Chapter

Mesophotic and Deep-Sea Vulnerable Coral Habitats of the Mediterranean Sea: Overview and Conservation Perspectives

Giovanni Chimienti, Francesco Mastrototaro and Gianfranco D'Onghia

Abstract

Although the different communities distributed in the mesophotic and deep waters play a fundamental role in the functioning of the marine ecosystems, the assessment of their global distribution is still far to be achieved. This is also true in the Mediterranean Sea, where exploration technologies are revealing a large diversity of unknown communities structured totally or partially by corals, which represent vulnerable marine ecosystems (VMEs) according to FAO's guidelines. This chapter aims to define and describe the main coral habitats of the mesophotic and aphotic zones of the Mediterranean, such as coralligenous formations, cold-water coral frameworks, coral forests and sea pen fields. The role of these habitats in providing benefit for a variety of invertebrates and fishes as well as a suite of ecosystem goods and services is highlighted. Fishing is one of the main anthropogenic impacts affecting Mediterranean coral habitats, and the current conservation measures are often ineffective. Ongoing attempts and future solutions aiming at the conservation of these VMEs are here discussed, including the fishing restriction in strategic areas characterized by lush coral communities, the implementation of controls against illegal fishery, the development of encounter protocols for vulnerable species and the use of observers onboard.

Keywords: vulnerable marine ecosystems, corals, coralligenous, cold-water corals, sea pens, conservation, Mediterranean

1. Introduction

The Mediterranean Sea covers only 0.7% of the world's ocean surface, but it hosts about 8% of the global marine biodiversity [1]. Despite the presence of many anthropic impacts, a high diversity of benthic habitats is present from the coastal zones to the deep-sea bottom of this semi-enclosed basin, representing a worldwide hot spot of biodiversity [2]. Some of these habitats are built by one or few ecosystem engineer species that create a biogenic habitat suitable for a variety of associated species, including endangered and protected ones, as well as species of high commercial value. This is the case of the *Posidonia oceanica* meadows [3], *Cystoseira* spp. canopies [4], rhodolith beds [5], as well as the so-called marine bioconstructions [6] and animal forests *sensu lato* [7].

Knowledge, protection and the management of many of these habitats are still scarce and fragmentary, except for the *P. oceanica* meadows, which have received a substantial attention in the past and are now all included in Sites of Community Importance thanks to the Habitat Directive [8]. Several other biogenic habitats are worthy of protection, most of them occurring in the mesophotic and in the deep-sea zones. These habitats are more difficult to be explored and studied with respect to coastal environments. In these zones, the sunlight decreases with the depth until it disappears, and the animal life develops with emerging shapes and structures. In fact, the light is one of the main abiotic drivers determining the distribution of benthic organisms, together with oxygen concentration, water movement, temperature, pressure, sedimentation rates, substrate type and geographical area [9]. According to the penetration of the sunlight and its effects on the macrobenthic communities, the marine environment is conventionally divided into: euphotic zone, where the irradiance is strong enough to allow the development of seagrass; mesophotic or twilight zone, from the limit of the seagrass to the limit of presence of algae (loss of net productivity at level of irradiance <1%) [10]; and aphotic zone or deep-sea, where the light is absent. Although there are some indicative and non-univocal depth ranges for each zone (e.g., in the Mediterranean Sea: euphotic zone above 50 m depth; mesophotic zone ca. 50–150 m depth; and aphotic zone below 150–200 m depth), they can vary according to the water transparency and other physical factors that affect light penetration [11].

Corals are among the main habitat formers of the Mediterranean mesophotic and aphotic zones, constituting vulnerable marine ecosystems (VMEs) intended as those populations, communities or habitats that may be vulnerable to impacts from fishing activities [12]. Recently, the General Fishery Commission for the Mediterranean (GFCM) defined Mediterranean VME indicators taxa, habitats and features [13–15]. Corals, together with sponges, echinoderms, molluscs and other benthic organisms, play a significant role in the formation of VMEs. Moreover, most of coral taxa are included in relevant lists of protected species, such as the Red List drawn by the International Union for the Conservation of Nature (IUCN) [16]. Their vulnerability is due to their uniqueness or rarity, functional significance, fragility, structural complexity, as well as their life-history traits which make their recovery difficult (e.g., slow growth rate, late age of maturity, low or unpredictable recruitment, long life expectancy). For these reasons, several Mediterranean mesophotic and deep-sea coral habitats are particularly vulnerable to the impacts of different fishing gears, deserving *ad hoc* management measures [17–22].

This chapter defines and describes the main vulnerable ecosystems of the Mediterranean mesophotic and aphotic zones that are totally or partially based on the habitat-forming activity of corals. Their features, together with their ecological importance and ecosystem goods and services that they provide are highlighted, as well as the need of proper conservation measures.

2. Mesophotic and deep-sea vulnerable marine ecosystems

Marine bioconstructions are among the most important Mediterranean habitats below 50 m depth and highly vulnerable to fishing practices [6]. The term includes all those biogenic structures built-up by organisms growing one on the other, generation after generation. Most of this secondary substrate is constructed by species that accumulate calcium carbonate, constituting peculiar structures as coralligenous outcrops and Cold-Water Coral (CWC) frameworks [6, 23]. Further sensitive habitats of the mesophotic and aphotic zones are mostly represented by the so-called coral forests (i.e., communities structured by one or few coral species characterized by a typical arborescent morphology) [7] and the fields formed by sea pens [24].

2.1 Coralligenous

The term coralligenous groups a variety of temperate biogenic formations built-up by a mixed community of coralline red algae, corals, bryozoans, sponges, serpulids and molluscs (**Figure 1a**). Coralligenous communities thrive in the

