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Deep Gorgonians and Corals of the Mediterranean Sea

Michela Angiolillo and Simonepietro Canese

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Abstract

Recent studies, carried out by means of innovative technological tools as remotely operated vehicles (ROVs), have highlighted the richness of the Mediterranean deep-sea environments, characterized by great diversity and abundance of organisms. In particular, corals, gorgonians, and sponges play the important ecological role of ecosystem engineers in deep marine environments, creating complex three-dimensional habitats enhancing high biodiversity and ecosystem functioning at every level. Coral forests and bathyal white coral communities, starting from depths of 50–70 m and below 300 m, respectively, represent the richest ecosystems known so far for the Mediterranean basin. The different assemblages show a strong heterogeneity, varying in terms of specific composition, abundance, size of colonies, and associated fauna, even on a small spatial scale. Unfortunately, the high commercial fishing effort of trawling and longline fleets mainly operating along this bathymetric range represents a major threat for these vulnerable marine ecosystems, particularly in consideration of their structuring organisms which are long-lived species with slow growth rates and recovery ability. Further knowledge on deep coral assemblages is urgently needed to implement effective management and proper conservation measures. This approach is now an international priority that proceeds together with the inclusion of the structuring species in numerous directives.

Keywords: corals, deep-sea benthic communities, animal forest, Mediterranean Sea, fishing impact, ROV-Imaging

1. Introduction

The Mediterranean basin, considered a biodiversity *hotspot* [1], has been widely investigated for centuries. Nevertheless, for obvious logistic reasons, most of the investigations have been carried out within the depth range of traditional scuba diving (~40 m depth) [2–5]. So, knowledge about Mediterranean coral and gorgonian assemblages in coastal areas and photic zone had significantly increased in recent decades [3]. Conversely, knowledge about the deep realm

and gorgonian assemblages located on the continental shelf and slope still remains largely unknown [1, 6–7]. Occurrence, in the Mediterranean Sea, of coral ecosystems dwelling at depth greater than 50 m depth was already reported in the 18th century. Their presence were mostly observed due to specimens by-cached by fishermen or withdrawn by blind destructive techniques, such as grabs and dredgers [8–9] for taxonomical studies [10]. In the Mediterranean, the scientific curiosity for these ecosystems arose for the first time about 10 years ago, after the discovery, in the Ionian Sea of living white corals reefs [11–12] between 500 and 600 m depth, hosting a very rich associated fauna [13, 14]. Successively, rich coral biocoenoses, the so-called coral forest [*sensu* 15], made of arborescent gorgonians and antipatharians, were reported also at bathymetric range starting within the circalittoral zone (50 m depth) and ending at the limit of the continental shelf, around 200 m depth, both along coastal areas and seamounts [16–28].

The most recent innovative technological development and increased availability of video-equipped towed gears, remotely operated vehicles (ROVs), and manned submersibles, coupled with multibeam echo-sounder (MBES), have significantly increased accessibility to deeper areas, allowing for controlled sampling and quantitative study of deep bottoms communities [4, 5, 16–31]. The use of ROV technology has revolutionized the knowledge of such environments, allowing scientists to obtain, through many operating hours of direct observation in not destructive way, new ecological data such as habitat preferences, bathymetric distribution, and species association. Moreover, the acquisition of small fragmented samples allowed scientist to obtain biological data on reproduction, fecundity, recruitment, genetics, and growth.

With increasing depth and as a result of light attenuation, benthic sessile organisms replace algal and seagrass "forests" and become progressively the most important contributors to the three-dimensional complexity of deeper ecosystems [32]. In particular, large benthic cnidarians can play an important ecological role in deep realm. From a structural point of view, they act as ecosystem engineers [*sensu* 33] forming complex structures that provide a suitable habitat, a colonizable substrate [2, 14, 18, 25], a refuge for numerous species, and a nursery area for fish [15, 19, 31]. From a functional point of view, corals promote a significant flow of matter and energy from the pelagic to the benthic system by capturing plankton and suspended particulate organic matter [2, 3, 25]. Current flow, food availability, and sediment re-suspension vary widely within the complex structures formed by the colonies, and this heterogeneity increases the abundance and functional diversity of the associated fauna [20, 25–32], sustaining high biodiversity levels in both epibenthic and proximal interstitial surroundings [7, 13, 23, 34]. In the Mediterranean Sea, the recent discovery of the two major coral ecosystems, mesophotic coral forests [15] (between 50 and 300 m depth) and bathyal white coral mounds (from 300 m depth), is progressively increasing awareness of their ecological relevance underlying their paramount ecological role. Unfortunately, these deepwater ecosystems are highly vulnerable to a wide spectrum of direct or indirect anthropogenic impacts [35]. In particular, high commercial fishing effort of trawling and longline fleets mainly operating along this bathymetric range represents a major threat for deepwater ecosystems, whose structuring organisms are long-lived species with slow growth rates and recovery ability [36–38]. However, there is still a great lack of information on communities' structure, extension and distribution, environmental constraints, and adaptive responses to stress of these habitats, mainly due to the technical difficulties associated with deep exploration.

The present chapter intends to focus its attention on these Mediterranean deep-sea coral environments, whose studies were carried out with the aim to give a biocenotic characterization, to describe the biodiversity and the ecological role of coral assemblages, and to evaluate the anthropic impact on the structuring species.

