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Contribution to the Special Issue: Marine Animal Forest of the World (MAF WORLD)

Can Marine Animal Forests benefit from existing conservation measures? A systematic approach towards the identification of protected sessile benthic species in the Mediterranean Sea

Lucia RIZZO[1,2,3], Tomás VEGA FERNÁNDEZ[2], Francesca NECCI[2,4], Michaël GRELAUD[5], Patrizia ZIVERI[5, 6, 7], Vasilis GEROVASILEIOU[8,9,10], and Sergio ROSSI[3,4]

[1] Institute of Sciences of Food Production, National Research Council (CNR-ISPA), Via Lecce Monteroni, 73100 Lecce, Italy
[2] Department of Integrative Marine Ecology, Stazione Zoologica Anton Dohrn, Villa Comunale, I-80121 Napoli, Italy
[3] National Interuniversity Consortium for Marine Sciences (CoNISMa), Piazzale Flaminio 9, 00196 Rome, Italy
[4] Dipartimento di Scienze e Tecnologie Biologiche e Ambientali (DiSTeBA), Università del Salento, 73100, Lecce, Italy
[5] Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Spain
[6] Institució Catalana de Recerca i Estudis Avancats (ICREA), 08010 Barcelona, Spain
[7] BABVE Dept. Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona Spain
[8] Department of Environment, Faculty of Environment, Ionian University, 29100 Zakynthos, Greece
[9] Hellenic Centre of Marine Research (HCMR), Institute of Marine Biology, Biotechnology and Aquaculture (IMBBC), 71500 Heraklion, Greece
[10] IUCN Species Survival Commission Sponge Specialist Group

Corresponding author: lucia.rizzo@cnr.it; Lucia RIZZO

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Abstract

Some marine benthic invertebrates increase the structural complexity of the seabed, thereby providing suitable habitats to several associated species, resulting in biodiversity hotspots. Marine Animal Forests (MAFs) encompass a set of the most important marine benthic habitats into which diversified sessile suspension feeders like sponges, corals, sea pens, tube worms, bivalves, bryozoans and ascidians occur. Such a mix of sessile species brings characteristic assemblages and supports important ecosystem functions. In the last decades, some species which form MAFs have been the object of international conventions, EU directives, and national policies aiming to address natural and human-induced disturbances. Effective conservation, monitoring, and restoration actions require summarizing the available information to include MAFs in conservation plans. In the present work, the main international policies for the protection of coastal and marine fauna were screened in order to provide a list of protected species which form Mediterranean MAFs. These international normative documents include the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on the Conservation of European Wildlife and Habitats (Bern Convention), the European Habitats Directive, and the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD Protocol) of the Barcelona Convention. The analysis of the normative items revealed that 62 Mediterranean potential MAF-forming species have been included in one or more legal annexes as protected species. These species belong to different phyla, including Porifera, Cnidaria, Bryozoa and Mollusca. A wider view was proposed by the International Union for Conservation of Nature (IUCN), setting the bases of a legal acknowledgement of the MAFs as one of the largest biomes on Earth. This study represents a first step to obtain a baseline of MAF legal protection framework in order to support the further implementation of management measures aimed at increasing the effective protection of MAFs. Reporting the status of the Mediterranean MAF species that should be considered in management plans and conservation measures will be crucial for policymakers, as well as for mitigating current and future impacts on these distinctive marine environments.

Keywords: marine conservation; marine policy; management measures; anthropogenic threats; human pressures.

Introduction

Some benthic invertebrate species can form three-dimensional structures increasing the architectural complexity of the habitat, thereby contributing to fostering species diversity and eventually giving rise to biodiversity hotspots. The involved species include diversified sessile suspension feeders (e.g., sponges, corals, sea pens, tube worms, bivalve molluscs, bryozoans, and ascidians), which share similar ecosystem functions. For this reason, the term "marine animal forests" (MAFs), which appeared in 1869 for the first time in the book "The Malay Archipelago" by Wallace (1869), has been re-introduced recently to merge these extremely diverse, productive, and little-known assemblages in a unique term based on the peculiar feeding behaviour and structural traits of these marine species. The aim was to shed light on the similarities of functions and structures between MAFs and terrestrial forests, although the latter are dominated by plants, while MAFs are dominated by animals (Rossi *et al.*, 2022; Orejas *et al.*, 2022). MAFs encompass some of the most important marine benthic habitats (Keith *et al.*, 2020). They are composed of benthic suspension feeding invertebrates with a size larger than 1 cm, providing complex structural habitats used by other species as refuge, foraging grounds, and nursery. As their terrestrial counterparts, MAFs can be monospecific (e.g., habitat forming sea pens or mussel beds) or multispecific (e.g., cold-water coral reefs and gardens, tropical and subtropical shallow water coral reefs). In the last years, technological advancements allowed to discover several previously unknown animal forests in the mesophotic and twilight zone (e.g., cold-water coral communities, sponge grounds, gorgonian and black coral gardens, among others), leading to an increasing interest on these assemblages by the scientific community (Rossi *et al.*, 2022; Rizzo *et al.*, 2025). MAFs cover wide areas of the seafloor and play a key role in ecosystem functioning. They provide nursery and shelter areas to several species, thereby contributing to fisheries sustainability, and their structures contribute to carbon immobilization in benthic ecosystems, hence helping to counteract the ongoing climate change (Cerrano *et al.*, 2000; Rossi & Rizzo, 2020; 2021; Soares *et al.*, 2020a,, 2023; Bramanti *et al.*, 2023). Moreover, MAFs inhabit a broad spectrum of diverse environments from the shallow tropical areas to the Antarctic shelf, down to deep cold-water environments, thus representing one of the most widely distributed biomes on the world (Keith *et al.*, 2020). Since they are largely unexplored, some MAFs could become extinct due to anthropogenic impacts without being ever known (Rossi *et al.*, 2017).

