Coralligenous assemblages: research status and trends of a key Mediterranean biodiversity hotspot through bibliometric analysis

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Received: 23 April 2023/ Accepted: 26 July 2023

Abstract. Coralligenous assemblages are biogenic calcareous formations endemic of the Mediterranean Sea, produced by the aggregation of calcareous red algae and other calcifying organisms in dim light conditions. Due to their high structural complexity, they are considered benthic biodiversity hotspots that provide several ecosystem functions and services. In this study, we conducted a comprehensive overview integrated with a bibliometric network analysis of the academic literature related to coralligenous assemblages. Analyses were performed using VOSviewer software. The bibliographic search on the Scopus database resulted in 339 documents published in a timeframe ranging from 1965 to 2022, with an increasing trend over time. Italy resulted the most productive country, with 202 documents and 4004 citations on this topic. The total number of authors publishing on coralligenous was 948. Piazzi was the most productive author in terms of number of documents (33), while Ballesteros was the most cited one (1109). The keyword "biodiversity" had the largest occurrence (86) and total link strength (735), highlighting the key role of these structurally-complex and heterogenic habitats. Among taxa, "algae", "anthozoa", and "bryozoa" were the keywords with the largest occurrence (58, 55, 31, respectively), which correspond to the main coralligenous calcifying and structuring taxa. A shift from taxonomic and ecologically-based studies, on species richness/diversity and community composition/structure, to conservation ecology ones, on anthropogenic impacts and ecosystem management, has been observed over time. These outcomes highlight the growing socio-economic awareness on the importance and vulnerability of coralligenous assemblages. Indeed, these coastal habitats have been recently recognized by the scientific and political communities for their role in providing ecosystem goods and services, although further research efforts are needed to deeply comprehend, value and protect them.

Keywords: anthozoa, anthropogenic impact, bioconstructions, coralline algae, rhodoliths, review.

1. Introduction

Coralligenous assemblages are biogenic calcareous habitats typical of the Mediterranean Sea. They build up under dim light conditions from 30–40 m down to 200 m depth (Sheehan and Fagerstrom, 1988; Corriero et al., 2019; Ballesteros, 2006; Baker et al., 2016; Ferrigno et al., 2018a). These assemblages occur on hard and vertical substrates, but they can also develop on horizontal soft bottoms starting from the aggregation and merger of rhodoliths, free-living forms of calcareous red algae (Basso, 1998; Rendina et al., 2020a; Rendina et al., 2022). Indeed, two main morphologies have been described: coralligenous cliffs and platforms (Bracchi et al., 2017; Montefalcone et al., 2021). The former develop on vertical/subvertical rocky substrates, while the latter grow on deeper horizontal bottoms of detritic substrates (Laborel, 1987; Ballesteros, 2006).

Differently from Mediterranean very shallow bioconstructions (Donnarumma et al., 2018; Ingrosso et al., 2018), coralligenous depth range is highly variable and mainly depends on solar irradiance, which is in turn related to water turbidity and sedimentation rates (Cocito et al., 2002). The formation of coralligenous assemblages is the result of the interspecific and dynamic relationships between bioconstructors and bioeroders (Fava et al., 2016; Ingrosso et al., 2018). Indeed, these bioconstructions consist of bioherms, with thickness ranging from few cm to over 2 m, deriving from the multilayer deposition of calcium carbonate, primarily produced by calcareous red algae (Ballesteros, 2006; Bracchi et al., 2022). Usually, on a base of crustose coralline algae (mostly of the genera *Mesophyllum*, *Lithophyllum*, and *Pseudolithophyllum*), a multi-layered substrate builds up in association with bryozoans (e.g., *Myriapora truncate*, *Pentapora fascialis*, *Schizomavella* spp., and *Turbicellepora avicularis*), sponges (e.g., *Agelas oroides*, *Aplysina cavernicola*, *Axinella* spp., *Chondrosia reniformis*, *Haliclona mediterranea*, *Ircinia* spp., *Oscarella lobularis*, *Petrosia ficiformis*, *Sarcotragus* spp. and *Spongia* spp.), cnidarians (e.g., *Caryophyllia* spp., *Corallium rubrum*, *Epizoanthus arenaceus*, *Eunicella cavolini*, *E. singularis*, *Leptopsammia pruvoti*, and *Paramuricea clavata*), and other ‘engineering’ taxa (Jones et al., 1994; Sartoretto, 1996; Ballesteros, 2006). This 3D heterogenic matrix supports a high alpha diversity (Cerrano et al., 2010). In fact, coralligenous assemblages are among the most relevant Mediterranean biocoenoses for their high structural complexity and heterogeneity, which promote a wide floral and faunal abundance and diversity (Garrabou et al., 2002; Ballesteros, 2006; Ferrigno et al., 2018b). They are considered crucial biodiversity hotspots of the Mediterranean Sea (Ballesteros, 2006), hosting more than 10% of the known Mediterranean marine benthic species, many of them endemic, vulnerable and protected (Boudouresque, 2004; Coll et al., 2010; Ferrigno et al., 2020). For example, the red coral *Corallium* *rubrum* is one of the most valuable endemic species within the coralligenous communities of the Mediterranean hard bottoms (Sarà, 1973; Giannini et al., 2003; Casas-Güell et al., 2015). It is a long-lived slow-growing coral that can constitute *facies* with fair densities, and a very high economic value (Zibrowius et al., 1984; Rossi et al., 2008; Ferrigno et al., 2020). Since ancient times, it has been overharvested all over the Mediterranean Sea, and its exploitation is now strictly regulated (Tescione, 1973; Abbiati et al., 1992; Santangelo et al., 1993; Santangelo and Abbiati, 2001; Tsounis et al., 2007; Cattaneo-Vietti et al., 2016).