2. Materials and methods

Since the first years of the 2000s, an increasing number of expeditions were carried out along the western Mediterranean coasts with the aim of studying biodiversity and ecology of the benthic communities and of evaluating the anthropic impact on the structuring species in the depth range of 70–500 m through ROV-Imaging and taxonomic sampling. Investigations and samplings focused on areas mainly located along the Italian, France, and Spanish coast (**Figure 1**). The surveys were carried out on board the oceanographic vessels, mainly instrumented with multibeam echo-sounder (MBES) and the remotely operated vehicle (ROV)
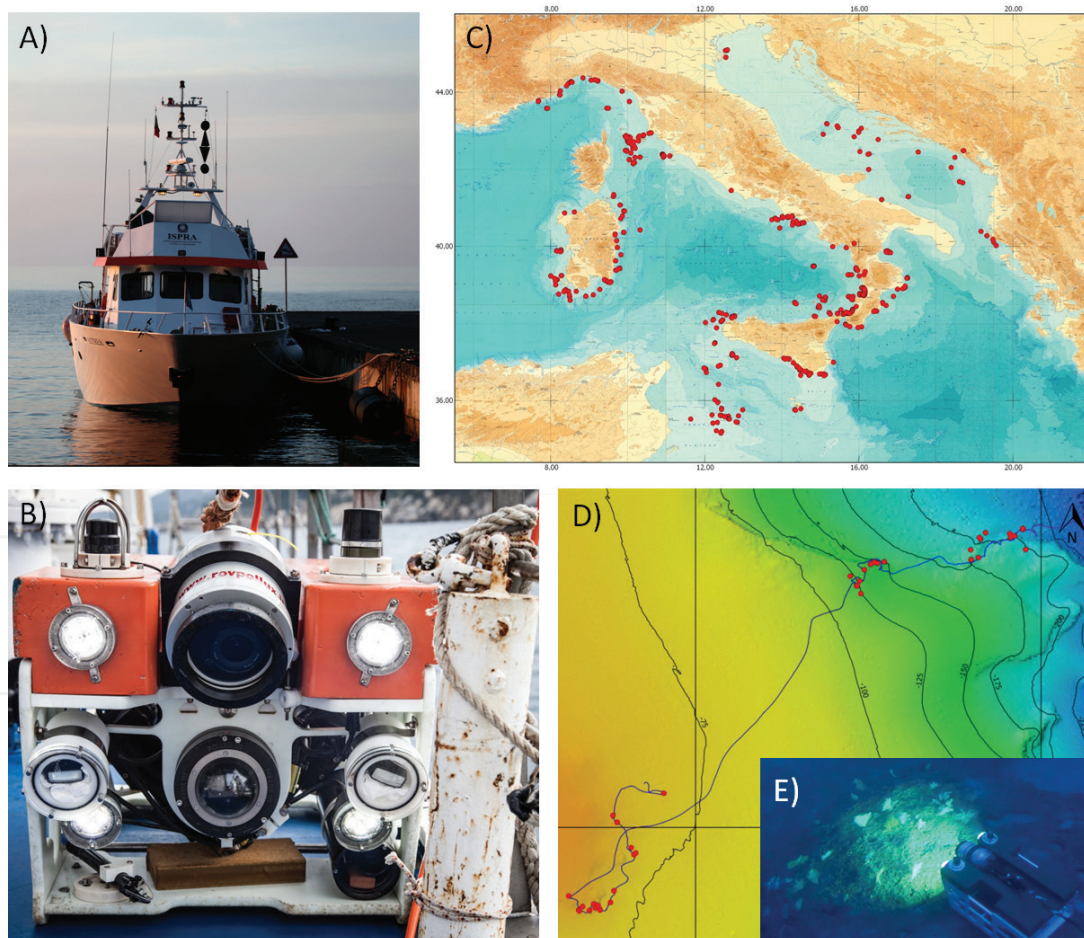

Figure 1. (A) The Italian R/V Astrea of ISPRA used for the surveys. (B) The Italian ROV "Pollux III" equipped for scientific purpose. (C) Study areas: example of location of ROV dives (dots) along the Italian seas. (D) example of morpho-bathymetric maps of a study areas and ROV transect (line). (E) The depth environment with the ROV in exploration phase.

equipped for scientific purpose (**Figure 1**). MBES provided high detailed morpho-bathymetric three-dimensional maps in order to localize rocky outcrops then explored by means of the ROV. The MBES is a device used to determine the depth of water and the nature of the seabed. It works by transmitting a broad acoustic fan shaped pulse from a transducer every seconds. The data processing of returning soundwaves is used to generate accurate high resolution three-dimensional maps of sea bottom. The ROV is an underwater unmanned vehicle that is able to navigate at a speed of approximately 2–3 knots equipped with video camera and connected to the surface through an umbilical cable (a long electrical cable) that carries the power source and control signals deriving from the vessel and transmits the acquired video and sensor data. The surface unit is composed of a console for the remote controls, a unit for the storage of data, and monitors to observe in real time the acquired images. The winch with the umbilical cable completes the set of equipment to guarantee the full operability of the system. The ROV has a depth sensor, a compass, and an Ultra Short Baseline underwater acoustic tracking position system, providing detailed records of the tracks along the seabed and a navigation Sonar. Moreover, some ROVs are furnished with specific scientific tools such as a digital high definition photo camera, underwater strobes, HD video camera, ultra-led power system providing light for the cameras, and laser beams placed at fixed distance and used as a metric scale of the images and the visual field. In addition, manipulator arms can be used to collect any biological samples.