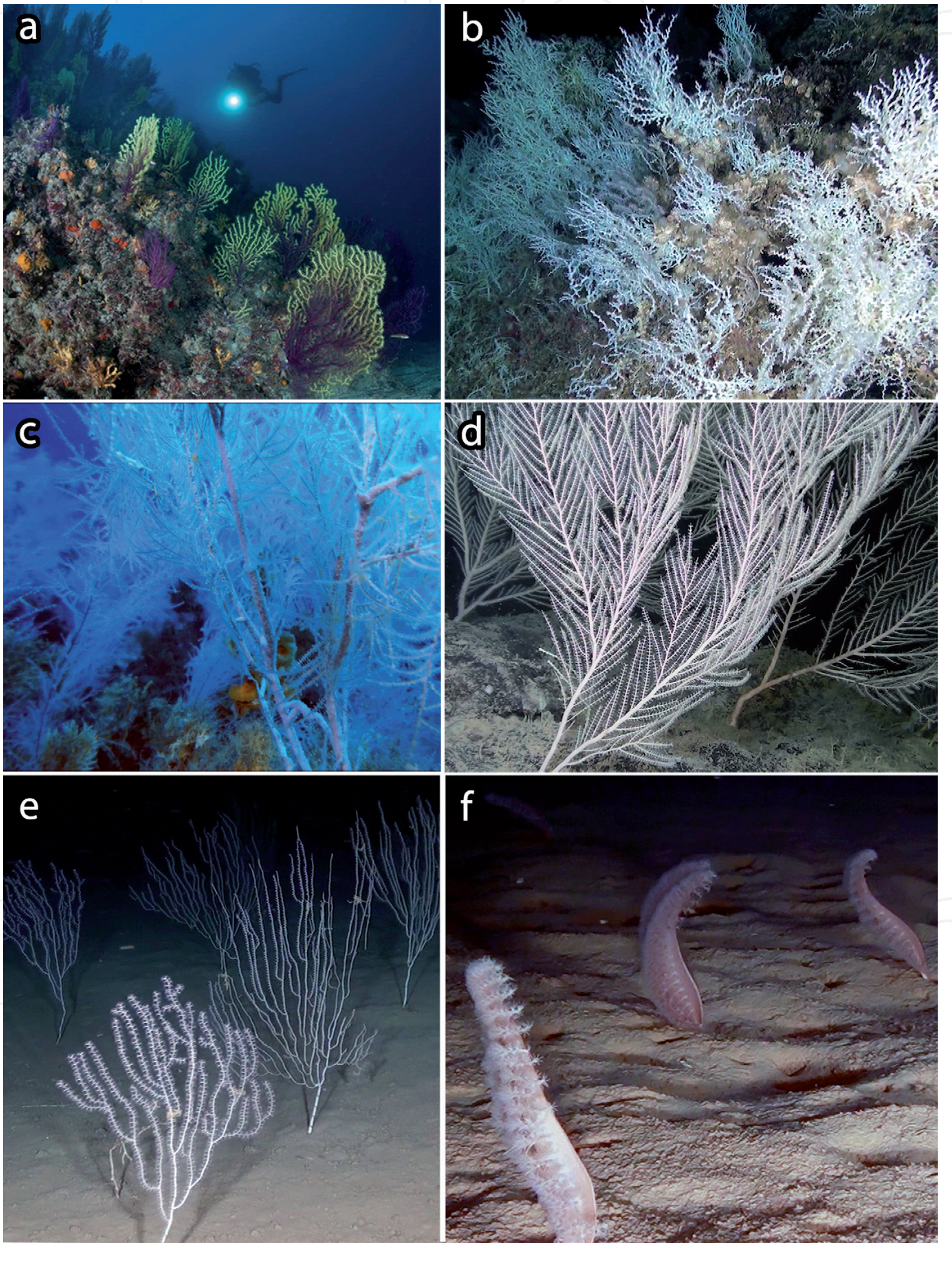

Figure 1.
Some of the mesophotic and deep-sea vulnerable habitats structured by corals in the Mediterranean Sea. (a) Coralligenous formation with the dominant presence of the red gorgonian Paramuricea clavata *(photo: A. Sorci; Tremiti Islands, Adriatic Sea); (b) CWC framework built up by the scleractinians* Madrepora oculata, Lophelia pertusa *and* Desmophyllum dianthus *(Santa Maria di Leuca, Ionian Sea); (c) forest of the black coral* Antipathella subpinnata *(Tremiti Islands, Adriatic Sea); (d) forest of the gorgonian* Callogorgia verticillata *on a deep hard bottom (Montenegro, Adriatic Sea); (e) forest of the bamboo coral* Isidella elongata *on a deep muddy bottom (off Ibiza; Balearic Sea); and (f) field of the red sea pen* Pennatula rubra *(Punta Alice, Ionian Sea).*

Mediterranean Sea from shallow waters (15–20 m of depth) up to the limit of the mesophotic zone [25, 26], and their existence is known since ancient time. The term "coralligène" was used for the first time by Marion [27] to describe the biogenic outcrops present between 30 and 70 m in depth in the Gulf of Marseille, called *broundo* by the local fishermen. Although the term *coralligène* literally means "coral producer," corals are not often the dominant component of the community and it is likely that Marion used the term "coraux" with the wide common meaning of his time, referring not strictly to scleractinians but to all those organisms that accumulate calcareous deposits such as corals, bryozoans and coralline algae. Afterward, also Pruvot [28–30] used the term *coralligène* to describe similar formations off Banyuls-sur-Mer (Gulf of Lion), and from the end of the nineteenth century, the coralligenous has been included in the bionomic description of the Mediterranean seabed [31].

Encrusting red algae represent a relevant component of the coralligenous formations, becoming less present with the decreasing of the light and disappearing in the aphotic zone, where the animal component dominates the bioconstructions. Locally, one or few species can be particularly abundant, representing the so-called *facies* [31], such as those of scleractinians, bryozoans or oysters. Arborescent anthozoans, such as black corals and alcyonaceans, can use the bioconstructions as secondary hard substratum to settle and form coral forests, increasing the three-dimensionality of this habitat (**Figure 1a** and **c**).

The coralligenous habitat represents a hot spot of biodiversity whose importance is comparable to that of the coral reefs in tropical ecosystems. In [25], the first estimate of the number of species associated with coralligenous formations is made, with about 1670 species. However, this is probably an underestimated number, because the complex structure of coralligenous assemblages and their highly diverse composition suggest that they probably host more species than any other Mediterranean habitats. This associated biodiversity includes species of conservation interest, as well as crustaceans and fish of high commercial value [32]. Thanks to the activity of its bioconstructors, coralligenous habitats represent an important CO_2 sink, playing a relevant role in the regulation of ocean acidification associated to global warming [25]. Moreover, the spectacular coralligenous formations distributed over 50 m depth (accessible to scuba diving activities) represent a great touristic attraction for their high esthetic value and are among the most preferred diving spots worldwide [33]. The main ecosystem goods and services provided by coralligenous habitats (*sensu* [34, 35]) are reported in **Table 1**.

2.2 CWC frameworks

There is not a general consensus about the use of the terms "reef" or "framework" to describe those marine bioconstructions structured by the so-called cold-water corals or white corals (subclass Hexacorallia, order Scleractinia), namely the colonial species *Madrepora oculata* Linnaeus, 1758 and *Lophelia pertusa* (Linnaeus, 1758) (recently renamed as *Desmophyllum pertusum*), as well as the solitary or pseudo-colonial coral *Desmophyllum dianthus* (Esper, 1794) (**Figure 1b**). These species can form extensive three-dimensional habitats in the Mediterranean Sea, from 180 to more than 1000 m depth [36], identified as biodiversity hot spots [37, 38]. Despite still far from being fully understood, the current known distribution of CWCs reveals some dozens of coral sites all over the Mediterranean Sea, form single occurrences to large CWC provinces [39]. These habitats provide a suitable hard ground for sessile species and act as shelter, feeding, spawning and nursery area for a variety of vagile species, representing an Essential Fish Habitat (EFH) for several commercial and non-commercial fish and invertebrate species [22, 40–49] (**Table 1**). For instance, it

Category	Ecosystem goods and services	Habitat			
		Coralligenous	CWC framework	Coral forest	Sea pen field
Supporting	Habitat forming	x	x	x	x
	Larval and gamete supply	x	x	x	x
	Breeding, spawning and nursery area	x	x	x	x
	Refuge and settling potential	x	x	x	x
	Primary production	x			
	Nutrient cycling	x	x	x	x
Provisioning	Food provision	x	x	x	x
	Active substances	x	x	x	x
	Genetic resources	x	x	x	x
Regulating	Climate regulation (CO_2 trapping)	x	x		
	Biological control	x	x	x	x
	Disturbance regulation	x	x		
	Bioremediation of waste	x			
	Erosion control and sediment retention	x	x	x	
Cultural	Recreation and tourism	x			
	Research and education	x	x	x	x
	Esthetic	x			

Table 1.
Ecosystem goods and services provided by the mesophotic and deep-sea vulnerable habitats of the Mediterranean Sea characterized by corals.

has been recognized that the presence of CWC habitats benefits adjacent fisheries in the central Mediterranean [50]. Moreover, the massive amount of calcified colonies that constitute the bioconstruction represents an important CO_2 sink and, between the branched colonies, large quantities of sediment and larvae are also retained (**Table 1**). Furthermore, it is becoming well known that CWC frameworks are hot spots of global biogeochemical cycling [51–53].

Solitary scleractinians such as, among others, *Stenocyathus vermiformis* (Pourtalès, 1868), *Javania cailleti* (Duchassaing & Michelotti, 1864), *Anomocora fecunda* (Pourtalès, 1871) and *Caryophyllia* spp. can be present in CWC habitats, but they have not been reported so far with a relevant aggregative behavior and their role in the bioconstruction is often minimal [54].