Because of the high biodiversity that they support, coralligenous assemblages provide a variety of valuable ecosystem services of social and economic relevance (Krieger and Wing, 2002; Henry and Roberts, 2007; Tonin, 2018). Specifically, they provide fruitful fishery grounds (provisioning services), attractive seascapes for diving tourism (cultural services), and contribute to climate regulation through carbon sequestration and stock (regulating services) (Ballesteros, 2006; Lloret, 2010; Salomidi et al., 2012; Chimienti et al., 2017; Appolloni et al., 2018a; Buonocore et al., 2020a,b).

Over the last decades, coastal benthic communities have been negatively affected by anthropogenic pressures, such as increasing of fishing activities and of fishing gear loss (Smith et al., 1991; Gilman, 2015; Ferrigno et al., 2018a; Ferrigno et al., 2021; Rendina et al., 2020b). These threats often led to degradation and decrease of structural heterogeneity of coralligenous assemblages (Piazzi et al., 2012; Gatti et al., 2015a; Betti et al., 2020). Indeed, bottom fisheries reduce macroalgal primary production with increasing water turbidity and sedimentation rates, and cause mechanical damages to large and erect megabenthic organisms, negatively affecting their growth rate, reproduction efficiency, resistance to diseases, and spatial competitive ability (Cerrano et al., 2005; Clark and Koslow, 2007; Althaus et al., 2009; Relini and Tunesi, 2009; Piazzi et al., 2012; Bavestrello et al., 2014; Bo et al., 2014). In particular, slow-growing species such as calcifying bryozoans, madrepores, and *Corallium rubrum*, or other fan corals (e.g. *Eunicella cavolini* and *Paramuricea clavata*) are very fragile, and their colonies are often broken, upturned, with necrosis and epibiont overgrowth due to mechanical damages by longlines and nets (Hall-Spencer et al, 2002; Bo et al., 2014; Ferrigno et al., 2018a). Furthermore, lost fishing gears and marine litter introduce xenobiotic compounds into marine food webs, with several toxic effects in marine animals and potential consequences for human health (Rochman, 2015; Markic et al., 2018; Pauna et al., 2019). In addition to local impacts, coralligenous will likely be threatened by global climate change. In fact, coralline algae and calcifying invertebrates are particularly vulnerable to both ocean warming and acidification (Gòmez-Gras et al., 2019, 2021; Rendina et al., 2019; Iborra et al., 2022). Indeed, several fan coral mortality events triggered by thermal anomalies have been recorded (Cerrano et al., 2000; Cupido et al., 2008; Gambi et al., 2010).

Climate change also facilitates the introduction of alien thermophilic species (Occhipinti-Ambrogi and Galil, 2010; Hulme, 2017) and limits the efficiency of carbonate storage from calcifying species (Kroeker et al., 2013; Vizzini et al., 2019).

The synergistic impacts of all these anthropogenic stressors can lead to shifts in species composition, going from structurally complex habitat-forming calcifying species towards opportunistic quickly-growing non-calcifying ones. This might result in worsening of community functions and loss of ecosystem services (Schiaparelli et al., 2001; Blanchard et al., 2004; Daskalov et al., 2007; Althaus et al., 2009).

In the last decades, the importance and vulnerability of coralligenous assemblages have been recognized at international level, and several protection instruments have been adopted (Tribot et al., 2016; UNEP, 2017; Thierry de Ville d'Avray et al., 2019). Specifically, coralligenous assemblages were included in the generic "reefs" habitats by the EU Habitats Directive 92/43/CE (E.C., 1992), but are intensively monitored in the Mediterranean Natura 2000 network (La Mesa et al., 2019). They are also subjected to specific conservation plans in the framework of the Barcelona Convention (UNEP, 2008, 2017). Finally, coralligenous assemblages have been recently included among the habitats of special interest within the Marine Strategy Framework Directive 2008/56/EC (E.C., 2008), and the assessment of their distribution and biodiversity has been included within the protocol to evaluate the "Good Environmental Status" of European marine waters.

Coralligenous species are indeed considered as reliable indicators of environmental quality for their high sensitivity to environmental changes (Ferrigno et al., 2017; Piazzi et al., 2022). Consequently, non-destructive techniques have been developed to assess the ecological quality and health status of coralligenous assemblages, and several indices based on visual census methods have been developed (UNEP, 2019). Shallower coralligenous cliffs are usually surveyed by scuba diving (Deter et al., 2012; Cecchi et al., 2014; Gatti et al., 2015a; Sartoretto et al., 2017; Piazzi et al., 2019; Casoli et al., 2019), while deeper coralligenous cliffs and platforms are mainly explored by Remotely Operated Vehicles (ROVs) (Bo et al., 2015; Canovas-Molina et al., 2016; Ferrigno et al., 2017, 2018b; Enrichetti et al., 2019). Both these approaches aim at acquiring HD videos and photos for image analyses. In this context, 'morphological groups', i.e., groups of species belonging to the same taxon and showing similar morphologies (*sensu* Ferrigno et al., 2017), have showed to be helpful proxies for the assessment of quality status of coralligenous assemblages (Ferrigno et al., 2018b; Appolloni et al., 2020).

Eventual ecosystem changes may be assessed only with detailed information on marine biodiversity. As for the coralligenous assemblages, their complexity and remoteness may explain the relatively limited bibliography dealing with their community structure and functioning (Tribot et al., 2016). The application of bibliometric network analysis to literature may help the scientific community to unveil the state of the art and to identify the presence of knowledge gaps in this topic, allowing the quantitative exploration of relationships among researchers, organizations, countries, and keywords. Indeed, recently, bibliometric network analysis has been extensively used to analyse trends and patterns of large scientific datasets (Buonocore et al., 2018; Castellanos-Galindo et al., 2021; Picone et al., 2021; Cocozza di Montanara et al., 2022; Rendina et al., 2022). The present study may contribute to fill these gaps by reviewing the global scientific literature on coralligenous habitats, applying network analysis to bibliometric science.