The ROV was generally conducted ~1.5 m above the seabed, at constant speed (approximately 0.5 knots). Explorative or vertical transects, from the shallow to depth, were carried out, and geographical positions and depth were registered from the beginning to the end of each transect, every 1 second. Along each transect, videos were constantly recorded and HD photos were systematically acquired in order to better identify and quantify the target species, the marine benthic litter, or misunderstanding items. ROV-Imaging analysis of video transects was carried out to examine diversity, spatial distribution, abundance, demography, and vulnerability of the gorgonian and coral species detected in order to obtain information about ecology of a single species or a benthic communities characterization. So data on occurrence, occupancy (frequency of coral patches m^{-1}), density (number of colonies m^{-2}), population size-frequency distribution by means of measure of the main morphometric parameters (colony height, basal diameter, and branching order), and community composition were extracted and analyzed. Usually, some large anthozoans were used as surrogate descriptors of mega-benthic marine biodiversity due to their richness, abundance, identification easiness, and ecological role. The correspondence between the visual assignment of an individual to a certain coral species and its actual taxonomic classification was checked through the collection of at least one sample per species. The collection of photographic material and high resolution videos helped to define the species composition of these populations. Moreover, environmental variables, such as substrate exposure, substrate slope, sediment cover, co-occurrence with other species, or debris presence, were collected to habitat characterization and benthic community's assessment.

To assess some anthropic impacts, such as the presence of marine debris, observed items were usually divided into categories: fishing gears, plastics, recreational litter, and so on. The presence of debris was evaluated both by occurrence (frequency of debris types), relative abundance

(debris items 100 m^{-2}), or taking into consideration the percentage of frames showing lost debris. To evaluate the impact of debris on the benthic fauna, different types of impact were identified (covering, abrasion, hanging, lying), and every damaged or entangled colony was annotated.

3. Animal forest

In the past, deep-sea ecosystems were among the least studied and explored marine regions of the world [4, 5, 35], and until a few years ago, a common assumption was to consider deep-sea areas to be lacking in terms of biodiversity. The exploration carried out with ROV leading to the discover that deep-sea ecosystems are characterized by a great heterogeneity of assemblages and dominated by sessile suspension feeder organisms (such as sponges, corals, gorgonians and bivalves) that vary in dimension, richness, and abundance, representing important natural heritages in the world [31, 35]. In the Mediterranean, cnidarian-rich deep-sea habitats, dominated by antipatharians, gorgonians, and scleractinians, as major habitat forming taxa, for the typical bush or arborescent development similar to the trees in the terrestrial forest, finally build up the so-called animal forest [15]. Comparable to earth forests in terms of stability, complexity, biodiversity, role, and longevity, these communities are widely distributed along rocky areas of Mediterranean Sea and represent unique ecosystems, very oasis of biodiversity [15, 20, 24–30, 32, 39].

Terrestrial forests supply food, protection, and support to a great variety of organisms, which may establish occasional or highly specialized relationships with both the dead and living portions of the trees [24, 40]. Similarly, oceans host astonishing examples of forests in the deep-sea, entirely structured by colonial animals, which represent the most frequently observed coral taxa in these ecosystems [18, 24, 25, 31].

Thanks to their flexible organic skeletons, which offer them a weak resistance to the current, gorgonians and black corals can tolerate strong currents, thus enabling them to obtain a greater quantity of food and favoring larval dispersal [24]. The local turbulent conditions that develop among the branches encourage the persistence of food in suspension and thus attracting numerous organisms both epibiontic, such as molluscs, platyhelminthes, hydroids, and bryozoans, and vagile organisms, such as fish, crustaceans, and echinoderms. So, they represent an attractive pole for a very rich associated fauna of small invertebrate, increase the possibility of new ecological niches, and also play key site and species-specific roles on the early-stage recruitment of other epibenthic assemblages [31]. Moreover, they provide refuges for numerous species and host nursery areas for several commercial fish, favoring the development of plentiful high-quality fish. As a consequence, the richness and biodiversity of these environments are increased. Hence, the important ecological role of these large anthozoans: major elements in the formation of forests and hosts of a rich associated fauna into and around their wide branches. Moreover, like the oldest terrestrial trees, also some of these coral species may live for thousands of years [24]. The most complex forests are the result of a long history of growth and structure. The oldest, for example, are formed by tall and branched corals such as the 1000-year-old smooth black coral, *Leiopathes glaberrima*, able to reach 2 m height [24]. These deep benthic communities show their best form on the rocky bottoms due

to habitat heterogeneity. The different assemblages vary strongly not only based on the specific composition, but also in terms of abundance, size of the colonies, and associated fauna, even on a small spatial scale. Their distribution is strongly influenced by multiple factors, as their limited larval dispersal, slow growth rates, low ability of recovery, late maturity age, availability of nutrients, heterogeneity of the habitat, rate of sedimentation, colonies vulnerability to impacts and habitat destruction, harvesting by fishery operation, or other threats are determined by human activity. In fact, these animal forests, of long-living, slow-growing organisms, are fragile ecosystems. They are able to adapt to environmental standard changes and to overcome occasional perturbations, but those which are more important and recurring, such as professional and recreational fishing, trawling, hypertrophication, and pollution, can have devastating effects when they all play in synergy, making recovery impossible.

For their importance from the ecological point of view, from their capacity to contribute to the creation of habitat, from the *facies* of deep coral to white coral reefs of the Mediterranean bathyal zone, certain species of anthozoan can be considered emblematic of the state of health of the benthic population of Mediterranean seas, heavily influenced by multiple human activities.