The colonial yellow coral *Dendrophyllia cornigera* (Lamarck, 1816) can occur on flat or gently sloping hard bottoms, as well as on flat muddy bottoms without any consistent anchorage, from the mesophotic to the aphotic zone [39]. This CWC species can occasionally form coral habitats that are mostly known as *Dendrophyllia* beds rather than frameworks, because the density of the colonies does not reach high-enough values to give the appearance of a compact structure to the habitat [19]. On the contrary, the congeneric *Dendrophyllia ramea* (Linnaeus, 1758) has a shallower distribution (from 80 to more than 700 m depth, although more common within 200 m depth) and it is present both on hard and sedimentary bottoms, as well as within coralligenous formations [54, 55].

The hydrocoral *Errina aspera* (Linnaeus, 1767) can also be included in the CWCs *sensu lato*, because it is an habitat-former species of the mesophotic and the upper aphotic zones, where it can occasionally form monospecific stands showing high densities and being similar to CWC habitats [56].

2.3 Coral forests

Coral forests are marine habitats created by the aggregation of arborescent coral colonies belonging to one or few species of alcyonaceans and antipatharians [39]. These communities can develop both on hard and soft substrata, including detritic bottoms with small scattered substrata, such as small rocks, shells or coral rubble. Hard-bottom coral forests can be settled on both mesophotic rocky bottoms and deep coralligenous bioconstructions (**Figure 1a** and **c**), while in the deep sea, they can develop on rocky bottoms, hardgrounds or CWC frameworks [57–60] (**Figure 1d**). Antipatharians, also known as black corals (subclass Hexacorallia, order Antipatharia), form monospecific or multispecific forests on hard bottoms in both mesophotic and aphotic zones. In particular, *Antipathella subpinnata* (Ellis & Solander 1786) is much common on mesophotic bottoms (**Figure 1c**), *Antipathes dichotoma* Pallas, 1766 and *Parantipathes larix* (Esper, 1788) thrive from the mesophotic to the upper aphotic zones, while *Leiopathes glaberrima* (Esper, 1788) develops mostly on deep bottoms [20, 37, 39, 57, 60, 61].

Several species of alcyonaceans (subclass Octocorallia, order Alcyonacea) are present on hard bottoms, covering a wide bathymetric range (from 15 to more than 1000 m in depth, depending on the species). For instance, the gorgonians *Paramuricea clavata* (Risso, 1826) (**Figure 1a**), *Ellisella paraplexauroides* Stiasny, 1936 and *Eunicella* spp. are among the most common species that form large aggregations on mesophotic coralligenous habitats, as well as on other coherent substrata, often on the continental shelf [59, 62–65]. *Acanthogorgia hirsuta* Gray, 1857, *Callogorgia verticillata* (Pallas, 1766) (**Figure 1d**), *Paramuricea macrospina* (Koch, 1882), *Placogorgia coronata* Carpine & Grasshoff, 1975, *Viminella flagellum* (Johnson, 1863) and the precious red coral *Corallium rubrum* (Linnaeus, 1758) can act as habitat formers from mesophotic to deep bottoms [39, 57, 66–68].

On soft bottoms, the bamboo coral *Isidella elongata* (Esper, 1788) can form extensive populations on compact mud between 110 and 1600 m depth, on relatively flat or gently inclined seabed [69] (**Figure 1e**). This typology of substratum is also suitable for bottom trawling, which has a strong mechanic impact on *I. elongata* colonies as well as on other sessile species. For this reason, the Mediterranean populations of *I. elongata* are in strong decline and the species has been categorized as "critically endangered" by IUCN [16]. Fortunately, some populations of the species are currently surviving in places where trawling is not carried out [39, 69].

The presence of a coral forest enhances the three-dimensionality of the seabed, often representing a hot spot of biodiversity. In fact, some recent new records of deep-sea invertebrates in the Mediterranean Sea occurred within *I. elongata* populations [70–72]. Among the suite of ecosystem goods and services that these habitats provide (**Table 1**), they are known to act as refuge, feeding, spawning and nursery areas for many associated species, including species of commercial value [69, 73–75].

2.4 Sea pen fields

Sea pens (subclass Octocorallia, order Pennatulacea) live on soft bottoms, from shallow to deep waters, and they can form dense aggregations known as sea pen fields which increase the complexity of an otherwise flat and monotonous seabed [76, 77]. *Pennatula rubra* (Ellis, 1761) (**Figure 1f**), *Pteroeides spinosum* (Ellis, 1764) and *Veretillum cynomorium* (Pallas, 1766) are typical field-forming species of the continental shelf, being occasionally present form the euphotic zone but forming true fields only in the mesophotic [24, 78–80]. *Pennatula phosphorea* Linnaeus, 1758 and *Virgularia mirabilis* (Müller, 1776) can occur from mesophotic to deep seabed, often in mixed aggregation with other soft-bottom anthozoans, while *Funiculina quadrangularis* (Pallas, 1766) and *Kophobelemnon stelliferum* (Müller, 1776) represent deep-sea pennatulaceans able to form dense fields on the aphotic muddy bottoms [31, 81, 82].

Sea pen fields can act as refuge and nursery area for small-size specimens of many taxa, among which some crustaceans and fish, attracting the vagile fauna and enhancing the biodiversity of the area [24, 82–84] (**Table 1**).

3. Conservation status

Coral habitats are considered valuable and productive fishing areas due to the presence and abundance of species of commercial interest, whose capture using bottom-contact or bottom-tending fishing gears represents the major threats to the habitats [22, 85]. These gears can be towed (e.g., trawl nets and dredges) or fixed (e.g., longlines, gillnets, trammel nets, traps and pots; although static on the seabed, they may be pulled across the bottom for short distances during retrieval or storms).

Trawl nets, as well as bottom-contact longlines, gillnets and trammel nets are the most destructive fishing gears in the mesophotic and aphotic zones of the Mediterranean Sea. Trawling has a high mechanical impact on soft-bottom communities, while on hard bottoms, it affects the vulnerable filter- and suspension-feeder fauna both directly (e.g., sediment resuspension, destruction of benthos, dumping of processing waste) and indirectly (e.g., post-fishing mortality and long-term trawl-induced changes to the benthos) [85–87]. Bottom longlines, widely deployed all over the basin, can have a significant mechanical impact and their coral bycatch can be high, particularly during retrieval operations [42, 74]. Moreover, longlines can easily remain entangled in the rocky bottoms, thus becoming lost and damaging the benthic communities. Artisanal fishing practices, such as gillnets and trammel nets, are usually deployed on coastal areas in close proximity of cliffs and steep topographies; thus, the chance to catch corals and the possibility of being entangled on them are high. Mechanical injuries on benthic species are even higher when the entangled tools are abandoned on the seabed, altering habitats [85].

Trawling is forbidden in areas deeper than 1000 m depth all over the Mediterranean Sea. However, this conservation measure is not enough, considering that the majority of the coral habitats known so far is present within this depth limit [36, 39]. For this reason, the limitation of trawling up to 800 m depth would be more effective for the conservation of deep-sea coral habitats. During the last decades, the deep-sea habitats have been protected through the institution of Fishery Restricted Areas (FRAs), established by the General Fishery Commission for the Mediterranean and Black Sea (GFCM) with the aims of protecting VMEs and/or Essential Fish Habitats (EFHs). However, only one of the six existing FRAs of the Mediterranean Sea has been created to target the conservation of a CWC habitat, such as the *Lophelia* Reef off Santa Maria di Leuca (Italy, Ionian Sea) [21]. Two FRAs, namely the Strait of Sicily (northeast and northwest Malta) and the Gulf of Lion, include some CWC sites but they have been created to manage fishing stocks; so trawling is present although somehow regulated. The Jabuka/Pomo Pit FRA aims to protect EFHs and an unquantified sea pen field [88], while the Eratosthenes Seamount FRA targets the protection of peculiar geologic formations

Figure 2.
Distribution of the deep-sea fishery restricted areas in the Mediterranean Sea, three of them created for the management of fishery resources and three for the conservation of benthic habitats (vulnerable marine ecosystems, VMEs).