Benthic ecosystems are influenced by a wide array of human activities and pressures, including fishing, pollution, bioinvasions, and global anthropogenic change (Duarte *et al.*, 2020). Past and present ecological impacts jeopardize essential processes at several scales, with negative effects on the ecosystem services provided by MAFs to human societies worldwide (Thurstan *et al.*, 2017). Due to the impacts of the ongoing anthropogenic activities and pressures on marine ecosystems (Halpern *et al.*, 2008), the United Nations Environment Program (UNEP) adopted "Life Below Water - Sustainable Development Goal 14" as an essential goal in the Decade of Ocean Science for Sustainable Development (2021–2030) (www.oceandecade.org). In addition, some MAF-relevant assemblages have been included in conservation and management actions in the last decades (Ban *et al.*, 2014; Boyes & Elliot, 2014; Mackelworth *et al.*, 2019). For instance, shallow water coral reefs are protected under several international initiatives (e.g., International Coral Reef Action Network-ICRAN and International Coral Reef Initiative-ICRI). Deep-sea species occur in remote zones of the marine environment, where the effects of anthropogenic disturbances appear less evident. However, they are directly affected by fishing activities (especially bottom trawling) exhibiting low resilience due to their long life cycles, slow growth rate and fragility (Maynou & Cartes, 2012; Bo *et al*., 2014; Lauria *et al*., 2017). For these reasons, they have been recognized as Vulnerable Marine Ecosystems (VMEs) and as priority habitats in need of protection (Orejas *et al.*, 2022).

Several MAF-forming benthic invertebrates are listed for protection in national policies, as well as European directives (e.g., Habitats Directive) and international conventions (e.g., the Barcelona and Bern Conventions) (Orejas *et al.*, 2022). Therefore, a systematic review of the main international marine policy frameworks for the protection of coastal and marine fauna was deemed essential and conducted to identify MAF species inhabiting the Mediterranean Sea and assess the adequacy of their protection at the regional level. The obtained results are presented to support future plans in the implementation of key policies. This includes the assessment of MAFs' conservation status according to the criteria of the International Union for Conservation of Nature (IUCN) Red List, which is the most comprehensive compilation of the global conservation status of species and is widely used as a tool for species management, conservation planning, monitoring and decision-making.

Materials and Methods

Overview of conservation policies

Four international legal frameworks and agreements that list Mediterranean marine animal species as deserving protection were screened to identify protected MAF-forming species (Table 1).

The Bern Convention (BC) was the first voluntary agreement on species conservation in European, African, and Middle Eastern countries. The BC includes lists of periodically updated species requiring priority in conservation measures (EU, 1992). In the European Union (EU), nature conservation policies have been defined and translated into national laws by Member States. The EU Habitats Directive (HD) represents the legal foundation of the European nature conservation policy, listing numerous protected habitats and species in its annexes (Di-

Table 1. Annexes of the EU Habitats Directive (HD), the Bern (BC) and Barcelona (SPA/BD) conventions as well as the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES). Text in bold highlights annexes (i.e., Latin numeration) which include marine animal species.

International legal frameworks	Annexes	Description
Habitats Directive (HD)	I-HD	Natural habitat types of EU interest whose conservation requires the designation of Special Areas of Conservation (SACs) forming the Natura 2000 Network
	II-HD	**Animal and plant species of community interest whose conservation requires the designation of SACs**
	III-HD	Selection criteria for areas to be designated as SACs
	IV-HD	**Animal and plant species of community interest in need of strict protection**
	V-HD	**Animal and plant species of community interest whose exploitation may be subject to management measures**
Bern Convention	I-BC	Strictly protected plant species
	II-BC	**Strictly protected animal species**
	III-BC	**Protected animal species**
	IV-BC	Prohibited tools and methods of killing, capturing, and exploiting species
SPA/BD protocol of Barcelona Convention	I-SPA/BD	Common criteria for the choice of protected marine and coastal areas that could be included in the SPAMI (Specially Protected Areas of Mediterranean Importance) List
	II-SPA/BD	**Endangered or threatened species**
	III-SPA/BD	**Species whose exploitation is regulated**
CITES	**I-CITES**	**Species threatened with extinction and that are or may be affected by trade, they 'must be subject to particularly strict regulation in order not to endanger further their survival and must only be authorized in exceptional circumstances'**
	II-CITES	**Species which although not necessarily now threatened with extinction may become so unless trade in specimens of such species is subject to strict regulation in order to avoid utilization incompatible with their survival'**
	III-CITES	**Species which any Party identifies as being subject to regulation within its jurisdiction for the purpose of preventing or restricting exploitation, and as needing the co-operation of other Parties in the control of trade'**

rective 97/62/EC, Regulation EC No. 1882/2003, Directive 2006/105/EC, Directive 2013/17/EU).

The Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Amended Barcelona Convention) is a regional convention adopted in 1976 and amended in 1995 to prevent pollution from ships, aircraft and land-based sources (dumping, run-off, and discharges) in the Mediterranean basin. The Barcelona Convention and its protocols form the unified legal body of the Mediterranean Action Plan, developed under the United Nations Environment Program (UNEP). In particular, marine protected areas (MPAs) benefit from the Protocol Concerning Specially Protected Areas and Biological Diversity (SPA/BD) in the Mediterranean, signed in 1995 and entered into force in 1999. Annexes of the SPA/BD Protocol include common criteria for the choice of protected marine and coastal areas, as well as lists of endangered or threatened species and species whose exploitation is regulated.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is the largest international body of legislation on the trade of wildlife, as a result of large declines in wild fauna and raising illegal trade confiscations (Waeber *et al.*, 2019). It contains three appendices, which regulate the commercial international trade of the identified species by using export and import permits. For taxa not included in the CITES list, no such regulatory framework exists to monitor their international trade.

Identification of protected species forming Marine Animal Forests

In this work a wide concept of MAF was adopted including potential MAF-forming species following the definition and characteristics proposed by Orejas *et al.* (2022). In particular, MAF include megabenthic invertebrates (> 1 cm) that form structural three-dimensional complexity of different sizes and sometimes canopies. A review of the relevant available information was conducted in order to identify protected MAF-forming species listed in the annexes of the HD, BC, SPA/BD and CITES (Table 1). In cases where protected taxa were listed at taxonomic ranks higher than the species level (e.g., genera *Aplysina* and *Tethya* for sponges, order Scleractinia for cup corals), species within these taxonomic groups occurring in the Mediterranean Sea were sourced from the World Register of Marine Species (WoRMS) and existing scientific literature (Coll *et al*., 2010).

Results and Discussion

Protected MAF- forming species

The analysis of the normative items showed that 62 Mediterranean species with the potential to form MAFs (*sensu lato*) have been included in one or more lists of protected species (Table 2). These species belong to four different phyla, including Porifera (14), Cnidaria (44), Mollusca (3), and Bryozoa (1). Only eight cnidarian species are protected by three different normative documents, while 16 species (6 Porifera, 7 Cnidaria, and 3 Mollusca) are protected both by SPA/BD and at least another normative document. The majority of species (38) are protected by only one normative item; more specifically, 12 MAF-forming species (8 Porifera, 3 Cnidaria, and 1 Bryozoa) are reported in one of the annexes of the SPA/BD and 25 cnidarians are only protected by CITES. The EU's HD protects only two MAF species, namely the red coral *Corallium rubrum* and the largest Mediterranean mollusc, *Pinna nobilis.* The former is listed in Annex V as being exploited according to management measures adopted locally (Tsounis *et al*., 2013), and the latter is reported in Annex IV, receiving high legal protection level since any form of collection, killing, possession and exchange for commercial purposes is prohibited. No marine species belonging to the phyla Porifera, Arthropoda, and Bryozoa, receive any kind of legal protection by HD.

Table 2. MAF-forming species protected by the EU Habitats Directive (HD), the Bern (BC) and Barcelona Conventions (SPA/BD) as well as the Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES). Available IUCN Red List categories are reported (CR – Critically Endangered, EN – Endangered, VU – Vulnerable, NT – Near Threatened, DD – Data Deficient, LC – Least Concern). Latin numbers refer to the annexes of each legislative documents.

Species	Authority	HD	BC	SPA/BD	CITES	IUCN
Porifera						
Aplysina aerophoba	(Nardo, 1833)	-	-	II	-	-
Aplysina cavernicola	(Vacelet, 1959)	-	II	II	-	-
Axinella cannabina	(Esper, 1794)	-	-	II	-	-
Axinella polypoides	Schmidt, 1862	-	II	II	-	-
Geodia cydonium	(Linnaeus, 1767)	-	-	II	-	-
Hippospongia communis	(Lamarck, 1814)	-	III	III	-	-
Sarcotragus foetidus	Schmidt, 1862	-	-	II	-	-
Sarcotragus pipetta	(Schmidt, 1868)	-	-	II	-	-
Spongia (Spongia) lamella	(Schulze, 1879)	-	III	III	-	-
Spongia (Spongia) officinalis	Linnaeus, 1759	-	III	III	-	-
Spongia (Spongia) zimocca	Schmidt, 1862	-	III	III	-	-
Tethya aurantium	(Pallas, 1766)	-	-	II	-	-
Tethya citrina	Sarà & Melone, 1965	-	-	II	-	-
Tethya meloni	Corriero, Gadaleta & Bavestrello, 2015	-	-	II	-	-
Cnidaria						
Antipathella subpinnata	(Ellis & Solander, 1786)	-	III	II	II	NT
Antipathes dichotoma	Pallas, 1766	-	III	II	II	NT
Antipathes fragilis	Gravier, 1918	-	III	II	II	-
Astroides calycularis	(Pallas, 1766)	-	II	II	II	LC