2. Materials and methods

2.1. Bibliographic data acquisition

The analysis of the scientific production on coralligenous assemblages was conducted through bibliometric network analysis. Scientific documents were collected on 9th January 2023 from the Scopus database. The research was performed by searching for the strings "coralligenous" on the document's title, abstract, and keywords to allow the presence of all the scientific documents on coralligenous assemblages. Timeframe was set to include all available publication years in the Scopus database. The metadata of the research were exported as ".csv" file after selecting the "citation information", "bibliographical information", and "abstract and keywords" options.

After the bibliographic research, a temporal trend analysis of the number of articles on coralligenous assemblages was performed.

2.2. Bibliometric network analysis

Bibliometric network analysis combines bibliometrics and social network analysis to survey a particular scientific field (Reuters, 2008; Zou et al., 2018). Bibliometrics exploits several statistical techniques to evaluate research quality and trace the development of scientific fields and networks (OECD, 2002; Reuters, 2008; Zou et al., 2018). Social network analysis is an approach useful to study social links and has been used for investigating social structures using networks and graph theory (Otte and Rousseau, 2002). This approach allows for the build of network maps and statistics based on the relationships among keywords, authors, organizations, journals, and countries connected to the investigated issue (Chen et al., 2016).

The VOSviewer software, version 1.6.18 (Van Eck and Waltman, 2018) was used to carry out the bibliometric analysis. It allowed the visualization and interpretation of maps created with the bibliometric network data, with clusters to visualize links among the bibliometric data.

Citation, co-authorship, and co-occurrence analyses were performed to produce network maps on scientific journals/documents, countries/ researchers, and keywords, respectively. For the co-occurrence keywords network analysis were also displayed a map showing the overlay visualization based on the average year of documents publication, and a map showing the main organisms composing coralligenous assemblages. For each map, node size is based on the number of documents, while "link strength" is determined by the line thickness. The number of clusters is determined by the resolution parameter value (Van Eck and Waltman, 2018), set to 1 for all the analyses.

3. Results and discussion

3.1. Temporal trend analysis

The 'coralligenous' search on Scopus found 339 documents published in the 1965 to 2022 timeframe. The low number of publications might be related to their limited geographic distribution (i.e., the Mediterranean Sea), together with their remoteness and consequent difficulties in observation and sampling.

Despite overall low, the number of publications shows an increasing trend, going from a minimum value of 1 document in 1965 to a maximum value of 40 documents in 2019 and 2021 (Fig. 1). In particular, the 6-fold increase over the last 17 years highlights the rising research interest in coralligenous assemblages over time.

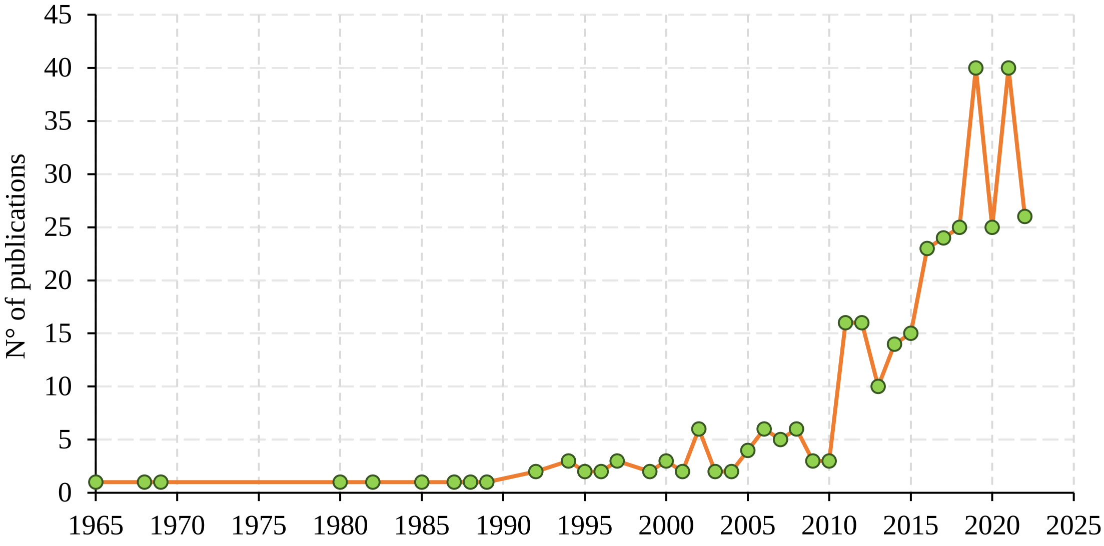

Fig. 1. Temporal trend of publications on coralligenous assemblages.

3.2. Bibliometric network analysis

3.2.1. Co-authorship countries network

The co-authorship analysis of countries generated 45 results. Italy ranked first, with the highest values for all the investigated parameters (202 documents, 4004 citations, 96 total link strength). Using a 3-documents-per-country threshold, 22 countries were selected (Table 1) and displayed in the co-authorship network map (Fig. 2). This map shows 6 main clusters in different colours grouping the countries with the higher level of interactions. The network map shows that Italy, Spain and France have a central collaborative relation with the other countries on the topic of coralligenous assemblages.

Table 1. Countries with at least 3 documents on coralligenous assemblages. Ranking is by number of documents.