(with only few specimens of solitary sleractinians recorded) [89] and the Nile Delta FRA is characterized by the presence of chemosynthetic fauna (**Figure 2**). Trawling and dredging are forbidden in the FRAs for the conservation of VMEs, while they are regulated in those for the management of EFHs. Bottom longlining can be allowed, often in a buffer zone and under authorization, depending on the regulamentation of the single FRA, while artisanal fishing practices are usually not performed in offshore areas as the existing FRAs. These FRAs result actually isolated, while a desirable network of FRAs is far to be created. This network should be established in the pathway of the Mediterranean water mass circulation in order to connect the different FRAs all over the basin by means of larval dispersal ([39] and references therein). For instance, along the southern Apulian margin, an almost continuous belt of CWC communities are crossed by the water masses that flow between the Southern Adriatic and Northern Ionian Seas [45, 58, 81, 90]. In this respect, the establishment of a FRA for the Bari Canyon has been proposed and the relative institution process is in progress [50].

The analogues of the Mediterranean FRAs are the Offshore Special Areas for Conservation in the North-Atlantic, such as the Darwin Mounds (northwest of Scotland), whose CWC ecosystem was discovered in 1998 and, from 2003, bottom-contact fisheries were banned in the area [91]. Also in the Sula Reef (Norway), one of the first reefs of *L. pertusa* discovered, trawling activities are banned [87].

Several actions have been undertaken also in the United States to address impacts of fishing on VMEs, such as banning of bottom trawls throughout the large area of the Western Pacific Fishery Management Council (3.9 million km^2) [92], as well as adoption of closed areas on Georges Bank in New England (Northwest Atlantic) [93]. Other solutions can include the shifting from gears with higher impacts to gears with lower impacts, as happened along the coast of California, where bycatch in the fishery of the California spot prawn *Pandalus platyceros* J.F. Brandt in von Middendorf, 1851 has been greatly reduced by shifting from bottom trawls to traps [94].

In the Caribbean, the Parque Nacional Natural Corales de Profundidad (Colombia) is the only deep-sea coral area actually under protection measures [95, 96].

Further extra-Mediterranean examples of effective conservation initiatives are those carried out by the Department of Fisheries and Oceans (DFO) in the North Atlantic which, during 2002, implemented its first fisheries closure to protect CWC populations in different areas of the Northeast Channel Coral Conservation Area (southwest of Nova Scotia, Canada) [97]. The management measures used in each area are different and the permitted activities vary from fishing regulation (though a limited number of licenses released and only for certain practices) to fishing closures and relative buffer areas, depending on each area features. In specific areas, such as the Northeast Channel Coral Conservation Area, a precautionary zone where fishing is not allowed has been identified below 500 m [97]. Management activities include logbooks, at-sea observers, vessel monitoring systems and surveillance overflights against illegal fishing practices. For instance, in 2004, DFO successfully prosecuted a longline fisher who did not have a fisheries observer onboard while fishing in the limited fisheries zone of the Northeast Channel [97]. Canada has undertaken a series of successful conservation actions also in the waters off British Columbia (Northeast Pacific) [98], with the concomitant adoption of four measures, such as: (1) identification of ecosystem-based spatial boundaries for the bottom trawl fleet to prevent further spatial expansion of fishery areas, exclusion of areas of historically high coral and sponge bycatch, as well as control that the area opened to bottom trawling did not disproportionately impact any single habitat type; (2) establishment of an habitat quota (i.e., a bycatch quota for habitat formers) through onboard observers; (3) development of an encounter protocol, such as a set of defined management steps to be applied when a fishing vessel encounters a significant amount of VME indicator taxa; and (4) implementation of the monitoring systems and formation of a scientific committee. Ten years before, the National Marine Fisheries Service in Alaska formulated a habitat protection alternative for the Aleutian Islands (North Pacific) based on an interdisciplinary cost-effective model for mitigating the adverse effects of fishing on deep sea developed by Oceana [99]. Working with the fishery operators, Oceana identified and delimited the actual fishing grounds where bottom-contact gears are deployed, avoiding the exploitation of further areas. This approach also uses observer data to identify VMEs, mostly as areas of high coral and sponge bycatch rates, to develop a comprehensive management policy that allows bottom trawling only in specific designated areas with current low habitat impacts and consistent fish harvest. All areas not specified as open and historically not exploited are closed to bottom trawling [99]. The Oceana's approach also includes coral and sponge bycatch limits in the trawled areas, as well as a plan for comprehensive seafloor research, mapping and monitoring [99]. Its enforcement is based on increased observer coverage, vessel monitoring systems and electronic logbooks, as well as its application for other fishing practices such as bottom longlining and artisanal fishery. The same approach has been adopted in the United States [100], freezing the existing bottom trawl footprint, regulating areas that have low fishing effort, closing sensitive areas such as coral gardens and seamounts and calling for further research and monitoring. According to the freezing-the-footprint approach, also the National Oceanic and Atmospheric Administration (NOAA) proposed a precautionary approach to manage adverse impacts of fishing on VMEs [101].

In the Mediterranean Sea, MPAs usually do not overlap with deep-sea VMEs, with the exception of the National Park of Calanques (France) and the Chella Bank (Seco de los Olivos, Spain); the latter declared also a Site of Community Importance (SCI) [102]. Mesophotic VMEs can be more or less accidentally included in MPAs, sometimes at the borders of the protected area and without a real awareness of their presence. On the contrary, a habitat-based maritime spatial planning of MPAs is needed to guarantee the strategic protection of mesophotic important sites, such as particular coralligenous formations, as well as forests of black corals and alcyonaceans. Although several MPAs have been designated where seascapes are particularly attractive for scuba divers and "beauty" has been the main reason for their proposal [103], including some spectacular coralligenous formations, in some areas, it is still present a limited overlap between the most visited diving sites and the presence of some forms of regulation, suggesting the presence of further areas worth of protection [33].

Generally speaking, most of the VMEs identified so far are not included in the existing FRAs and MPAs, as well as in others local form of protection. New conservation measures, which are comprehensive of the high diversity of habitats present all over the Mediterranean Sea, are difficult to be achieved. Recently, several attempts have been made to identify those strategic areas whose protection is of priority importance [6, 33, 39, 88], although they were biased by the targeted habitats, with different scenarios depending on whether the priority is given to deep-sea vs. coastal habitats, soft-bottom vs. hard-bottom communities, etc. For instance, bioconstructions such as coralligenous and CWC frameworks are often the result of centuries or even millennia of biological activities; their destruction can be almost irreversible, and for this reason, they require the greatest attention in any conservation measures [6]. Black coral forests can take long time to be formed and are highly sensitive to artisanal fishery, as well as to indirect effects from trawl fishing; thus, protected areas should be created to protect the last surviving forests of the Mediterranean Sea [104]. Soft-bottom habitats such as *I. elongata* gardens are the most sensitive to fishing pressures, particularly to trawling; they are critically endangered, representing a priority for conservation measures [39, 69]. In the same way, sea pen fields are sensitive to trawl fishing and are very important to be protected [88, 105]. All these priorities could be confounding for decision-makers, and usually it is not possible to give a hierarchy of priorities for conservation since all the habitats mentioned above are under urgent need for protection.