Continued

Table 2 continued

Species	Authority	HD	BC	SPA/BD	CITES	IUCN
*Balanophyllia (Balanophyllia) europaea**	(Risso, 1827)	-	-	-	II	LC
*Balanophyllia (Balanophyllia) regia**	Gosse, 1853	-	-	-	II	DD
Callogorgia verticillata	(Pallas, 1766)	-	-	II	-	NT
*Caryophyllia (Caryophyllia) calveri**	Duncan, 1873	-	-	-	II	DD
*Caryophyllia (Caryophyllia) cyathus**	(Ellis & Solander, 1786)	-	-	-	II	DD
*Caryophyllia (Caryophyllia) sarsiae**	Zibrowius, 1974	-	-	-	II	-
*Caryophyllia (Caryophyllia) smithii**	Stokes & Broderip, 1828	-	-	-	II	LC
*Caryophyllia (Caryophyllia) inornata**	(Duncan, 1878)	-	-	-	II	LC
Ceratotrochus magnaghii	Cecchini, 1914	-	-	-	II	DD
Cladocora caespitosa	(Linnaeus, 1767)	-	-	II	II	EN
*Cladocora debilis**	Milne Edwards & Haime, 1849	-	-	II	II	DD
Cladopsammia rolandi	Lacaze-Duthiers, 1897	-	-	-	II	DD
Coenocyathus anthophyllites	Milne Edwards & Haime, 1848	-	-	-	II	DD
Coenocyathus cylindricus	Milne Edwards & Haime, 1848	-	-	-	II	-
Corallium rubrum	(Linnaeus, 1758)	V	III	III	-	EN
Dendrophyllia cornigera	(Lamarck, 1816)	-	-	II	II	EN
Dendrophyllia ramea	(Linnaeus, 1758)	-	-	II	II	VU
Desmophyllum dianthus	(Esper, 1794)	-	-	II	II	EN
Desmophyllum pertusum	(Linnaeus, 1758)	-	-	II	II	EN
Ellisella paraplexauroides	Stiasny, 1936	-	-	II	-	VU
Errina aspera	(Linnaeus, 1767)	-	II	II	II	-
Guynia annulata	Duncan, 1872	-	-	-	II	DD
Hoplangia durotrix	Gosse, 1860	-	-	-	II	DD
Isidella elongata	(Esper, 1788)	-	-	II	-	CR
Javania cailleti	(Duchassaing & Michelotti, 1864)	-	-	-	II	DD
Leiopathes glaberrima	(Esper, 1792)	-	III	II	II	EN
Leptopsammia pruvoti	Lacaze-Duthiers, 1897	-	-	-	II	LC
Madracis pharensis	(Heller, 1868)	-	-	-	II	DD
Madrepora oculata	Linnaeus, 1758	-	-	II	II	EN
Monomyces pygmaea	(Risso, 1827)	-	-	-	II	LC
Oculina patagonica	de Angelis D'Ossat, 1908	-	-	-	II	LC
Paracyathus pulchellus	(Philippi, 1842)	-	-	-	II	DD
Parantipathes larix	(Esper, 1788)	-	III	II	II	NT
Phyllangia americana	Milne Edwards & Haime, 1849	-	-	-	II	DD
Polycyathus muellerae	(Abel, 1959)	-	-	-	II	LC
Pourtalosmilia anthophyllites	(Ellis & Solander, 1786)	-	-	-	II	DD
Savalia savaglia	(Bertoloni, 1819)	-	II	II	-	NT
Sphenotrochus (Sphenotrochus) andrewianus	Milne Edwards & Haime, 1848	-	-	-	II	DD
Stenocyathus vermiformis	(Pourtalès, 1868)	-	-	-	II	DD
Thalamophyllia gasti	(Döderlein, 1913)	-	-	-	II	DD
Mollusca						
Pinna nobilis	Linnaeus, 1758	IV	-	II	-	CR
Pinna rudis	Linnaeus, 1758	-	II	II	-	-
*Dendropoma petraeum***	(Monterosato, 1884)	-	II	II	-	-
Bryozoa						
Hornera mediterranea	Harmelin, 2020	-	-	II	-	-

* Uncertain MAF.

** Genetic studies have shown that a complex of cryptic species is included under the name *Dendropoma petraeum*, therefore all the species comprising this complex should be included in the annexes of the Bern and Barcelona conventions.

Porifera

Sponges are one of the most important faunal components of marine ecosystems and play a critical role in maintaining ecosystem function and structure (Bell, 2008; Lesser & Slattery, 2013; Bell *et al.*, 2023). With their high morphological diversity and three-dimensional complexity, Porifera create highly structured habitats on either shallow or deep-sea bottoms, which are known as sponge grounds or aggregations (Maldonado *et al.*, 2017; Santín *et al.*, 2021). These habitats serve as shelter or nursery (also known as "living hotels") for an abundant and rich associated fauna (Koukouras *et al*., 1996; Bell, 2008; Gerovasileiou *et al*., 2016). In the North-eastern Atlantic, deep-sea sponge aggregations have been characterized as VMEs by the Food and Agriculture Organization of the United Nations (FAO) and the Commission of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR). Nevertheless, there are still important gaps concerning sponge distribution, patterns of temporal variation in their populations and assemblages, as well as their global conservation status (Bell *et al.*, 2015; Gerovasileiou *et al.*, 2018). Our review revealed that 16 sponges are protected by normative items, specifically the Bern and the Barcelona Conventions, of which 14 can be considered as MAF-forming species *sensu lato* (Table 2). Two species, the carnivore demosponge *Lycopodina hypogea* and the calcarean *Petrobiona massiliana* are protected by the Bern and Barcelona Conventions, but they were not considered MAF-forming species here due to their rather small size (usually < 1 cm) and density. Among the protected MAF-forming species, two are listed in the II-BC as strictly protected fauna and 10 are included in the II-SPA/BD as endangered or threatened species (Table 2). In addition, the four Mediterranean bath sponges, *Spongia* (*Spongia*) *lamella*, *S.* (*S.*) *officinalis*, *S.* (*S.*) *zimocca*, and *Hippospongia communis*, which have been exploited by humans since antiquity (Voultsiadou *et al*., 2011), are listed in the III-BC as protected species and the III-SPA/BD as species whose exploitation is regulated. No sponge is protected by the HD or is included in the CITES lists. Overall, the number of protected sponge species is very low when considering their high diversity in the Mediterranean Sea (i.e., approximately 700–800 species half of which are endemics) and their key role in ecosystem functioning (Voultsiadou, 2009; Gerovasileiou & Voultsiadou, 2012). Barea-Azcon *et al.* (2008) expressed concern for the conservation status of the species *Aplysina aerophoba*, *Calyx nicaeensis*, *Petrosia ficiformis*, and *Scopalina lophyropoda* in Andalusian waters (Spain). In a recent study, Gerovasileiou *et al.* (2018) evaluated for the first time the regional conservation status of 20 sponge species in the Aegean Sea (species listed in the annexes II-BC, III-BC, II-SPA/BD, III-SPA/BD and certain Aegean endemics), using the IUCN Red List criteria. According to their findings, nine endemic and rarely reported species should be characterized as data deficient due to the limited available data, seven species should be assigned to the least concern category due to their broad geographical range and the absence of serious threats, while the four harvested Mediterranean bath sponges should be assigned to the endangered category, based on their population decline during the past decades (Voultsiadou *et al*., 2011; 2013; Gerovasileiou *et al*., 2018). However, to date only 24 Pacific sponge species have been included in the IUCN Red List while the Red List assessment of Mediterranean Porifera was initiated in 2019 by the IUCN Centre for Mediterranean Cooperation (IUCN-Med) and is still under way in collaboration with the ongoing Biodiversa+ SponBIODIV project (https://sponbiodiv.org/). An IUCN Species Survival Commission (SSC) Sponge Specialist Group was recently established with the aim of driving sponge conservation assessment and planning (Xavier *et al*., 2025).