Country	Documents	Citations	Total Link Strength
Italy	202	4004	96
France	73	2156	91
Spain	63	2983	81
United States	19	428	39
Croatia	17	402	38
Greece	14	505	42
United Kingdom	14	461	39
Turkey	11	229	24
Portugal	7	76	27
Israel	6	208	7
Montenegro	5	94	8
Australia	4	178	10
Belgium	4	72	8
Denmark	4	76	12
Ireland	4	72	4
Malta	4	183	12
Norway	4	67	14
Brazil	3	49	2
Germany	3	94	15
Monaco	3	392	6
Morocco	3	18	4
Tunisia	3	95	11

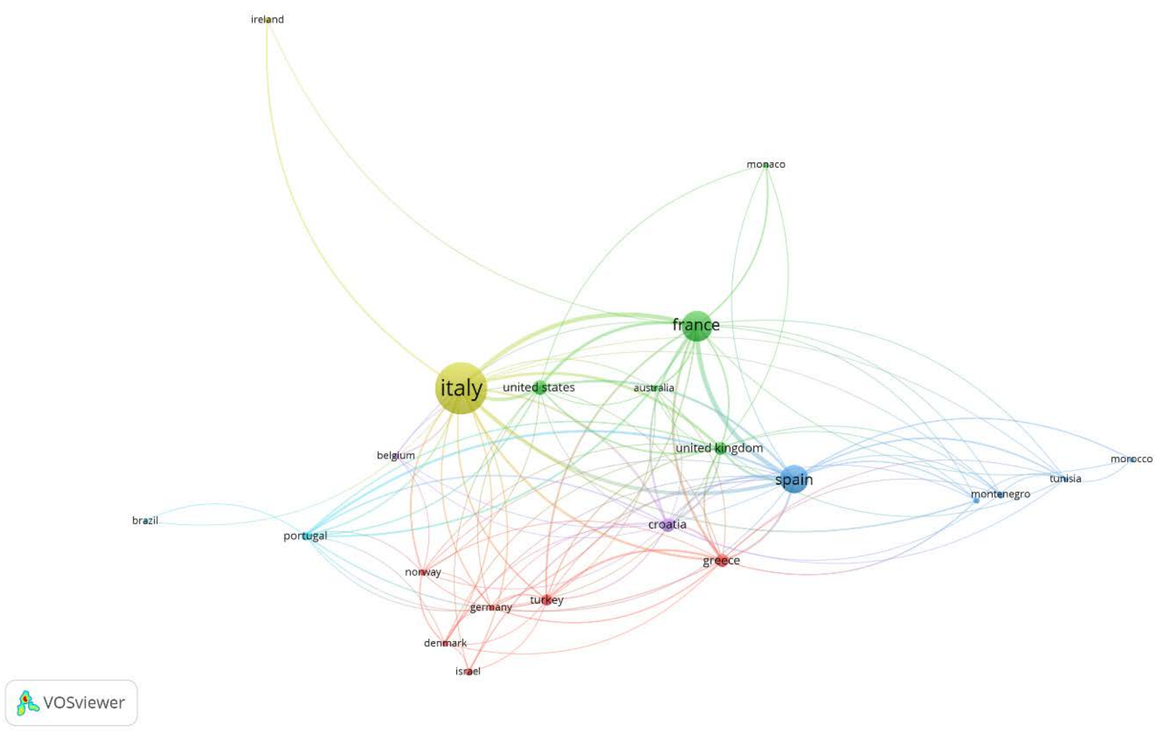

Fig. 2. Co-authorship countries network map (cluster visualization). Node size is based on the number of documents, while clusters are defined by different colours.

3.2.2. Co-authorship authors network

The total number of authors publishing on coralligenous assemblages was 948, of which only 23 (2.4%) published at least 10 documents (Table 2). Piazzi was the most productive author in terms of number of documents (33), while Ballesteros was the most cited one (1109). The co-authorship network maps based on the number of documents (Fig. 3a) and citations (Fig. 3b) display 77 authors, and include only authors with at least 5 publications.

Table 2
Authors with at least 10 documents on coralligenous assemblages. Ranking is by number of documents.

Author	Documents	Citations	Total Link Strength
Piazzi L.	33	617	118
Bavestrello G.	31	842	126
Cerrano C.	21	672	65
Garrabou J.	20	815	56
Morri C.	19	532	97
Bianchi C.N.	18	486	95
Montefalcone M.	16	380	68
Cecchi E.	15	312	66
Linares C.	15	619	43
Abbiati M.	14	392	39
Basso D.	14	193	35
Russo G.F.	13	316	54

Ballesteros E.	12	1109	35
Bertolino M.	12	338	62
Ceccherelli G.	12	74	48
Bo M.	11	302	54
Cebrian E.	11	351	41
Balata D.	10	381	23
Cattaneo-Vietti R.	10	324	53
Ponti M.	10	339	37
Sandulli R.	10	217	50
Savini A.	10	116	35
Serena F.	10	164	48