3.1. Gorgonians

Gorgonians are one of the most important and diverse bioengineering organisms in the Mediterranean Sea, forming dense assemblages that extended over vast areas. The majority of them have a fan-like structure that can be as wide as 2 m, but they can also be found in the arborescent or finely branched form, bush-like, or also devoid of branches. They are typical of the hard seabeds, but they are also able to tolerate high levels of sedimentation or anchor themselves on soft bottoms. They have a wide bathymetric and geographical distribution. According to the species, they can be predominant in deep areas, forming different association and assemblages. In the Mediterranean basin, the most abundant and frequent deep gorgonian species are *Eunicella singularis* (Esper, 1791), *Eunicella cavolini* (Koch, 1887), *Paramuricea clavata* (Risso, 1826), *Paramuricea macrospina* (Koch, 1882), *Corallium rubrum* (Linnaeus, 1758), *Acanthogorgia hirsuta* (Gray, 1857), *Callogorgia verticillata* (Pallas, 1766), *Ellisella paraplexuroides* (Stiasny, 1936), *Viminella flagellum* (Johnson, 1863), *Swiftia pallida* (Madsen, 1970), *Villogorgia bebrycoides* (Koch, 1887), *Bebryce mollis* (Philippi, 1842), and *Muriceides lepida* (Carpine & Grasshoff, 1975). These gorgonians can form dense monospecific *facies* that gradually shift to other *facies* or more complex assemblages, made by sponges, antipatharians, scleractinians, alcyonacean, and associated fauna [15, 18, 20–26, 28, 32, 39, 41]. Depth clearly segregates gorgonians and the assemblage composition varied strongly from sites to another. However, a general pattern of high gorgonian diversity is observed (**Figure 2**), since these species have been recently found with increasing frequency on rocky substrates at similar depths in different areas of the Mediterranean Sea [7, 16–28, 32, 37–39, 41–44, 46–52].

Overall, spatial structure of these gorgonian distribution can be generalized: i) coastal species extending their distribution to deep coralligenous banks (*E. singularis, E. cavolini,* and *P. clavata; E. paraplexuroides; C. rubrum*); ii) dominance of one single species on the continental shelf (*P. macrospina, E. cavolini, C. rubrum*); iii) concentration of several gorgonian species on the
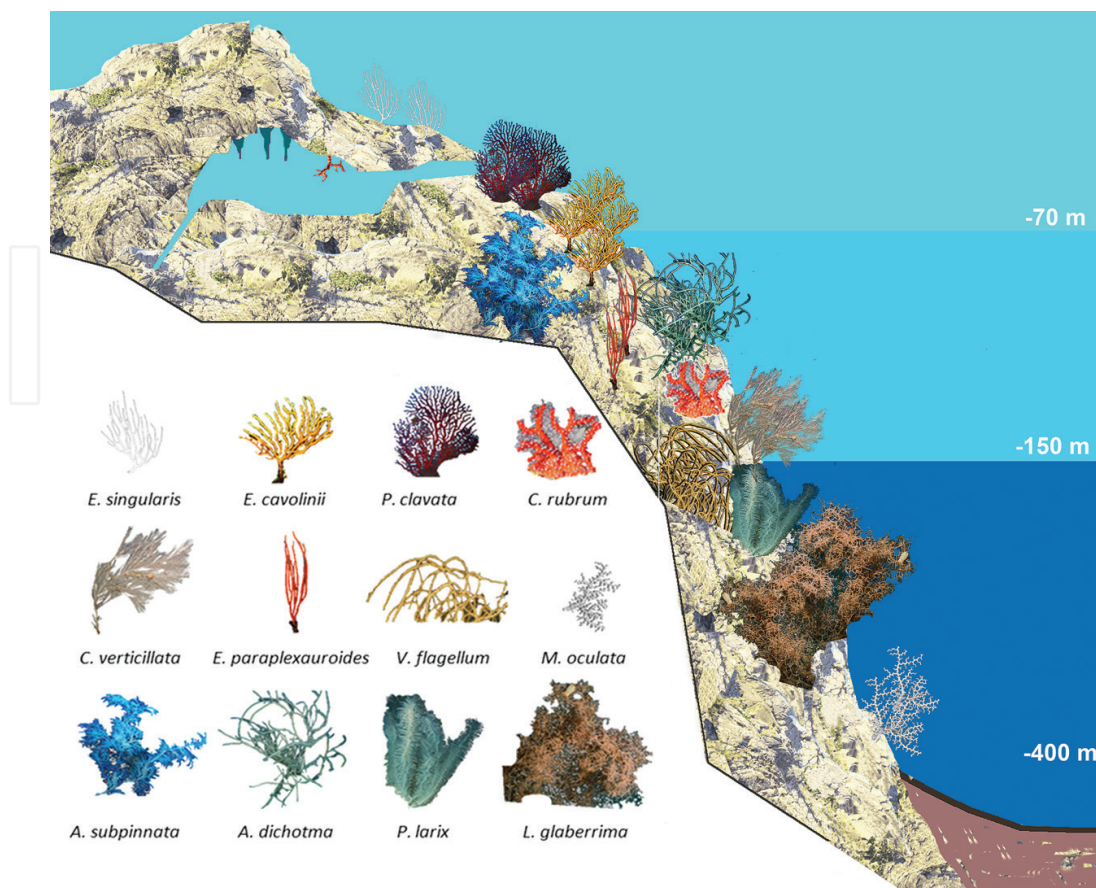
Figure 2. Zonation of the megabenthic assemblages. The figure presents the distribution of the most conspicuous and abundant components of the megafauna dwelling at about 50–500 m depth.

shelf edge (*E. cavolini*, *P. macrospina*, *S. pallida*, *A. hirsuta*, *V. flagellum*, *B. mollis* and *C. verticillata*, and *C. rubrum*); iv) species extending their distribution deeper into the upper slope (*B. mollis*, *C. verticillata*, *V. flagellum*, *V. bebrycoides*, and *S. pallida*).