Cnidaria

Cnidarians can be found in various marine environments worldwide, ranging from the intertidal zones to the deep ocean. The subphylum Anthozoa includes hard and soft corals, gorgonians, sea pens, black corals, and anemones. Anthozoans play a crucial role in the formation and development of reef structures, particularly in tropical and subtropical waters. Several anthozoan species play a vital role as bio-constructors, creating habitats that provide shelter for many other organisms and harbour great biodiversity (Rossi *et al.*, 2019). The analysis of the main regulations envisaged in the Mediterranean has revealed 44 protected cnidarians, all of which can be considered MAF-forming species *sensu lato*. Three classes are represented: Hexacorallia (39), Octocorallia (4), and Hydrozoa (1). The Bern and Barcelona Conventions list 19 anthozoan species in their annexes (Table 2). In the Mediterranean Sea, CITES has been ratified by all States and plays a role in the protection of Mediterranean cnidarians. Currently, a total of 39 MAF-forming cnidarians are included in the II-CITES, such as the stony corals (Scleractinia), black corals (Anthipatharia), and a species belonging to the Anthoathecata order (i.e., *Errina aspera*), strengthening the cooperation between Mediterranean countries concerning their trade and regulations.

Protected Cnidarian MAFs: class Hexacorallia

Within Hexacorallia, the orders Antipatharia, Scleractinia and Zoantharia are represented in the examined legislation. Antipatharians ("black corals") are considered important habitat formers of the Mediterranean mesophotic and aphotic zones (Bo *et al.*, 2008; Chimienti *et al.*, 2020). Among the protected antipatharians four species (*Antipathella subpinnata*, *Antipathes dichotoma*, *Leiopathes glaberrima*, and *Parantipathes larix*) are currently assessed as near threatened or endangered by IUCN at Mediterranean level (https://www.iucnredlist.org/; Otero *et al.*, 2017; Mačić *et al.*, 2024). Among scleractinians, 33 Mediterranean species are covered by the existing legislation, most of which belong to the families Caryophylliidae (15 species) and Dendrophylliidae (7 species). The families Cladocoridae (*Cladocora caespitosa* and *C. debilis*) and Flabellidae (*Javania cailleti* and *Monomyces pygmaea*) are represented with two species each, while Guyniidae (*Guynia annulata*), Pocilloporidae (*Madracis pharensis*), Madreporidae (*Madrepora oculata*), Oculinidae (*Oculina patagonica*), Turbinoliidae (*Sphenotrochus andrewianus*) and Stenocyathidae (*Stenocyathus vermiformis*) are represented by only one species. In the Mediterranean Sea, coral reefs were widely distributed in the past (Aguirre & Jimenez, 1998; Kersting & Linares, 2012), but they currently have a reduced extension and distribution across the basin. Among the protected scleractinians, the species *Cladocora caespitosa, Dendrophyllia cornigera, Desmophyllum dianthus, Desmophyllum pertusum* and *Madrepora oculata*, which form shallow (for *C. caespitosa*) and cold-water (remaining species) coral reefs, are listed as endangered. *Dendrophyllia ramea* is listed as vulnerable in the IUCN Red List at the Mediterranean level (Otero *et al.*, 2017). The remaining species have been assigned to the least concern category (eight species), seventeen are data deficient, while two species have not yet been evaluated for their conservation status (Table 2). In the Mediterranean Sea scleractinians are known to contribute to the so-called 'mesophotic coral ecosystems' (Soares *et al.*, 2020b) and to coralligenous bioconstructions, which represents the main calcareous formation of biogenic origin in the basin (Ballesteros, 2006). Scleractinia can build "forests" in the form of facies (e.g., facies with zooxanthellate and azooxanthellate Scleractinia in the infralittoral zone, facies with Scleractinia in the circalittoral zone) according to the interpretation manual of the Barcelona Convention Reference List of Marine Habitat Types in the Mediterranean Sea (UNEP/MAP-SPA/RAC, 2021). Although most Mediterranean scleractinian species are solitary (Ballesteros, 2006), species such as *Balanophyllia regia* and *Caryophyllia* spp. have been reported to form dense clusters. In the Adriatic Sea, specimens of *B. regia* have been reported to be crowded together and quite abundant, reaching 5–8 specimens m^{-2} (Kruzic *et al.*, 2002), while *B. europaea* on eastern Ligurian rocky coasts had an average density of 16 individuals m^{-2} and a peak of 113 individuals m^{-2} (Goffredo *et al.*, 2004). *Caryophyllia inornata* along the western Italian coasts ranged from 100 to 1500 individuals m^{-2} and *C. smithii* reached the maximum abundance of 100 individuals m^{-2} in the Dardanelles (Özalp *et al.*, 2014; Caroselli *et al.*, 2015). The scleractinians of the genera *Madracis*, *Leptopsammia*, *Polycyathus*, and *Hoplangia* genera can be also considered to form dense facies on the ceilings of marine caves and overhangs (Gerovasileiou & Bianchi, 2021).