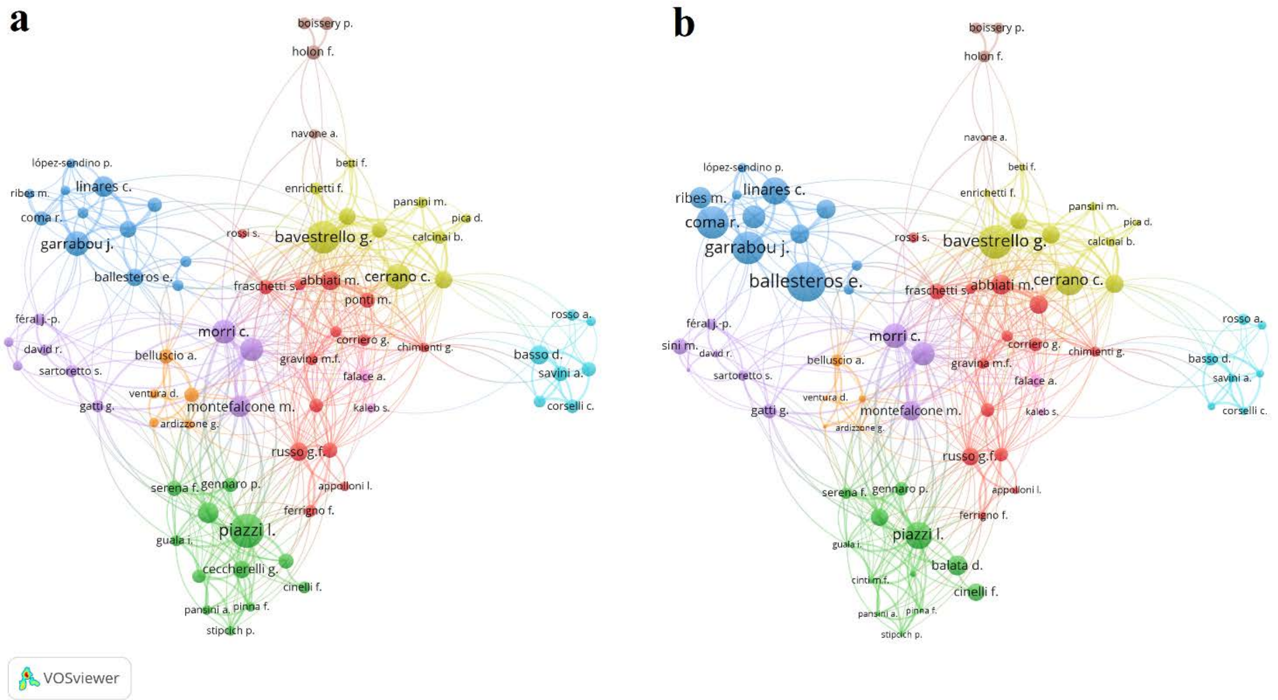

Fig. 3. Co-authorship network maps of authors (cluster visualization). **a.** Node size is based on the number of documents. **b.** Node size is based on the number of citations. Clusters are defined by different colours.

3.2.3. Co-occurrence keywords network

The co-occurrence of keywords analysis provided 2387 results. Setting a minimum threshold of 10 occurrences to be included in the co-occurrence keywords network, 103 keywords were selected. The top 20 keywords are reported in Table 3. The keyword "biodiversity" had the largest occurrence (86) and total link strength (735), highlighting the importance of these complex and heterogenic habitats (Fig. 4 a,b). Indeed, coralligenous bioconstructions are key benthic biodiversity hotspots of the Mediterranean Sea, that offer shelter for a wide spectrum of species, some of them of commercial interest (Ballesteros, 2006).

The most studied organisms composing coralligenous assemblages are reported in Table 4 and visualized in Fig. 5. “Algae”, “anthozoa”, and “bryozoa” keywords have the largest occurrence (58, 55, 31, respectively) and total link strength (156, 128, 110, respectively). In the network map, four clusters are easily recognizable. They represent the main taxa composing coralligenous assemblages, in detail: Bryozoa and Anthozoa belong to the red-violet cluster, coralline algae (Corallinophycidae, Rhodophyta) to the blue cluster, Porifera to the yellow cluster, and Mollusca and Crustacea, the only two taxa with vagile species, to the green cluster. The node size indicates that the most frequent keywords are represented by sessile and calcifying-structuring species. Most of these taxa are sensitive to human pressures, such as fishing and deep-sea mining at local scale (Ramirez-Llodra et al., 2010), or climate changes (ocean acidification and warming) at global scale (Martin and Gattuso, 2009). When threatened, these communities may change in composition and structure (Althaus et al., 2009; Ferrigno et al., 2018a), often with no possible recovery (Williams et al., 2010).

Fig. 4b shows the overlay visualization map based on the average year of documents’ publication. The keywords distribution along a temporal gradient allowed for the understanding of the evolution in coralligenous research, highlighting the latest studies and lines of research. A shift from taxonomic and ecologically-based studies, on species richness and diversity and community composition and structure, to conservation ecology ones, on ecosystem monitoring and management, is incoming in these last years. This shift is evident in Fig. 4b by the colour variation from blue to yellow, moving through green. In fact, the keywords related to the anthropogenic pressures and impacts on coralligenous were only 5 and their occurrence was relatively low: “climate change” (20), “anthropogenic effect” (15), “fisheries” (14), “human activity” (14) and “fishing” (12); nevertheless, their colour tending to yellow (Fig. 4b) highlights the increasing awareness of the scientific and, more largely, the overall community to these topics, with positive effects on habitat conservation (e.g. management and protection).

In areas under high anthropic pressures, more detailed information at local scale are needed to allow effective measures for habitat protection (Appolloni et al., 2018b; Buonocore et al., 2019). Although the ecological and economic relevance of coralligenous assemblages, little is known about their specific biodiversity patterns, especially of deeper ones. Hence, a detailed assessment of the communities’ composition, abundance and distribution may provide useful management information, allowing the design and management of marine protected areas with different protection levels (Bo et al., 2014; Bavestrello et al., 2015).

Table 3. Top 20 keywords on coralligenous assemblages ranked according to their occurrence.

Keyword	Occurrences	Total Link Strength

Biodiversity	86	735
Algae	58	435
Anthozoa	55	492
Coral Reef	55	500
Benthos	46	394
Coralligenous	46	201
Animals	45	455
Coral	43	388
Ecosystems	43	372
Animal	39	389
Ecosystem	35	375
Invertebrates	32	263
Bryozoa	31	265
Conservation	31	292
Coralline Alga	31	241
Species Diversity	26	258
Environmental Protection	25	270
Paramuricea clavata	24	183
Adriatic Sea	23	132
Coral Reefs	23	218