Despite the fragmented geopolitical scenario, the heterogeneity of fishing practices and the different fishery resources and local settings characterizing the Mediterranean, the abovementioned conservation approach adopted in Northeast and North Pacific could be taken into account also in this basin for a future comprehensive protection of VMEs from bottom-fishing activities, particularly trawling and longlining (**Figure 3**). The logbooks and Vessel Monitoring by satellite System

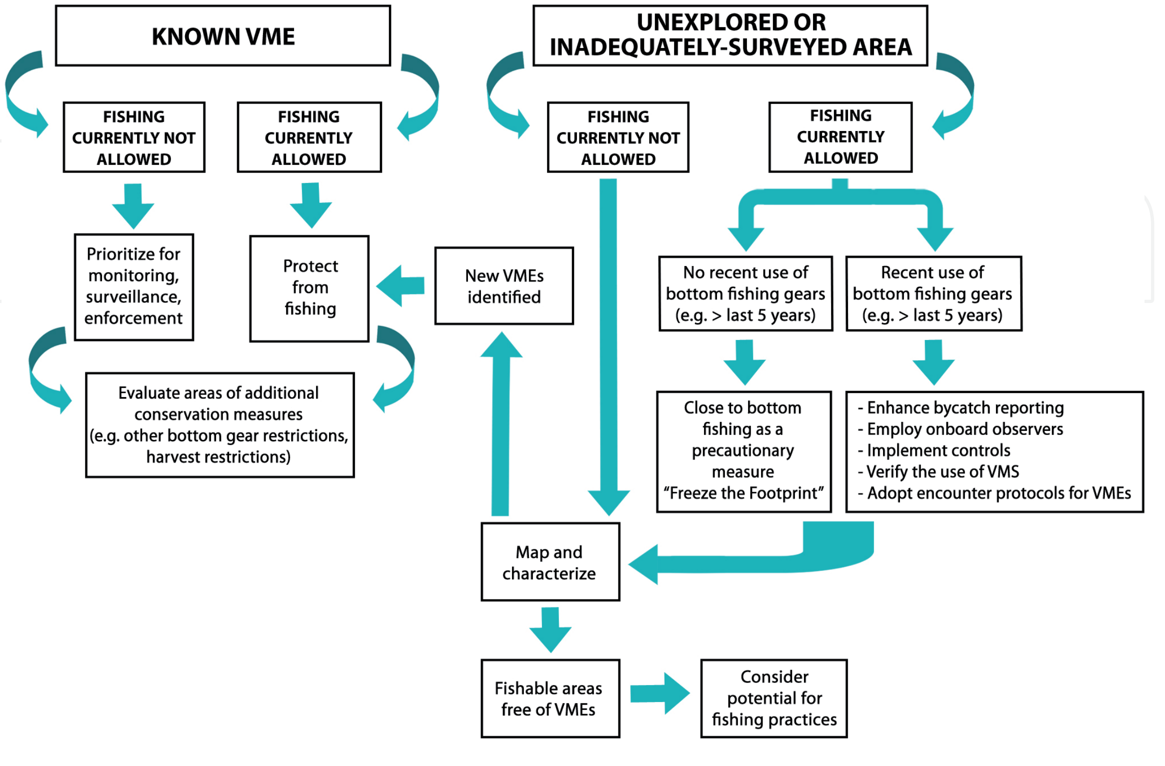

Figure 3.
A scheme of a precautionary approach to manage bottom-tending fishing gears that could be applicable on Mediterranean vulnerable marine ecosystems. Modified from [101].

(VMS), together with the closed season and closed areas, such as FRAs, are measures already adopted for the management of fishery resources on the northern side of the basin. All these measures could combine VME conservation and fisheries management objectives according to the Ecosystem Approach to Fisheries (EAF) [106].

In European waters, these measures are coupled with a large-scale monitoring of the fishing impact as part of the Marine Strategy Framework Directive [107]. The existing measures related to fisheries management could be implemented to include the assessment of VME incidental catches and to enforce controls for illegal fishing activities in restricted areas. However, the complex geopolitical setting of the basin, the distance of the fishing grounds from the coasts and the lack of proper controls do not favor its implementation. For instance, logbooks have been formally adopted, but the information reported is often incomplete and unreliable, for both commercial catches and discard. The use of observers onboard is still missing in commercial fishery, while it is limited to few research projects for a short time. Moreover, VMS data are not easily accessible and are scantly used for control, although they can reveal certain illegal fishing activities inside a FRA [21].

The regular use of observers onboard the fishing boats could help to collect a suite of reliable data about catches of commercial species and bycatch of vulnerable or protected species, as well as to avoid infringements and illegal fishery on VMEs or no-fishing areas. Observers would be also involved in the adoption and implementation of commercial encounter protocols for VMEs in order to limit impacts by fishing practices [92, 98]. These protocols can be set up after *ad hoc* studies that assess a maximum distance that a vessel should have to move after the catch (either shallower or deeper) of a specific quota of VME indicator taxa, which would vary depending on the species. Considering that many areas of the deep Mediterranean Sea are still scantly explored or unknown, the report of VME incidental catches could improve our understanding about the occurrence and distribution of these habitats on a basin scale, representing a needed effort for a comprehensive conservation of VMEs, including coral habitats (**Figure 3**).

Management measures, such as encounter protocols with associate thresholds and closure areas, can be developed and implemented according to the FAO's International Guidelines for the Management of Deep-sea Fisheries [108] in order to ensure VME protection from significant adverse fishing impacts. The use of onboard observers and the correct adoption of digital logbooks could be applicable to trawl fishing vessels and to most of the deep-sea benthic longlining vessels, which must be equipped with VMS and/or Automated Identification Systems (AIS) in correct working order. On the contrary, the management and control of the numerous and small artisanal fishing boats, which use gillnets and trammel nets in mesophotic habitats, could be done though the designation of landing points, obligations of notice of arrival in port and control of landings.

4. Conclusions

Although our understanding on the distribution and the main features of vulnerable coral habitats in the Mediterranean Sea is still incomplete, the information available is strong enough to support conservation strategies, based on what is currently known. Control enforcements, employment of onboard observers and implementation of a network of protected or fishing restricted areas are urgently needed measures to guarantee a proper conservation of these VMEs. A network of protected areas (mostly MPAs and FRAs) would satisfy both conservation of coral habitats and management of fishery resources according to the EAF. Conservation planning should take into account ecological issues and socioeconomic aspects related to the cost of preventing the use of these areas by humans. Public awareness, stakeholder involvement and a credible system of monitoring, control and surveillance will be fundamental to meet such conservation and management objectives. However, it is unlikely that all the Mediterranean benthic habitats will be comprehensively mapped in the near future. Thus, a precautionary approach for conservation is needed to ensure that, after the closure of a specific area to destructive fishing practices (at least trawling and longlining), fishing effort is properly managed and does not move into further areas that may be susceptible to damage (i.e., VMEs). This approach, combined with the identification of hot spots for conservation, would trigger an iterative process to develop effective management solutions to protect VMEs under a precautionary approach, combining habitat protection with maintaining commercial fishing opportunities.

Acknowledgements

This chapter benefited from funding by the Italian Ministry of Education, University and Research (PON 2014-2020, AIM 1807508, Attività 1, Linea 1), the Ente Parco Nazionale del Gargano (Research agreement with CoNISMa N. 21/2018) and the National Geographic Society (Grant EC-176R-18).

Conflict of interest

The authors declare no conflict of interest.

Author details

Giovanni Chimienti[1,2]*, Francesco Mastrototaro[1,2] and Gianfranco D'Onghia[1,2]

1 Department of Biology, University of Bari Aldo Moro, Bari, Italy

2 CoNISMa, Roma, Italy

*Address all correspondence to: giovanni.chimienti@uniba.it

References

[1] Costello MJ, Coll M, Danovaro R, et al. A census of marine biodiversity knowledge, resources, and future challenges. PLoS One. 2010;**5**(8):e12110

[2] Danovaro R, Company JB, Corinaldesi C, et al. Deep-sea biodiversity in the Mediterranean Sea: The known, the unknown, and the knowable. PLoS One. 2010;**5**:e11832

[3] Abadie A, Pace M, Gobert S, Borg JA. Seascape ecology in *Posidonia oceanica* seagrass meadows: Linking structure and ecological processes for management. Ecological Indicators. 2018;**87**:1-13

[4] Ballesteros E, Sala E, Garrabou J, Zabala M. Community structure and frond size distribution of a deep water stand of *Cystoseira spinosa* (Phaeophyta) in the northwestern Mediterranean. European Journal of Phycology. 1998;**33**:121-128