E. singularis dominated assemblages located on the continental shelf on rocky and horizontal substrate (**Figure 3 (A)**) and in the western side of basin (along the Spanish coast), in particular water transparency condition, it can extend its distribution to deeper water [26, 42]. In deeper environments, populations of *P. clavata* were found in low-density patches on coralligenous banks at 70–90 m depth [26, 30, 39, 42] and few colonies on the shelf edge and slope at 100–120 m depth [20, 37, 39]. Colonies, generally, achieved larger sizes than in shallower environments [3], as a possible consequence of the higher environmental stability of deeper areas. The common Mediterranean coastal species *E. cavolini* showed a wide distribution: it was found on sloping and vertical rocky on deep coralligenous banks on the continental shelf and on the shelf edge (45–150 m depth), where it can form dense *facies*. Commercially harvested since ancient times, the red coral *C. rubrum* is emblematic species occurring on rocky bottoms over a wide bathymetric range (15–800 m) [15, 43–45]. Recent deep investigation led to discovery of new thriving deep population [45] (**Figure 3 (B)**). The brick-red candlestick colonies of *E. paraplexuroides* were rare and discontinuously distributed in the Mediterranean. They were very shallow (12–35 m) and abundant in Chafarinas Islands and around Alboran
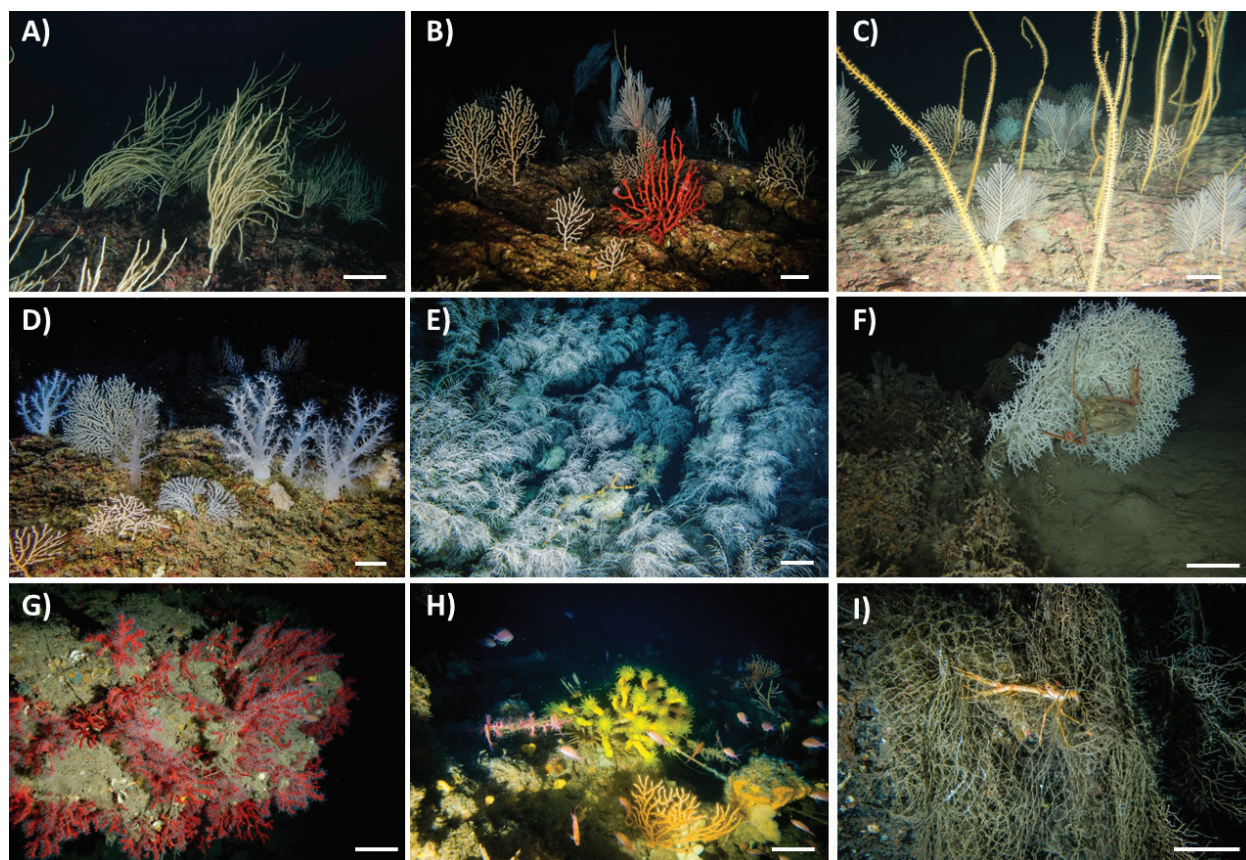
Figure 3. Coral assemblages and impacts of fishing litter on the rocky bottom of the Tyrrhenian Sea. (A) Rocky elevation covered by *E. singularis facies*, 50 m. (B) Example of coral forest, composed of *C. rubrum, C. verticillata, E. cavolini,* and *B. mollis*, 140 m. (C) Mixed assemblage of *V. falgellum, E. cavolini,* and juvenile colony of *C. verticillata*, 180 m. (D) Multi-species meadows of *E. cavolini, V. bebrycoides,* and the new species of Mediterranean soft coral *Chironephthya Mediterranean n. sp.*, recently described, 120 m. (E) Arborescent colony of *A. subpinnata*, 97 m. (F) Alive white corals *M. oculata*, associated with the crustacean *Paromola cuvieri*, which often carries a sponge on its exoskeleton, 470 m. (G) The precious red coral colonies entangled and abraded by an old line snagged on the rocks, 114 m. (H) Lines, colonized by alcyonarians and hydroids, are fully incorporated in the yellow scleractinia *D. cornigera*, 80 m. (I) Example of the so-called ghost fishing: *Munida rugosa* caught by an abandoned or lost net, 150 m.