The only protected species which belongs to the order Zoantharia is the gold coral *Savalia savaglia.* This species grows in the mesophotic twilight zone over other anthozoans (e.g., antipatharians), sometimes until it causes their death through necrosis (Previati *et al.*, 2010). The geographic distribution of *S. savaglia* within the Mediterranean Sea ranges from the Gibraltar Strait to the Sea of Marmara (Giusti *et al.*, 2015; Poliseno *et al.*, 2022). Colonies in the mesophotic zone increase habitat complexity, providing substrata for other organisms (Cerrano *et al.*, 2010; Canessa *et al.*, 2024). Together with other branching anthozoans that host epibionts, *S. savaglia* is threatened by human activities such as artisanal and recreational fishing, coastal pollution, and boat anchoring, being considered a near threatened species (Otero *et al.*, 2017).

Protected Cnidarian MAFS: classes Octocorallia and Hydrozoa

Among octocorals, the Mediterranean species *Callogorgia verticillata*, *Corallium rubrum*, *Ellisella paraplexauroides* and *Isidella elongata* are reported under different protection statuses. The gorgonian *C. verticillata* forms mixed coral gardens with other branched anthozoans and is listed as near threatened in the IUCN Red List (Otero *et al.*, 2017). The critically endangered bamboo coral *I. elongata* is a near-endemic species to the Mediterranean Sea (Lauria *et al.*, 2017; Georges *et al.*, 2024). Trawling activities, bottom line fishing, pollution, and sediment resuspension prompted by land-based activities are the main threats to bamboo corals (Maynou & Cartes, 2012; Mastrototaro *et al.*, 2017; Gerovasileiou *et al*., 2019). Likewise, soft corals (Rizzo *et al.*, 2021) and sea pen forests (Bastari *et al.*, 2018) provide essential fish habitats and constitute vulnerable marine ecosystems (VMEs) according to the European Commission. In this context, it is noteworthy that some sea pens (*Funiculina quadrangularis*, *Pennatula rubra*, *Pennatula phosphorea* and *Pteroeides spinosum*), and gorgonians (*Paramuricea clavata* and *Eunicella verrucosa*) are listed as vulnerable in the IUCN Red List (Cupido *et al.*, 2008; Otero *et al.*, 2017; Chimienti, 2020), while the gorgonian *Eunicella cavolinii* appears as least concern. Further studies are required to ascertain the gorgonian population status to evaluate their potential inclusion in the legal framework, including *Paramuricea macrospina*, a dominant gorgonian species in some Mediterranean mesophotic assemblages (Aguilar *et al.*, 2015; Grinyó *et al.*, 2016). The gorgonian *Ellisella paraplexauroides* is a large colonial invertebrate but presents a discontinuous distribution in the Mediterranean basin (Angiolillo *et al.*, 2012), with a noteworthy occurrence and high density in Chafarinas Islands (Maldonado *et al.*, 2013; Templado *et al.*, 2021). This species was included in 2013 in II-SPA/BD and is listed as vulnerable in the IUCN Red List since fishing gear entanglement causes damage, while pathogenic microbes and abnormally high seawater temperatures drive tissue necrosis.

Finally, the precious red coral *C. rubrum* is protected by V-HD, III-BC and III-SPA/BD, but is not protected by CITES. Its banks represent an important economic resource along the Mediterranean coasts since millennia and should be fully protected from exploitation down to 50 m deep to allow its slow recovery (Tsounis *et al.*, 2013; Bavestrello *et al.*, 2014). The General Fisheries Commission for the Mediterranean (GFCM) has established a minimum harvest colony size of 7 mm in basal diameter, equivalent to an age of 30–35 years (Marschal *et al.*, 2004; Cau *et al.*, 2013; Priori *et al.*, 2013). Local regulations, quotas, and fishing periods can be issued by each region (Tsounis *et al.*, 2013; Bramanti *et al.*, 2014). Red coral is protected by regional, national, and international laws and conventions and has recently been classified as an endangered in the IUCN Red List. However, red coral protection remains difficult to implement, because its harvesting is hard to manage, and illegal fishery still occurs in the basin (Santangelo & Bramanti, 2010). It is evident that over the past century, there has been a consistent decline in red coral landings, due to the near depletion of populations in numerous regions (Garrabou & Harmein, 2002; Tsounis *et al.*, 2013) as well as mass mortalities linked to seawater warming (Garrabou *et al.*, 2001; Cattaneo-Vietti *et al.*, 2016; Toma *et al.*, 2022). For these reasons, it becomes evident that current measures are not enough to ensure the survival of *C. rubrum* and the conservation of the habitats it supports (Tsounis *et al.*, 2013). Additional anthozoan species that could be also subjected to illegal trade (e.g., *Savalia savaglia*, *Ellisella paraplexauroides*) should be proposed for their inclusion in the CITES Appendices. Within the class Hydrozoa, the hydrocoral *Errina aspera* is the only protected species. Despite its taxonomic and biogeographical importance, few studies have focused on this calcareous deep species of the Mediterranean Sea (Salvati *et al.*, 2010).