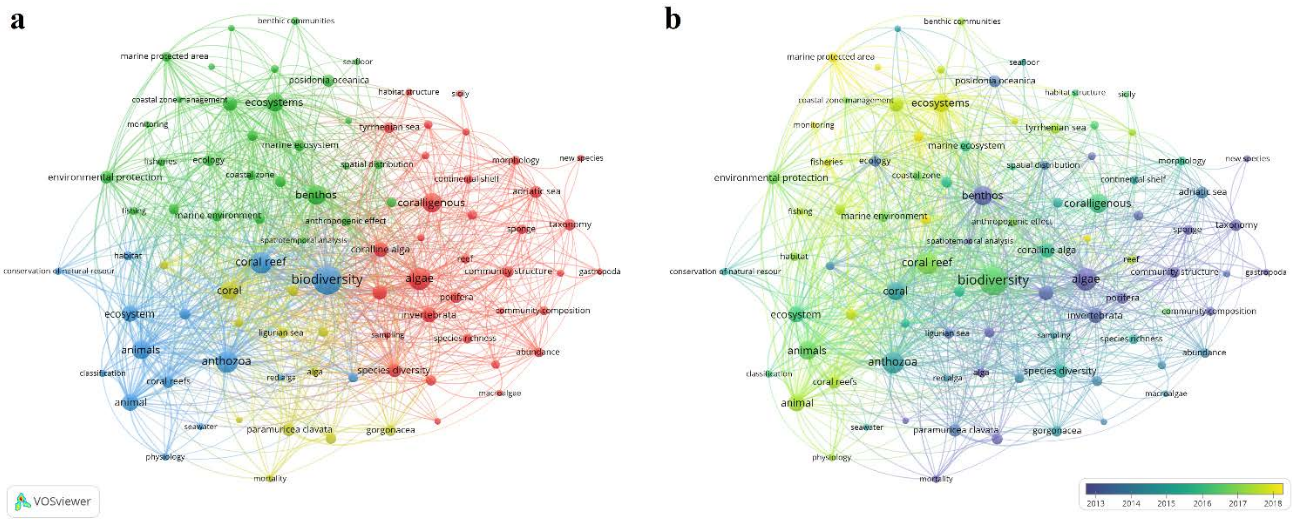

Fig. 4. Network maps of keywords co-occurrence. **a.** Cluster visualization. Clusters are defined by different colours. **b.** Overlay visualization, average publication year. Node size is based on the occurrence. Colours change according to the average publication year (scale).

Table 4. Keywords with at least 5 occurrences of the organisms composing coralligenous assemblages. Ranking is by number of occurrences.

Keyword	Occurrences	Total Link Strength
algae	58	156
anthozoa	55	128
bryozoa	31	110
coralline alga	31	76
paramuricea clavata	24	83

porifera	21	55
gorgonacea	19	73
gorgonia	19	68
rhodophyta	16	59
sponge	16	38
alga	15	40
corallium rubrum	15	39
bryozoan	14	35
macroalga	14	33
bivalvia	11	50
gastropoda	10	42
macroalgae	10	17
red alga	10	36
coralline algae	9	13
demospongiae	8	18
eunicella cavolini	8	32
mollusca	8	27
soft coral	8	33
sponge (porifera)	8	24
bivalve	7	27
cnidaria	7	32
eunicella singularis	7	31
polychaeta	7	34
alcyonaria	6	23
brachiopoda	6	15
corallinales	6	16
crustacea	6	22
gorgonians	6	16
mollusc	6	20
rhodolith	6	14
sponges	6	8
crustose coralline algae	5	9
gastropod	5	17
gorgonian	5	25
green alga	5	26
paramuricea	5	27
pentapora fascialis	5	15
pisces	5	12
red coral	5	10

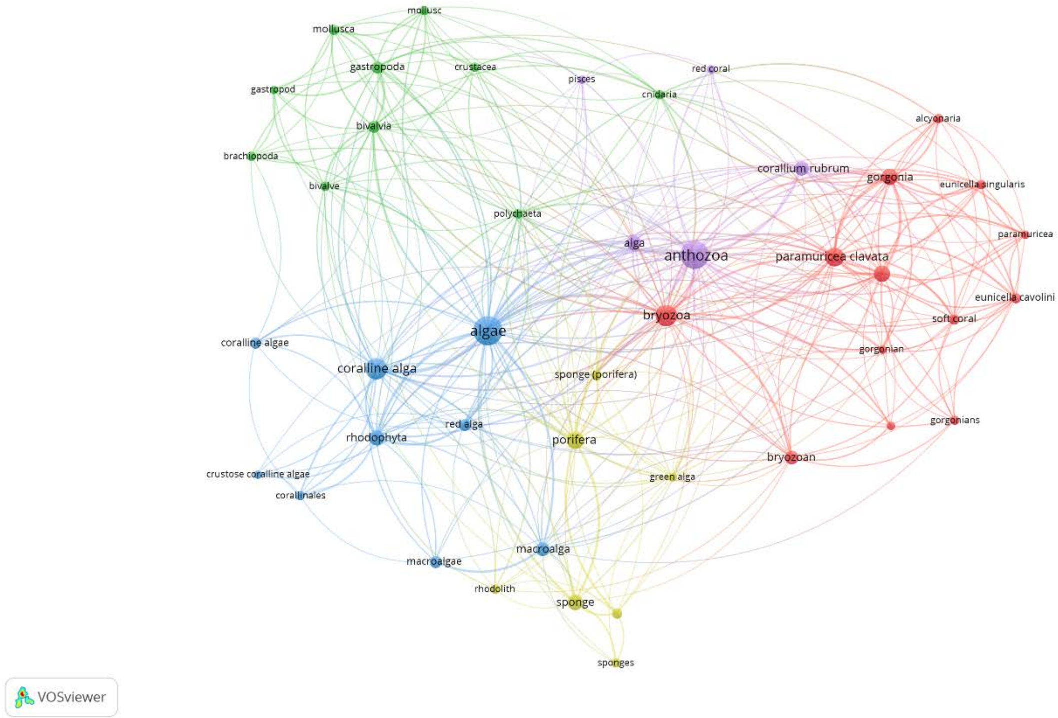

Fig. 5. Network map of keywords co-occurrence (cluster visualization) showing the main organisms composing coralligenous assemblages. Node size is based on the number of documents, while clusters are defined by different colours.