[5] Basso D, Babbini L, Ramos-Esplá AA, Salomidi M. Mediterranean rhodolith beds. In: Riosmena-Rodríguez R, Nelson W, Aguirre J, editors. Rhodolith/Maërl Beds: A Global Perspective. AG Cham, Switzerland: Springer International Publishing; 2018. pp. 281-298

[6] Ingrosso G, Abbiati M, Badalamenti F, et al. Mediterranean bioconstructions along the Italian coast. Advances in Marine Biology. 2018;**79**:61-136

[7] Rossi S, Bramanti L, Gori A, Orejas C, editors. Marine Animal Forests. The Ecology of Benthic Biodiversity Hotspots. AG Cham, Switzerland:Springer International Publishing; 2017. 1366p

[8] EEC Reg. 43 On the Conservation of Natural Habitats and of Wild Fauna and Flora (Habitat Directive). 1992. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1494715607826&uri=CELEX:31992L0043 [Accessed: August 10, 2019]

[9] Gattuso JP, Gentili B, Duarte CM, et al. Light availability in the coastal ocean: Impact on the distribution of benthic photosynthetic organisms and their contribution to primary production. Biogeosciences. 2006;**3**:489-513

[10] Lesser MP, Slattery M, Leichter JJ. Ecology of mesophotic coral reefs. Journal of Experimental Marine Biology and Ecology. 2009;**375**:1-8

[11] Kahng SE, Garcia-Sais JR, Spalding HL, et al. Community ecology of mesophotic coral reef ecosystems. Coral Reefs. 2010;**29**:255-275

[12] FAO. International Guidelines for the Management of Deep-sea Fisheries in the High Seas. Rome: FAO; 2009. 73p

[13] GFCM. Criteria for the identification of sensitive habitats of relevance for the management of priority species. In: Meeting of the Sub-Committee on Marine Environment and Ecosystems (SCMEE). 30 November–3 December 2009; Malaga, Spain; 2009

[14] GFCM. Report of the First Meeting of the Working Group on Vulnerable Marine Ecosystems (WGVME). 3-5 April 2017; Malaga, Spain; 2017. 45p

[15] GFCM. Report of the Second Meeting of the Working Group on Vulnerable Marine Ecosystems (WGVME). 26-28 February 2018; Rome, Italy; 2018. 57p

[16] Otero MM, Numa C, Bo M, et al. Overview of the Conservation Status of Mediterranean Anthozoans. Málaga: IUCN; 2017. 73p

[17] Orejas C, Gori A, Lo Iacono C, et al. Cold-water corals in the cap de Creus canyon, northwestern Mediterranean: Spatial distribution, density and anthropogenic impact. Marine Ecology Progress Series. 2009;**397**:37-51

[18] Ramirez-Llodra E, Tyler PA, Baker MC, et al. Man and the last great wilderness: Human impact on the deep sea. PLoS One. 2011;**6**:e22588

[19] Bo M, Bava S, Canese S, et al. Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. Biological Conservation. 2014;**171**:167-176

[20] Bo M, Bavestrello G, Angiolillo M, et al. Persistence of pristine deep-sea coral gardens in the Mediterranean Sea (SW Sardinia). PLoS One. 2015;**10**(3):e0119393

[21] D'Onghia G, Calculli C, Capezzuto F, et al. Anthropogenic impact in the Santa Maria di Leuca cold-water coral province (Mediterranean Sea): Observations and conservation straits. Deep-Sea Research Part 2. 2017;**145**:87-101

[22] D'Onghia G. Cold-water corals as shelter, feeding and life-history critical habitats for fish species: Ecological interactions and fishing impact. In: Orejas C, Jiménez C, editors. Mediterranean Cold-Water Corals: Past, Present and Future. Chapter 30. Coral Reefs of the World 9. AG Cham, Switzerland: Springer International Publishing; 2019. pp. 335-356

[23] Orejas C, Jimenez C, editors. Mediterranean Cold-Water Corals: Past, Present and Future. Coral Reefs of the World 9. AG Cham, Switzerland: Springer International Publishing; 2019. 582p

[24] Chimienti G, Angeletti L, Rizzo L, et al. ROV vs trawling approaches in the study of benthic communities: The case of *Pennatula rubra* (Cnidaria: Pennatulacea). Journal of the Marine Biological Association of the UK. 2018;**98**(8):1859-1869

[25] Ballesteros E. Mediterranean coralligenous assemblages: A synthesis of present knowledge. Oceanography and Marine Biology: An Annual Review. 2006;**44**:123-195

[26] Martin CS, Giannoulaki M, De Leo F, et al. Coralligenous and maërl habitats: Predictive modelling to identify their spatial distributions across the Mediterranean Sea. Scientific Reports. 2014;**4**:5073

[27] Marion AF. Esquisse d'une topographie zoologique du Golfe de Marseille. Annales du Musée d' Histoire Naturelle de Marseille. 1883;**1**(2):1-50

[28] Pruvot G. Sur les fonds sous-marins de la région de Banyuls et du cap de Creus. Comptes Rendus de l'Académie des. Sciences. 1894;**118**:203-206

[29] Pruvot G. Coup d'oeil sur la distribution générale des invertébrés dans la région de Banyuls (Golfe du Lion). Archives de Zoologie Expérimentale et Générale. 1895;**3**:629-658

[30] Pruvot G. Essai sur les fonds et la faune de la Manche Occidentale (côtes de Bretagne) comparées à ceux du Golfe de Lion. Archives de Zoologie Expérimentale et Générale. 1897;**5**:511-660

[31] Pérès JM, Picard J. Nouveau manuel de bionomie benthique de la mer Méditerranée. Recueil des Travaux de la Station Marine d'Endoume. 1964;**31**:1-137

[32] Cavanagh RD, Gibson C. Overview of the Conservation Status of Cartilaginous Fishes (Chondrichthyans) in the Mediterranean Sea. IUCN Species Survival Commission. Gland,

Switzerland and Malaga, Spain IUCN, Centre for Mediterranean Cooperation; 2007. 42p

[33] Chimienti G, Stithou M, Dalle Mura I, et al. An explorative assessment of the importance of Mediterranean Coralligenous habitat to local economy: The case of recreational diving. Journal of Environmental Accounting and Management. 2017;**5**(4):310-320

[34] Millennium Ecosystem Assessment (MA). Ecosystems and Human Well-Being: A Framework for Assessment. Washington DC: Island Press; 2003

[35] Liquete C, Piroddi C, Drakou EG, et al. Current status and future prospects for the assessment of marine and coastal ecosystem services: A systematic review. PLoS One. 2013;**8**(7):e67737

[36] Chimienti G, Bo M, Mastrototaro F. Know the distribution to assess the changes: Mediterranean cold-water coral bioconstructions. Rendiconti Lincei Scienze Fisiche e Naturali. 2018;**29**:583-588

[37] Mastrototaro F, D'Onghia G, Corriero G, et al. Biodiversity of the white coral ecosystem off cape Santa Maria di Leuca (Mediterranean Sea): An update. Deep-Sea Research Part 2. 2010;**57**:412-430

[38] Watling L, France SC, Pante E, Simpson A. Biology of deep-water octocorals. Advances in Marine Biology. 2011;**60**:41-123

[39] Chimienti G, Bo M, Taviani M, Mastrototaro F. Occurrence and biogeography of Mediterranean cold-water corals. In: Orejas C, Jiménez C, editors. Mediterranean Cold-Water Corals: Past, Present and Future. Chapter 19. Coral Reefs of the World 9. AG Cham, Switzerland: Springer International Publishing; 2019. pp. 213-243

[40] D'Onghia G, Maiorano P, Sion L, et al. Effects of deep-water coral banks on the abundance and size structure of the megafauna in the Mediterranean Sea. Deep-Sea Research Part 2. 2010;**57**:397-411

[41] D'Onghia G, Indennidate A, Giove A, et al. Distribution and behaviour of the deep-sea benthopelagic fauna observed using towed cameras in the Santa Maria di Leuca cold water coral province. Marine Ecology Progress Series. 2011;**443**:95-110