Mollusca

Molluscs are generally well represented in lists of protected species from appendices to legal texts at the international level, such as CITES, as well as at national levels in several parts of the world (e.g., Endangered Species Act in the USA, Law of 10 July 1976 on Nature Conservation in France, and the Wildlife & Countryside Act of 1981 in UK) (Bouchet *et al.*, 1999). Yet, in the Mediterranean basin only three MAF-forming molluscs are protected, namely the pen shell *Pinna nobilis* (IV-HD and II-SPA/BD), the fan mussel *Pinna rudis* (II-BC and II-SPA/BD) and the vermetid gastropods of the genus *Dendropoma* (II-BC and II-SPA/BD).

The largest Mediterranean bivalve *Pinna nobilis* can reach high density as reported in the Aegean Sea (14.30± 9.14 individuals 100 m^{-2}) (Basso *et al.*, 2015), however, since 2016, a dramatic mass mortality event (MME) has affected the species in most Mediterranean areas and has brought *P. nobilis* close to extinction (e.g., Özalp & Kersting, 2020; Zotou *et al.*, 2020; Papadakis *et al.*, 2023; Stranga *et al.*, 2024). The first surveys suggested that *Haplosporidium pinnae*, a parasitic eukaryote, was the main etiological agent (Catanese *et al.*, 2018), but recent studies have indicated that multiple causes may be responsible for this phenomenon (Scarpa *et al.*, 2020). Molecular diagnostic analyses on *P. nobilis* and congeneric *P. rudis*, showed the occurrence of a multifactorial disease; *Mycobacterium* spp., pathogenic bacteria, and *H. pinnae* are not necessarily associated with the illness, further demonstrating how the *P. nobilis* MME is far from being fully understood (Scarpa *et al.*, 2020). *Pinna nobilis* species is now included in the IUCN Red List as critically endangered (Kersting *et al.*, 2019). This widespread disease outbreak of *P. nobilis* seems to favor *P. rudis* locally (Kersting & Ballesteros, 2021). Indeed, *P. rudis* is documented to be spreading northward and eastward in the Mediterranean (Gvozdenović *et al.*, 2019; Zotou *et al.*, 2023; Oprandi *et al.*, 2024). In addition to the above-mentioned bivalves, species of the gastropod genus *Dendropoma* can also form MAFs (Milazzo *et al.*, 2016). Recent studies revealed that these dominant endemic reef-building vermetids comprise a complex of several species (Templado *et al.*, 2016). The *Dendropoma* reefs provide numerous ecosystem services including protection from coast erosion, sediment transport regulation, carbon sinks, and habitat provision for invertebrates and fish (Milazzo *et al.*, 2016). In the Mediterranean Sea, such vermetids are commonly distributed along the warm-water coasts of the southern basin, where the temperature of water surface is not lower than 14 °C in winter and 24 °C in summer (Antonioli *et al.*, 1999; Calvo *et al.*, 2009; Donnarumma *et al.*, 2018). These reefs are functionally like tropical coral fringing reefs (Milazzo *et al.*, 2016), being also biodiversity hotspots. In recent years, a dramatic decrease and local extinction have been documented in the Eastern Mediterranean basin (Galil, 2013; Rilov, 2013; Badreddine *et al.*, 2019), hence the need for protection of these vermetid reefs has been highlighted by Gordó-Villaseca *et al.* (2022), among others. Notably, 95 living clusters of *D. anguliferum* were recently discovered in Israel after the fast decline in the *Dendropoma* populations observed during the last decades (Barneah *et al.*, 2024).

In addition to the abovementioned protected species, it is important to underline the importance of deep oyster reefs formed by *Neopycnodonte cochlear* in mesophotic Mediterranean environments (Angeletti & Taviani, 2020; Cardone *et al.*, 2020) and *N. zibrowii* along the European shelf and slope (Beuck *et al.*, 2016). European legislation currently supports the conservation of Mediterranean bioconstructions as resulting biogenic habitats (EU, 1992; Gubbay *et al.*, 2016). Coordinated actions at the basin scale should be crucial for the protection of these biogenic reefs in order to support local conservation efforts.