3.2.4. Citation analysis of journals and documents

The citation analysis of journals provided 144 results. Table 5 reports the journals with at least 4 documents on the coralligenous topic. *Ecological Indicators* ranked first for all the investigated parameters (18 documents, 368 citations, 181 total link strength). Using a 4-articles-per journal threshold, the citation network map included 21 journals (Fig. 6). These journals indicate that the study of the coralligenous assemblages extends in different fields of marine sciences and can have different applications, even though the central topics are represented by taxonomic and communities' studies or evaluation of the habitat health status and protection. This finding is in line with the co-authorship authors and co-occurrence keywords network analyses.

The most-cited documents dealing on coralligenous assemblages are reported in Table 6 and displayed in Fig. 7. The comprehensive review article "Mediterranean coralligenous assemblages: A synthesis of present knowledge" published in *Oceanography and Marine Biology* by Ballesteros (2006) has the highest number of citations (543).

Table 5. Journals with at least 4 documents on coralligenous assemblages. Ranking is by number of documents.

Source	Documents	Citations	Total Link Strength
Ecological Indicators	18	368	181

Frontiers In Marine Science	13	178	34
Plos One	13	721	90
Scientific Reports	13	290	84
Mediterranean Marine Science	10	145	88
Scientia Marina	10	194	83
Aquatic Conservation: Marine And Freshwater Ecosystems	9	233	119
Marine Pollution Bulletin	9	200	151
Marine Ecology	7	316	40
Diversity	6	35	33
Marine Biology	6	225	55
Regional Studies In Marine Science	6	71	28
Acta Adriatica	5	21	0
Estuarine, Coastal And Shelf Science	5	73	91
Journal Of The Marine Biological Association Of The UK	5	75	25
Marine Environmental Research	5	141	88
Coral Reefs	4	87	49
Marine Ecology Progress Series	4	243	26
Marine Geology	4	44	3
Ocean And Coastal Management	4	72	17
Palaeogeography, Palaeoclimatology, Palaeoecology	4	83	13

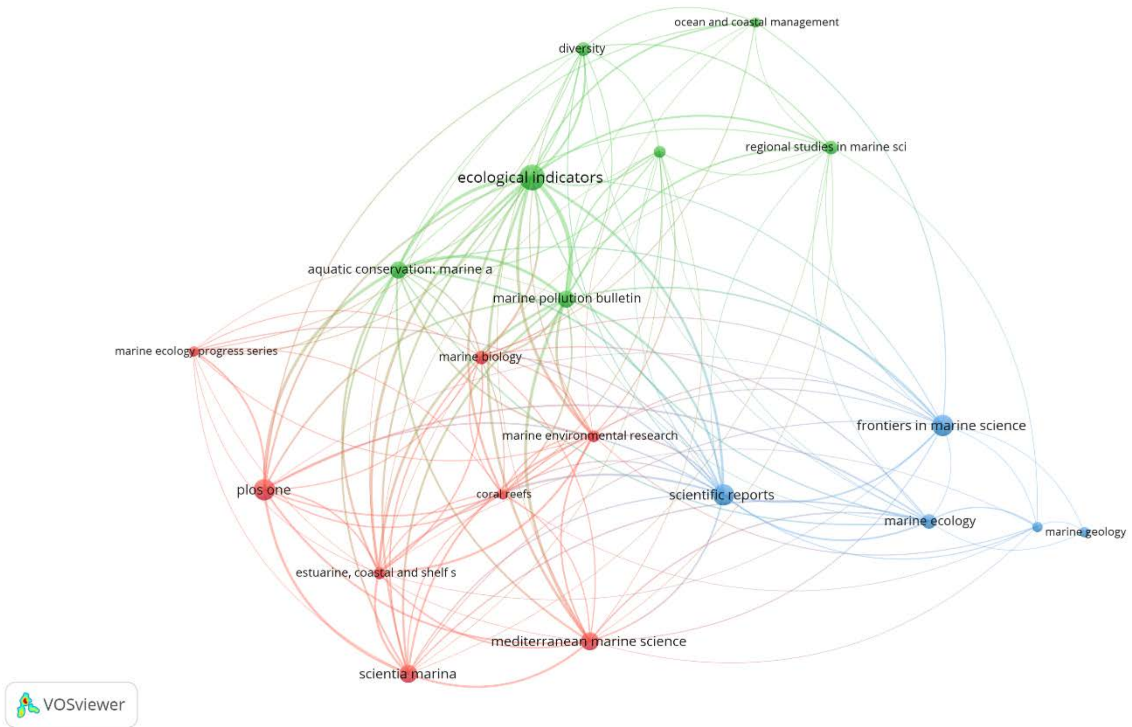

Fig. 6. Citations network map of journals (cluster visualization). Node size is based on the number of documents, while clusters are defined by different colours.

T**able 6.** Most cited documents on coralligenous assemblages. Ranking is by number of citations.

Document	Citations

Ballesteros E. (2006)	543
Martin and Gattuso (2009)	331
Canals and Ballesteros (1997)	156
Bavestrello et al. (1997)	136
Linares et al. (2005)	128
Giakoumi et al. (2013)	125
Linares et al. (2008)	123
Trygonis and Sini (2012)	118
Calvo et al. (2011)	114
Bo et al. (2011)	106
Coma et al (2004)	102
Ribes et al. (2012)	98
Balata et al. (2005)	96
Mokhtar-Jamaï et al. (2011)	91
Ingrosso et al. (2018)	89
Martin et al. (2013)	89
Martin et al. (2014)	86
Uriz et al. (1992)	82
Colloca et al. (2015)	79
Coma et al. (2006)	79
Sala et al. (1996)	74
Ponti et al. (2014)	72
Gatti et al. (2015a)	71
Teixidó et al. (2013)	70
Gili and Ros (1985)	70
Casellato and Stefanon (2008)	65
Virgilio et al. (2006)	63
Barberá et al. (2012)	61
Kipson et al. (2011)	60
Piazzi et al. (2012)	57
Teixidó et al. (2011)	57
Gatti et al. (2015b)	55
Cebrian et al. (2012)	55
Ferdeghini et al. (2000)	54
Deter et al. (2012)	53
Piazzi et al. (2004)	53
Franzese et al. (2017)	52
Ponti et al. (2011)	51
Rosso and Di Martino (2016)	50
Bertolino et al. (2013)	50
Baldacconi and Corriero (2009)	50
Linares et al. (2015)	49
Gatti et al. (2012)	46
Piazzi et al. (2007)	46
Rosso et al. (2013)	45
Cocito et al. (2002)	45
Galli et al. (2017)	42
Lacoue-Labarthe et al. (2016)	42
Peña et al. (2015)	42