[42] D'Onghia G, Maiorano P, Carlucci, et al. Comparing deep-sea fish fauna between coral and non-coral "megahabitats" in the Santa Maria di Leuca cold-water coral province (Mediterranean Sea). PLoS One. 2012;**7**(9):e44509

[43] D'Onghia G, Capezzuto F, Cardone F, et al. Macro- and megafauna recorded in the submarine Bari canyon (southern Adriatic, Mediterranean Sea) using different tools. Mediterranean Marine Science. 2015;**16**(1):180-196

[44] D'Onghia G, Capezzuto F, Carluccio A, et al. Exploring composition and behaviour of fish fauna by *in situ* observations in the Bari canyon (southern Adriatic Sea, Central Mediterranean). Marine Ecology. 2015;**36**:541-556

[45] D'Onghia G, Calculli C, Capezzuto F, et al. New records of cold-water coral sites and fish fauna characterization of a potential network existing in the Mediterranean Sea. Marine Ecology. 2016;**37**(6):1398-1422

[46] Capezzuto F, Ancona F, Carlucci R, et al. Cold-water coral communities in the Central Mediterranean: Aspects on megafauna diversity, fishery resources and conservation perspectives. Rendiconti Lincei Scienze Fisiche e Naturali. 2018;**29**(3):589-597

[47] Capezzuto F, Sion L, Ancona F, et al. Cold-water coral habitats and canyons as essential fish habitats in the southern Adriatic and northern Ionian Sea (Central Mediterranean). Ecological Questions. 2018;**29**(2):9-23

[48] Capezzuto F, Calculli C, Carlucci R, et al. Revealing the coral habitat effect on the bentho-pelagic fauna diversity in the Santa Maria di Leuca cold-water coral province using different devices and Bayesian hierarchical modelling. Aquatic Conservation. 2019; **29**(10):1608-1622

[49] Sion L, Calculli C, Capezzuto F, et al. Does the Bari canyon (Central Mediterranean) influence the fish distribution and abundance? Progress in Oceanography. 2019;**170**:81-92

[50] D'Onghia G, Sion L, Capezzuto F. Cold-water coral habitats benefit adjacent fisheries along the Apulian margin (Central Mediterranean). Fisheries Research. 2019;**213**:172-179

[51] Van Oevelen D, Duineveld GCA, Lavaleye MSS, et al. The cold-water coral community as hotspot of carbon cycling on continental margins: A food web analysis from Rockall Bank (Northeast Atlantic). Limnology and Oceanography. 2009;**54**:1829-1844

[52] Cathalot C, Van Oevelen D, Cox TJS, et al. Cold-water coral reefs and adjacent sponge grounds: Hotspots of benthic respiration and organic carbon cycling in the deep sea. Frontiers in Marine Science. 2015;**2**(37):1-12

[53] Rovelli L, Attard K, Bryant LD, et al. Benthic O_2 uptake of two cold-water coral communities estimated with thenon-invasive eddy correlation technique. Marine Ecology Progress Series. 2015;**525**:97-104

[54] Zibrowius H. Les scléractiniaires de la Méditerranée et de l'Atlantique nord-oriental. Mémoires de l'Institute Océanographique, Monaco. 1980;**11**:1-284

[55] Orejas C, Gori A, Jiménez C, et al. Occurrence and distribution of the coral *Dendrophyllia ramea* in Cyprus insular shelf: Environmental setting and anthropogenic impacts. Deep-Sea Research Part 2. 2019;**164**:190-205

[56] Salvati E, Angiolillo M, Bo M, et al. The population of *Errina aspera* (Hydrozoa: Stylasteridae) of the Messina Strait (Mediterranean Sea). Journal of the Marine Biological Association of the UK. 2010;**90**(7):1331-1336

[57] Bo M, Canese S, Spaggiari C, et al. Deep coral oases in the South Tyrrhenian Sea. PLoS One. 2012;**7**(11):e49870

[58] Angeletti L, Taviani M, Canese S, et al. New deep-water cnidarian sites in the southern Adriatic Sea. Mediterranean Marine Science. 2014;**15**(2):225-238

[59] Grinyó J, Gori A, Ambroso S, et al. Diversity, distribution and population size structure of deep Mediterranean gorgonian assemblages (Menorca Channel, Western Mediterranean Sea). Progress in Oceanography. 2016;**145**:42-56

[60] Cau A, Follesa MC, Moccia D, et al. *Leiopathes glaberrima* millennial forest from SW Sardinia as nursery ground for the small spotted catshark *Scyliorhinus canicula*. Aquatic Conservation. 2017;**27**:731-735

[61] Bo M, Bavestrello G, Canese S. Coral assemblage off the Calabrian coast (South Italy) with new observations on living colonies of *Antipathes dichotoma*. Italina Journal of Zoology. 2011;**78**(2):231-242

[62] Cerrano C, Danovaro R, Gambi C, et al. Gold coral (*Savalia savaglia*) and

gorgonian forests enhance benthic biodiversity and ecosystem functioning in the mesophotic zone. Biodiversity and Conservation. 2010;**19**:153-167

[63] Gori A, Rossi S, Berganzo E, et al. Spatial distribution patterns of the gorgonians *Eunicella singularis*, *Paramuricea clavata*, and *Leptogorgia sarmentosa* (cape of Creus, northwestern Mediterranean Sea). Marine Biology. 2011;**158**(1):143-158

[64] Gori A, Rossi S, Linares C, et al. Size and spatial structure in deep versus shallow populations of the Mediterranean gorgonian *Eunicella singularis* (cap de Creus, northwestern Mediterranean Sea). Marine Biology. 2011;**158**(8):1721-1732

[65] Gori A, Bramanti L, López-González P, et al. Characterization of the zooxanthellate and azooxanthellate morphotypes of the Mediterranean gorgonian *Eunicella singularis*. Marine Biology. 2012;**159**(7):1485-1496

[66] Bavestrello G, Bo M, Bertolino M, et al. Long-term structure and dynamics of the red coral community in the Portofino MPA. Marine Ecology. 2014;**36**(4):1354-1363

[67] Enrichetti F, Bavestrello G, Coppari M, et al. *Placogorgia coronata* first documented record in Italian waters: Use of trawl bycatch to unveil vulnerable deep-sea ecosystems. Aquatic Conservation. 2018;**28**:1123-1138

[68] De la Torriente A, Aguilar R, Serrano A, et al. Sur de Almería-Seco de los Olivos. Proyecto LIFE + INDEMARES. Fundación Biodiversidad del Ministerio de Agricultura, Alimentación y Medio Ambiente Madrid, Spain; 2014. 102p

[69] Mastrototaro F, Chimienti G, Acosta J, et al. *Isidella elongata* (Cnidaria: Alcyonacea) *facies* in the western Mediterranean Sea: Visual surveys and descriptions of its ecological role. European Zoological Journal. 2017;**84**(1):209-225

[70] Mastrototaro F, Chimienti G, Capezzuto F, et al. First record of *Protoptilum carpenteri* (Cnidaria: Octocorallia: Pennatulacea) in the Mediterranean Sea. The Italian Journal of Zoology. 2015;**82**(1):61-68

[71] Mastrototaro F, Chimienti G, Montesanto F, et al. Finding of the macrophagous deep-sea ascidian *Dicopia antirrhinum* Monniot, 1972 (Chordata: Tunicata) in the Tyrrhenian Sea and updating of its distribution. The European Zoological Journal. 2019;**86**(1):181-188

[72] Chimienti G, Aguilar R, Gebruk A, Mastrototaro F. Distribution and swimming ability of the deep-sea holothuroid *Penilpidia ludwigi* (Holothuroidea: Elasipodida: Elpidiidae). Marine Biodiversity. 2019:12. DOI: 10.1007/s12526-019-00973-9

