densities of the invasive species, record of damage to other organisms
8	Sedimentation	SED	Sediment on benthic species	Cover % of sediment
9	Diving activity (relevant above all in narrow underwater passages such as tunnels, caves, canyons, and arcs)	PF05	*Corallium rubrum*, gorgonians, erect sponges, scleractinians, large tunicates, bryozoans, crustose algae	Frequentation of a site, number, and level of scuba diver per site, % cover of air trapped on the ceiling, variation in density and height/level of exposure of indicator species, % of necrosis/epibiosis

steps needed to develop a unified index are illustrated in the framework below (Figure 1) and detailed here:

1. Adoption of a standardized method of data acquisition (regardless of the underwater exploration technique). Darwin Core glossary terms should be used as the biodiversity data standard (Wieczorek et al., 2012; Di Camillo et al., 2018b). When possible, data should be integrated through Marine Citizen Science (MCS) protocols, Local Ecological Knowledge (LEK, Azzurro et al., 2019), and Web Ecological Knowledge (WEK, Di Camillo et al., 2018a).
2. Definition of a scale of scores correspondent to different classes of coralligenous quality.
3. Set up of a user-friendly digital tool that could support the collection of data and its visualization and improve the applicability of the index. The new tool should both calculate the index (as per the software for assessing the quality of soft-bottom benthic macroinvertebrate communities (AMBI, Borja et al., 2000)) and allow the spatial and temporal visualization of the scores through geographic information systems (as per the plugin to compute the MedSens index (Turicchia et al., 2021b).
4. Consideration of FAIR principles (Findability, Accessibility, Interoperability and Reusability (Tanhua et al., 2019) to make protocols, digital support tools and collected data more readily available.

Until now, the only open access data is the Reef Check Med dataset on key Mediterranean marine species (Turicchia et al., 2021c), hosted by the European Marine Observation and Data Network (EMODnet; Martín Míguez et al., 2019), and periodically updated on the dedicated webpage (https://www.reefcheckmed.org).

Open science is a priority for the European Commission (EC), and data obtained from the application of a monitoring protocol and the relative index should respect the FAIR principles (Findability, Accessibility, Interoperability and Reusability (Tanhua et al., 2019); therefore, data should be shared for their

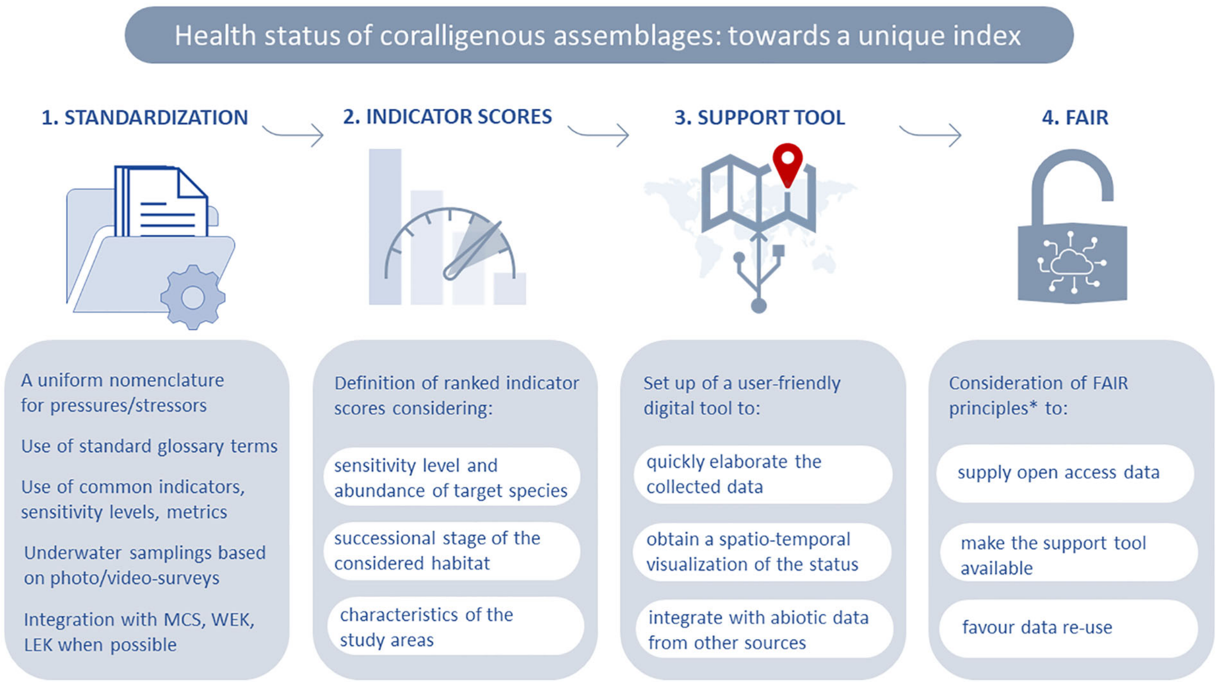

FIGURE 1
Main stages proposed to develop a unified index to assess the health status of the coralligenous habitat. MCS, Marine Citizen Science; LEK, Local Ecological Knowledge; WEK, Web Ecological Knowledge; FAIR, Findability, Accessibility, Interoperability and Reusability.

re-use in an EU repository (e.g., the European Marine Observation and Data Network (EMODnet, https://emodnet.ec.europa.eu), Copernicus, https://www.copernicus.eu/among others).

All data are available as tables embedded in this study.

Author contributions

CDC conceived the idea, and wrote the original draft. MP contributed to writing the original draft. AS, CS, CR, TM, MC, CC contributed to searching articles and preparing tables. All authors contributed to the article and approved the submitted version.

Funding

This research was supported by the Università Politecnica delle Marche (Ricerca Scientifica di Ateneo, RSA).

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