sea [46–48], whereas only isolated deep colonies (70–200 m) were found in the southern western basin [49–50]. Populations of the whip-like gorgonian *V. flagellum* were known to have a patchy distribution, alternating dense meadows with sparse colonies, in vertical and subhorizontal rocky bottoms [10, 50]. Recent records [17, 32, 49–51] have showed wider distribution of this species in the deep water (100–250 m) of the western basin, where it is one of the most abundant and frequent [39] (**Figure 3 (C)**). *A. hirsuta* is a species showing restricted distribution, occurring in few locations of the shelf edge at 150–200 m depth [39]. This species usually occurred on lightly silted rocky substrates and it often observed together with other anthozoan species [10, 52], suggesting a certain adaptability to various environmental conditions. *P. macrospina* dwelled on rocky substrates and never as a dominant species [39], but it was also observed that it associated with horizontal Maërl beds on the continental shelf where it can raise very high abundances [39]. Moreover, *P. macrospina* can also grow as a fouling and epibiontic organism, suggesting a fast growth rate [19]. Populations of *C. verticillata* formed

dense *facies* [20, 23, 27, 32] mainly in areas characterized by high sedimentation rates and the low values of coral abundance, providing a general "forest-like" aspect to the coral communities [32]. The small size gorgonian *B. mollys*, *S. pallida,* and *V. bebrycoides* were observed to extend their distribution under 200 m depth [39] from the shelf edge to the upper slope. Together with sponges, they can create a sort of "underbrush," living at the base of bigger species. So, a rich community of filtrating organisms is supported (**Figure 3 (D)**), composed principally of corals and erect sponges of large dimensions, thus representing an important passage in transferring energy between the benthic and the pelagic zone. On the scarce rocky substrates occurring in these deeper environments, gorgonian abundance tends to decrease with increasing depth, and antipatharians become the dominant arborescent species [24, 53].

At these depth (100–250 m) are also recorded some rare species like the stylasterid *Errina aspera* in the Messina Strait [28], or the parasitic zoanthid *Isozoanthus primnoidis* (Carreiro-Silva, 2011) that when mechanically stimulated, produced an intense green-blue bioluminescence that disappeared after some seconds [23]. Moreover, *facies* of the scleractinians as *Dendrophyllia ramea* in Cyprus and Sicily and *D. cornigera* were recorded often in the Western Mediterranean [23, 41]. Finally, the soft sediments of these deeper environments can be colonized by the bamboo coral *Isidella elongata* [24, 36], which can form extended assemblages in bathyal muds [8] or in natural protected enclaves [24].

Distribution of coral communities may be determined by the combination of both biological and environmental factors that can synergistically affect spawn, larval development and settling, growth, and death rates of individuals and geomorphological characteristics of settlement substrates that affect sediment accumulation rates, bottom currents, and the rates of food supply [39]. Overall, these factors shape Mediterranean coral communities, which show very high variability within the smallest spatial scale [32].

3.2. Black corals

Black corals are spread throughout all the oceans of the world. They are found especially in tropical and subtropical areas, where they can colonize very shallow waters, and in temperate and polar regions, where they dwell in deep water. The black corals have a black skeleton, from which they derive their common name, while the living organisms have a whitish color and heavily branched tufts. In the past, it was believed that they had magical and curative properties—in fact, the scientific name, Antipatharia, refers to the Latin term which indicated a talisman against witchcraft. Some species was used for jewelry trade [54–55]. Black corals seem to be keystone species, essential for the maintenance of high biodiversity levels. Six species are described for the Mediterranean Sea: *Antipathes dichotoma* (Pallas, 1766), *Antipathes fragilis* (Gravier, 1918), *Parantipathes larix* (Esper, 1790), *Leiopathes glaberrima* (Esper, 1792), *Antipathella subpinnata* (Ellis and Solander, 1786), and *Antipathella wollastoni* (Johnson, 1899) [56]. In this basin, black corals are usually restricted to deep habitats, probably to avoid strong seasonal fluctuations of temperature [57]. The shallowest species were found never shallower than 50 m in depth, while the majority occurs between 100 and 300 m depth only on rocky slopes and isolated shoals [56] (**Figure 2**). These organisms carry out an important ecological role in the deep sea. Considered to be among the rarest coral species of the Mediterranean

Sea [56], instead, new findings indicate that black corals are among the most conspicuous and widely distributed components of the Mediterranean deep-circalittoral coral communities, where they can form huge meadows [7, 18–19, 22–24, 57]. They may reach impressive abundances and sizes, forming important *facies* in the deep-sea realm [22]. The large, white, branched *A. subpinnata* is a common component of the lower fringe of the circalittoral (60–150 m) and is the most widespread [57]. It is able to form dense meadows (**Figure 3 (E)**), counting more than 30,000 colonies [18], starting at 60 m, and is also occasionally recorded at up to 500 m associated with white coral mounds [14]. The congeneric *A. wollastoni* forms conspicuous populations in both shallow and deep Atlantic waters, but has also recently been recorded in the Mediterranean basin in the vicinity of the Gibraltar Strait [22, 58]. *A. dichotoma* is characterized by tall arborescent colonies with loose, long, flexible branches and large polyps [19, 22]. Sparse colonies were found at 100 m and deeper in several Mediterranean areas in benthic assemblage characterized by several coral species [14, 16–17, 41, 59]. *A. fragilis* is a doubtful species. It has never been found again with certainty, and since the type specimen is lost, there is no possibility to verify, at present, its taxonomic status [22]. *L. glaberrima* is a tall arborescent, bright orange or white, black coral species, among the most common black corals of the Mediterranean basin [22]. Occasionally found at 100 m, it forms dense forests only from 200 m along the rocky bench terraces [23–24, 52, 60] or among white coral reefs [14, 61]. It is a frequent bycatch of long-line fishermen or trawlers [55]. *P. larix* is a monopodial or sparsely branched species showing a characteristic bottle-brush pinnulation pattern, up to 2 m tall [22]. This Atlantic-Mediterranean species living on rocky bottoms both along the continental shelf and in very deep waters (up to 2300 m) [54, 62] is usually very sparsely distributed [22, 62]. Exceptional forests dominated by dense monospecific populations of *P. larix* were recorded only off the Island of Montecristo (Tuscan Archipelago, Tyrrhenian Sea) [22]. Similar to other filtering colonial organisms, black corals tend to settle in areas of moderate to strong current, maximizing food capture and larval dispersion. The black coral population is inhabited by a huge variety of sessile, encrusting, and vagile organisms, searching for a refuge or a source of food, supporting the hypothesis that the existence of the coral canopy is able to enhance biodiversity at every level [4, 24, 56].