[73] Fabri MC, Pedela L, Beuck L, et al. Megafauna of vulnerable marine ecosystems in French Mediterranean submarine canyons: Spatial distribution and anthropogenic impacts. Deep-Sea Research Part 2. 2014;**104**:184-207

[74] Mytilineou C, Smith CJ, Anastasopoulou A, et al. New cold-water coral occurrences in the eastern Ionian Sea: results from experimental long line fishing. Deep-Sea Research Part 2. 2014;**99**:146-157

[75] Mastrototaro F, Aguilar R, Chimienti G, et al. The rediscovery of *Rosalinda incrustans* (Cnidaria: Hydrozoa) in the Mediterranean Sea. The Italian Journal of Zoology. 2016;**83**(2):244-247

[76] Williams GC. The global diversity of sea pens (Cnidaria: Octocorallia: Pennatulacea). PLoS One. 2011;**6**:e22747

[77] Chimienti G, Angeletti L, Mastrototaro F. Withdrawal behaviour of the red sea pen *Pennatula rubra* (Cnidaria: Pennatulacea). European Zoological Journal. 2018;**85**(1):64-70

[78] Porporato EMD, Mangano MC, De Domenico F, et al. First observation of *Pteroeides spinosum* (Anthozoa: Octocorallia) fields in a Sicilian coastal zone (Central Mediterranean Sea). Marine Biodiversity. 2014;**44**:589-592

[79] Chimienti G, Tursi A, Mastrototaro F. Biometric relationships in the red sea pen *Pennatula rubra* (Cnidaria: Pennatulacea). In: Proceedings of the IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea); 8-10 October 2018; Bari, Italy. 2018. pp. 212-216

[80] Chimienti G, Di Nisio A, Lanzolla AML, et al. Towards non-invasive methods to assess population structure and biomass in vulnerable sea pen fields. Sensors. 2019;**19**:2255

[81] Freiwald A, Beuck L, Rüggeberg A, et al. The white coral community in the Central Mediterranean Sea revealed by ROV surveys. Oceanography. 2009;**22**(1):58-74

[82] Mastrototaro F, Maiorano P, Vertino A, et al. A *facies* of *Kophobelemnon* (Cnidaria, Octocorallia) from Santa Maria di Leuca coral province (Mediterranean Sea). Marine Ecology. 2013;**34**:313-320

[83] Pardo E, Aguilar R, García S, et al. Documentación de arrecifes de corales de agua fría en el Mediterráneo occidental (Mar de Alborán). Chronica Naturae. 2011;**1**:20-34

[84] Baillon S, Hamel JF, Wareham VE, et al. Deep cold-water corals as nurseries for fish larvae. Frontiers in Ecology and the Environment. 2012;**10**(7):351-356

[85] Hinz H. Impact of bottom fishing on animal forests: Science, conservation, and fisheries management. In: Rossi S et al., editors. Marine Animal Forests: The Ecology of Benthic Biodiversity Hotspots. Switzerland: Springer; 2017. pp. 1041-1059

[86] Jones JB. Environmental impact of trawling on the seabed: A review. New Zealand Journal of Marine and Freshwater Research. 1992;**26**:59-67

[87] Fosså JH, Mortensen PB, Furevik DM. The deep-water coral *Lophelia pertusa* in Norwegian waters: Distribution and fishery impacts. Hydrobiologia. 2002;**471**:1-12

[88] Bastari A, Pica D, Ferretti F, et al. Sea pens in the Mediterranean Sea: Habitat suitability and opportunities for ecosystem recovery. ICES Journal of Marine Science. 2018;**75**(6):2289-2291

[89] Galil B, Zibrowius H. First benthos samples from Eratosthenes seamount, eastern Mediterranean. Marine Biodiversity. 1998;**28**(4):111-121

[90] Taviani M, Vertino A, López Correa M, et al. Pleistocene to recent scleractinian deep-water corals and coral facies in the eastern Mediterranean. Facies. 2011;**57**(4):579-603

[91] Huvenne VAI, Bett BJ, Masson DG, et al. Effectiveness of a deep-sea cold-water coral Marine protected area, following eight years of fisheries closure. Biological Conservation. 2016;**200**:60-69

[92] Code of Federal Regulations. Fisheries off west coast state and in the Western Pacific: Gear restrictions. Code of Federal Regulation. 2002;**50**:461-556

[93] Collie JS, Escanero GA, Valentine PC. Effects of bottom fishing

on the benthic megafauna of Georges Bank. Marine Ecology Progress Series. 1997;**35**:159-172

[94] Reilly PN, Geibel J. Results of California Department of Fish and Game Spot Prawn Trawl and Trap Fisheries Bycatch Observer Program, 2000-2001. Monterey, California, Belmont: California Department of Fish Game; 2002. p. 88

[95] Reyes J, Santodomingo N, Gracia A, et al. Southern Caribbean azooxanthellate coral communities off Colombia. In: Freiwald A, Roberts JM, editors. Cold-Water Corals and Ecosystems. Berlin Heidelberg: Springer-Verlag; 2005. pp. 309-330

[96] Urriago J, Santodomingo N, Reyes J. Formaciones coralinas de profundidad: criterios biológicos para la conformación de áreas marinas protegidas del margen continental (100-300 m) en el Caribe colombiano. Boletín de Investigaciones Marinas y Costeras. 2011;**40**(1):89-113

[97] Breeze H, Fenton DG. Designing management measures to protect cold-water corals off Nova Scotia, Canada. In: George RY, Cairns SD, editors. Conservation and Adaptive Management of Seamount and Deep-Sea Coral Ecosystems. Rosenstiel School of Marine and Atmospheric Science: University of Miami; 2007. pp. 123-133

[98] Wallace S, Turris B, Driscoll J, et al. Canada's pacific groundfish trawl habitat agreement: A global first in an ecosystem approach to bottom trawl impacts. Marine Policy. 2015;**60**:240-248

[99] Shester G, Ayers J. A cost effective approach to protecting deep-sea coral and sponge ecosystems with an application to Alaska's Aleutian Islands region. In: Freiwald A, Roberts JM, editors. Cold-Water Corals and Ecosystems. Berlin Heidelberg: Springer-Verlag; 2005. pp. 1151-1169

[100] Shester G, Warrenchuk JUS. Pacific coast experiences in achieving deep-sea coral conservation and marine habitat protection. Bulletin of Marine Science. 2007;**81**(1):169-184

[101] NOAA. NOAA Strategic Plan for Deep-Sea Coral and Sponge Ecosystems: Research, Management, and International Cooperation. Silver Spring, MD: NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP; 2010;**11**:67

[102] Otero MM, Marin P. Conservation of cold-water corals in the Mediterranean: Current status and future prospects for improvement. In: Orejas C, Jiménez C, editors. Mediterranean Cold-Water Corals: Past, Present and Future. Chapter 46. Coral Reefs of the World 9. AG Cham, Switzerland: Springer International Publishing; 2019. pp. 535-545

[103] Boero F, Foglini F, Fraschetti S, et al. CoCoNET: Towards coast to coast networks of marine protected areas (from the shore to the high and deep sea), coupled with sea-based wind energy potential. Scientific Research and Information Technology. 2016;**6**:1-95

[104] Bo M, Tazioli S, Spanò N, Bavestrello G. *Antipathella subpinnata* (Antipatharia, Myriopathidae) in Italian seas. The Italian Journal of Zoology. 2008;**75**:185-195

[105] Kenchington E, Murillo FJ, Cogswell A, Lirette C. Development of encounter protocols and assessment of significant adverse impact by bottom trawling for sponge grounds and sea pen fields in the NAFO regulatory area. NAFO Scientific Council Report. 2011;**11**(75):53

[106] Garcia SM, Zerbi A, Aliaume C, et al. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper. 2003;**443**:71

[107] EC Reg. 56 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive). 2008. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056 [Accessed: August 10, 2019]

[108] Armstrong CW, Foley NS, Kahui V, et al. Cold water coral reef management from an ecosystem service perspective. Marine Policy. 2014;**50**:126-134