Ben-Eliahu and ten Hove (1992)	42
Cecchi et al. (2014)	41
Casas-Güell et al. (2015)	40
Casellato et al. (2007)	40
Pezzolesi et al. (2019)	39
Morganti et al. (2017)	39
Lloret and Riera (2008)	39
Verdura et al. (2019)	38
Consoli et al. (2019)	38
Albano and Sabelli (2011)	38
Ferrigno et al. (2018a)	37
Ferrigno et al. (2017)	37
Muñoz et al. (2008)	37

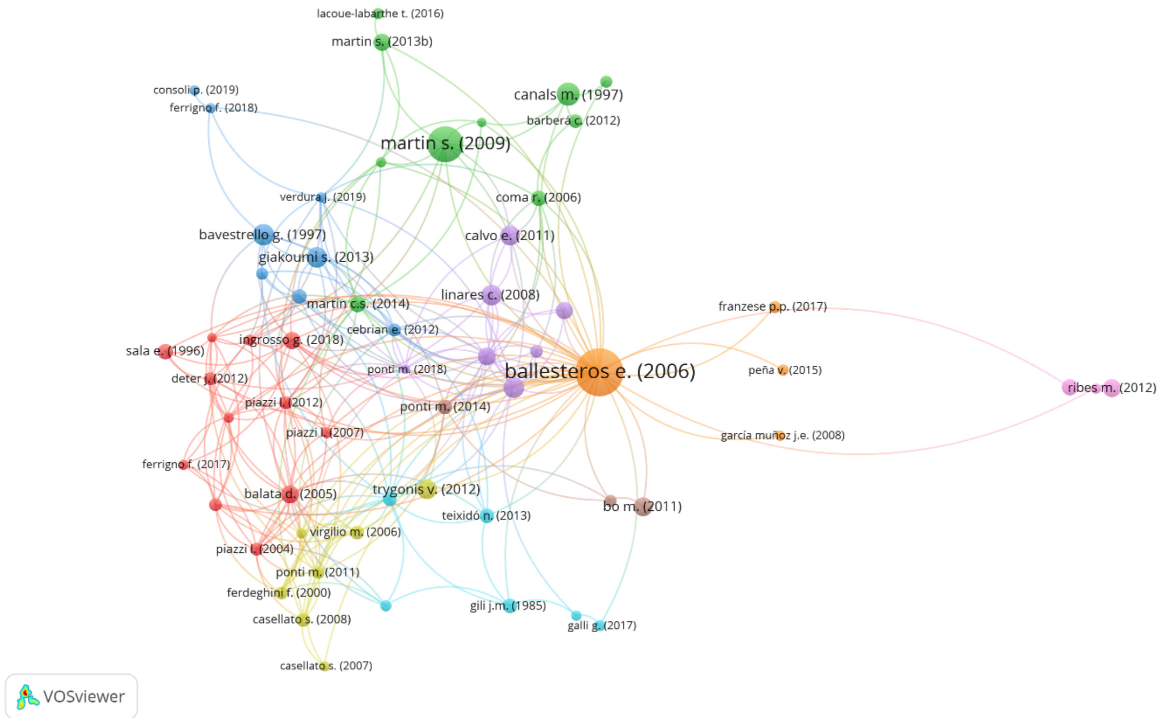

Fig. 7. Citations network map of documents (cluster visualization). Node size is based on the number of documents, while clusters are defined by different colours.

3. Conclusions

In this work, the whole scientific literature on coralligenous assemblages was investigated trough a bibliometric network analysis, providing a complete overview of the indexed scientific literature on this issue.

The total number of scientific publications on this topic (339) showed that the information on coralligenous assemblages is still very fragmented, even if there is an evident growth in the attention of the scientific community to these remote benthic habitats unique of the Mediterranean Sea. The analyses revealed that Piazzi was the most productive author in terms of number of documents (33), while Ballesteros was the most cited one (1109). Italy resulted the country with the highest values for all investigated parameters (202 documents, 4004 citations, 96 total link strength), creating, together with Spain and France, a “central” collaborative relation.

The term “biodiversity” was the keyword with both the largest occurrence (86) and total link strength (735), highlighting the importance of these complex and heterogenic habitats. Among the taxonomic groups, “algae” (58), “anthozoa” (55), and “bryozoa” (31) were the keywords with the largest occurrence, indicating that the most frequent keywords are represented by structuring taxa. Only 5 keywords were related to the anthropogenic pressures/impacts and their occurrence was relatively low, but with an increasing trend in the last years: “climate change” (20), “anthropogenic effect” (15), “fisheries” (14), “human activity” (14) and “fishing” (12). Finally, *Ecological Indicators* (Elsevier) ranked first by number of documents (18), citations (368), and total link strength (181), while the review article “Mediterranean coralligenous assemblages: A synthesis of present knowledge” published in *Oceanography and Marine Biology* by Ballesteros (2006) has the highest number of citations (543).

Overall, the results showed a publication trend shifting from the taxonomy/ecology-based field, with studies on community composition and structure, to the conservation ecology one, with studies on anthropogenic impacts, ecosystem conservation and management. These findings underline the importance and vulnerability of coralligenous bioconstructions and the necessity to adopt efficient monitoring programs and protection policies to preserve these crucial habitats and maintain the coastal ecosystem functions and services they provide.

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.

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