It is intriguing how these species, known for centuries and representing a conspicuous structure-forming component of relatively deep coral ecosystems in a well-known basin such as the Mediterranean Sea, have avoided attention for such a long time. In comparison, recent explorations are progressively unveiling the characteristics of Mediterranean black coral forests [18–19, 55].

3.3. White corals

The so-called white coral bathyal community or cold-water coral (CWC) [8] consists of the scleractinians species as *Lophelia pertusa* (Linnaeus, 1758), *Madrepora oculata* (Linnaeus, 1758), and *Desmophyllum dianthus* (Esper, 1794). These taxa, known to be well alive in the Atlantic Ocean at present, were considered almost eradicated from the Mediterranean basin from the last deglaciation age [65]. In the Mediterranean Sea, the last ROV exploration and fishery operations [12, 64] step-by-step led to discovery of many new still-alive CWC sites [65]. Live stocks were and are unevenly distributed in the Mediterranean Sea

under 300 m depth (**Figure 2**), with six cold-water coral provinces identified thus far: the Southwestern Adriatic CWC (Bari Canyon), the Northern Ionian CWC (Santa Maria di Leuca), the Strait of Sicily CWC (South Malta), the Nora canyon, offshore the southern Sardinia [63], the Alboran Sea CWC (Melilla), and the Catalan-Provençal-Ligurian canyons CWC, to which to add more spotty records of live CWC [65]. The distribution of living CWC in the Mediterranean does not overlap everywhere the occurrence of subfossil counterparts, and this is particularly evident in the eastern basin [63]. These areas include both highly-structured ecosystems covering substantial surfaces, and patchy or spot records [27, 29, 60, 64–69]. The structural complexity offered by CWC habitats allows for the development of highly diverse associated communities that usually result in considerably higher biodiversity than the surrounding environment [30]. Antipatharians, gorgoniaceans, the scleractinians *Dendrophyllia cornigera* and sponges such as *Pachastrella compressa* and *Poecillastra monilifera* are also characteristic components of CWC communities elsewhere [21, 63, 67, 69]. The living coral colonies offer shelter to many invertebrates, such as the decapod crustaceans *Munida* cf. *tenuimana* and *Anamathia rissoana*. The vagrant macrofauna within or around coral grounds includes also a few echinoderms, such as the echinoids *Cidaris* sp. and *Echinus* sp., the sea star *Peltaster placenta*, and the spider crab *Paromola cuvieri* (**Figure 3F**). CWC bioconstructions are found and work as nurseries for several deepwater species of commercial interest (i.e., gadids or lophids) and are probably important for the maintenance of superficial stocks [5, 9, 10]. Demersal fish such as blackbelly rosefish *Helicolenus dactylopterus*, the Atlantic wreckfish *Polyprion americanus*, the large lender rockfish *Scorpaena elongata*, and the Blackspot seabream *Pagellus bogaraveo* are the principal species of fishes associated with CWC. The rare scale-rayed wrasse *Acantholabrus palloni* and the rare Ophidiidae *Benthocometes robustus* and several shark species such as *Hexanchus griseus* are also observed [63]. The dead coral portions are characterized by iron oxide and are fouled by hydroids, zoanthids, bryozoans, and brachiopods [63]. The solitary coral *D. dianthus* is almost ubiquitous preferentially settling live and dead colonies. The bivalve oyster *N. zibrowii* serves as substrate to living *D. dianthus* and *M. oculata*, but one living specimen was observed settling a dead *M. oculata* frame [63]. As it is the common rule in CWC grounds, the highest diversity is encountered in the dead part of the coral reef and within the interspersed soft sediment. Recent research has shown that canyons may be home to lush CWC communities [32, 63, 70–72]. This holds true for the Mediterranean Sea as well where important CWC presence has been documented at a number of canyons [27, 29, 44, 63, 65, 67, 73]. Because of their general patchiness inside canyon systems and intrinsic exposure to a number of direct and indirect dangers, canyon coral habitats are classified as vulnerable marine ecosystems (VME) [27] and obviously deserve protection [73–75].

4. Impacts and threats

In recent years, a marked increase of the human activities impact on deep-sea habitats has been observed [75, 76]. Dumping, increasing littering, oil spilling, mineral extraction, on-bottom framework works (e.g., pipes, cables), and fishing activity [34] are affecting the health status