Bryozoa

Most of the habitat-forming bryozoans are heavily calcified species, which regularly attain sizes over 50 mm and increase the three-dimensional complexity of benthic habitats and the creation of bioconstructions. Large bryozoans provide habitat for diverse associated assemblages, particularly for other bryozoans, molluscs, annelids, arthropods, cnidarians, sponges, echinoderms and macroalgae (Wood *et al.*, 2012; Lombardi *et al.*, 2008, 2020). They constitute nursery grounds for some juvenile fish species, support rich macroinvertebrate assemblages and are also associated with commercial fishing grounds

(Cocito *et al.*, 2001; Wood *et al.*, 2012). Habitat-forming bryozoans are common in temperate continental shelf environments where water circulation is high and continuous (Wood *et al*., 2012). Bryozoans are abundant in several areas worldwide including New Zealand, Antarctica, the North Pacific (around Japan), the northern Mediterranean Sea (e.g., Adriatic Sea), and along the English Channel and the North Sea (Wood *et al.*, 2012). In the Mediterranean Sea, the updated bryozoan checklist consists of 588 species, 220 genera and 99 families and represents a unique tool to monitor and conserve regional biodiversity (Rosso & Di Martino, 2023). However, only one species is protected by the Mediterranean legislation, namely *Hornera mediterranea* (reported as *H. lichenoides* in II-SPA/BD). *Hornera* Lamouroux, 1821, is a genus which includes large, rigidly erect, and ramified species (Harmelin, 2020). It is not clear why this species was designated as threatened, and it is probable that this is the result of wrong attribution and further confusion between Mediterranean *H. frondiculata* and *H. mediterranea* (Harmelin, 2020). Based on current knowledge, both *Hornera* species are believed to be exclusive to the Mediterranean region. Their habitats are different, with *H. frondiculata* found at depths of 30 to 100 m on rocky walls and flat bottoms with coarse elements, while *H. mediterranea* is found at depths of 55 to 200 m on flat sandy bottoms (Harmelin, 2020). Further studies are needed to verify its capacity to form aggregations.

Although bryozoans are one of the main components of the sessile macrozoobenthos (Harmelin, 1985; Lombardi *et al.*, 2014; Casoli *et al.*, 2020), they are a forgotten group on the red lists (Lombardi *et al.*, 2020). The effective protection of threatened species is troublesome by the fact that bryozoans create a frequently unrecognized habitat type (Wood *et al.*, 2012). Among Mediterranean unprotected MAF-forming bryozoans, there are large bush-like well-skeletonized colonial species (e.g., *Adeonella* spp., *Myriapora truncata*, *Pentapora* spp., *Reteporella* spp., and *Smittina* spp.) since they are able to act as frame-builders in unstable substrates and semi-dark rocky environments (Sala *et al.*, 1996; Garrabou *et al.*, 1998; Casoli *et al.*, 2016; Rosso *et al.*, 2019; Pagès-Escolà *et al.*, 2020; Lombardi *et al.*, 2020). The first step to protect these species will be to map, describe and quantify their populations. Identifying and mapping these habitat-forming species is crucial to protect these ecologically important habitats from detrimental human pressures (e.g., mechanical damage due to recreational activities, bottom fishing, increased sedimentation, and pollutants), as well as to adopt international protocols for the protection of bryozoans in VMEs.

Conclusions

This paper reviewed key conservation policies to identify Mediterranean MAF-forming species subject to legal protection. It provides an overview of the existing legislative framework, serving as a starting point to identify conservation gaps and mitigate the loss of MAF biomass, functionality, and biodiversity in the Mediterranean basin. In total, 62 MAF-forming species are currently protected in the Mediterranean Sea, with only two species (i.e., *Corallium rubrum* and *Pinna nobilis*) being listed in the EU Habitats Directive, the primary legislative tool for nature conservation in the EU.

Many MAF-forming species are long-lived, deeply threatened by multiple pressures and difficult to recover. Beyond human-induced environmental change, recent explorative campaigns conducted within the Mediterranean basin have shown that different MAFs are threatened by fisheries activities such as trawling, dredging and harvesting. The Marine Strategy Framework Directive (EU, 2008) emphasizes key descriptors of “Good Environmental Status” (GES) such as “Biodiversity”, which should be preserved in its natural state, and “Sea-floor Integrity”, which should be regularly monitored to ensure that structures and functions of ecosystems are safeguarded, and benthic ecosystems are not adversely affected. Although recent technological advancements in marine robotics and remote sensing allowed to explore the mesophotic and twilight zone, addressing data gaps and monitoring MAF status, much of the information about MAFs and their threats comes from a few and relatively small, surveyed areas. A recent study revealed that most of the invertebrates listed in II-SPA/BD are under-studied, with important knowledge gaps across several species within existing MPA networks (Stranga *et al.*, 2024). Broader conservation efforts should include protection of habitats, establishment of MPAs, and expansion of the available legal instruments (Combes *et al.*, 2021). Regional Fishery Management Organizations (e.g., FAO-GFCM) are legally obligated to protect VMEs), yet many indicator species (e.g., sponges) remain unprotected due to limited data on their distribution and abundance (Auster *et al.*, 2011; Fabri *et al.*, 2014). In addition, many currently non-protected species would deserve consideration, especially those MAF-forming species which could contribute to the mitigation of climate change through sequestration of carbon in their bodies (Rossi & Rizzo, 2020).

The effective protection of MAF species requires a transdisciplinary and transboundary cooperation among Mediterranean countries to share experiences and data sharing, ensure enforcement and promote the adoption of ecosystem-based management measures. Without unified environmental standards and coordinated implementation of protective measures, some protected areas are effectively “paper parks”, as illegal fishing and other anthropogenic activities lead to deterioration of these habitats (Matz-Lück & Fuchs, 2014). Awareness about the importance of conservation of the natural capital is continuously increasing as a scientific, government, and management issue. Future research on MAFs, specially that on data-deficient species, will be crucial to fill current knowledge gaps on most MAFs dampening the implementation of appropriate conservation and management measures in the Mediterranean basin.

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