of such bottom communities. In addition, indirectly, global warming trends affect vital hydrographical attributes and progress in ocean acidification [34]. However, major direct threats are connected to fishing practices, which include (accidental) trawling, long lining, and crab trapping [77]. The effects of fishing activities on the benthic biocoenoses represent a worldwide problem particularly relevant in the Mediterranean Sea, a site characterized by intense historical fishing traditions. The majority of the studies concerning fishing impact have been addressed on the soft bottom assemblages subjected to trawling activities [33, 78], while very few information is available on the response of hard bottom communities, with the exception of some priority habitats such as seamounts [79] and white coral forests [29, 61, 73]. The recent ROV investigations in the western Mediterranean basin have revealed the heavy impact of fishing activities on the benthic communities as an omnipresent feature in all the surveyed localities [20, 23–24, 27, 29, 37–38, 80]. In the Mediterranean Sea, the rocky bottoms between 50 and 700 m depth, being generally avoided by trawlers, represent important fishing grounds for artisanal and recreational fleets. The rocky areas populated by coral forests attract a rich associated fauna, including fish species of commercial interest, which therefore increase the importance of these habitats for fishermen [25, 37]. Coral bycatch data suggest a dramatic effect of certain gears, estimated in various dozens of eradicated colonies per fishermen per year [73]. Moreover, due to complex structure of rocky bottom, some gears (e.g., trammel nets, gill nets, and long lines) can become entangled in the surrounding rocks, breaking and covering all the organisms that elevate on the substrate (e.g. corals, sponges, bryozoans) and accumulating in great quantity and at any depth (**Figure 3 (G)**). The gears also produce a continuous mechanical scouring on the sea bottom, determining sediment re-suspension. As a result, progressive and extended habitat degradation is observed [81, 82, 33] with substantial modifications of the structure and functioning of deep ecosystems through a shift in species composition toward opportunistic species with a faster growth rates and adapted to live on more silted or unstable habitats [37]. The abrasive action due to entangled gears on the colonies causes a continuous removal of their tissues (**Figure 3 (H)**), making them more vulnerable to parasite or bacterial infections as well as the epibiont agglomerates covering [37–38], which in the long term can also cause the colony mortality [83]. The introduction of very strong fishing gears, made of non-biodegradable synthetic materials, contributes to the phenomenon of "ghost fishing": the abandon nets, still in their working position, may continue to catch for a long span of time a large spectrum of organisms [82, 84] (**Figure 3 (I)**). Due to the extremely slow degradation of nylon, lost gears may persist for a centuries [85, 86] accumulating on the sea bottom, altering the surrounding habitat, and covering wide portions of the settled communities impeding the re-colonization for large anthozoans [87]. In the sea bottom, also other kind of litters, such as tyres, cans, glass bottles, and bigger objects (washing machines, bins, etc.), were observed. This debris can be adapted as shelters and colonized by encrusting or sessile organisms, vagile fauna, formed by echinoderms, fish, crabs, and other crustaceans [86, 88]. Although such artificial substrata enhance biodiversity, they are an alteration of the natural environment and of the communities which might settle down [89].

Generally, the most impacted species are those with a medium-large colony size, an arborescent morphology, and a flexible skeleton, that easily remain entangled. Coral skeletal characteristics, such as stiffness, flexibility, or fragility, are known to play an important role in the resistance of friction, which explains the different responses of coral to mechanical

impacts [27, 37–38, 52]. Some species are often removed, while other are frequently crushed or only scrape the soft tissue of the branches [37–38, 52]. It is likely that such colonies can be completely eradicated from some heavily fished sites where coral forests have almost disappeared. Finally, in some highly impacted sites, the high percentage of damaged colonies that are partially or entirely covered by epibionts may suggest a general state of stress of the community [52]. The continuous pressures of human activity on such particular animal forests make them extremely vulnerable and are one of the major causes of degradation of the marine environment [82, 86, 88].

Different regional fishing traditions, accessibility of the fishing grounds, distance from the coast and the exploited depth range, hence efforts, as well as the typology of employed gears, the species composition of the community and, therefore, the response of the community to the impact and its recovery ability can play a synergistic role in defining different impact among the investigated areas [37]. In the Mediterranean basin, with impressive peaks along some areas [27, 37–38], the deep shoals are progressively depleting with dramatic consequences that have a negative effect also on the productivity of artisanal fishing. These data suggest that it is highly probable that pristine coral forests no longer exist also on rocky sea bottoms, especially in traditionally exploited fishing grounds [37].

5. Conclusion

The Mediterranean Sea offers an example on how advancement in marine technology and the recent increasing effort to investigate the deep-sea frontier have led to a revolution in the knowledge about deep realm [63]. The deep-sea benthos of the Mediterranean basin did target preferentially soft bottom (mobile) substrates, easier to sample by trawls, dredges, grabs, and corers. On the contrary, hard substrates have been understandably little touched by the biological exploration especially when associated with canyons and seamounts because of the intrinsic risk to imperil sampling gears [65, 89]. ROV exploration has opened new perspectives in the study of the deep benthic fauna, providing qualitative and quantitative description of benthic assemblages and progressively unveiling the characteristics of Mediterranean coral forests [22, 18–19, 55]. The high-density deep coral assemblages may provide an approximate idea of how Mediterranean continental shelves and upper slopes stood before decades of commercial fishing. These coral communities include the most common species which suffer by-catch of bottom trawling, trammel nets, and longline fishing which can have far-reaching and long-lasting negative effects [24]. Effects of fishing activities on the seabed and benthic communities have been indeed compared to those of forest clear-cutting, with an immediate reduction of the structural diversity and following alteration of biogeochemical cycles, species recovery, and settling rates [24]. Animal forest has now been internationally recognized as unique habitats characterized by numerous structuring species, generating complex and fragile ecosystems, which act as important oases of biodiversity in the deep realm. For these reasons, the international scientific community has recently proposed the inclusion of some of these species in many protection lists, recognizing their ecological value and their vulnerability to human activities: the Convention of Biological Diversity [17]; "Coral Garden" habitats were added to the OSPAR (Oslo and Paris Conventions for the Protection

of the Marine Environment of the North-East Atlantic) "List of threatened and/or declining species and habitats" in 2007 [17]. Moreover, due to the fact that they are considered sensitive habitats, they may be identified as vulnerable marine ecosystems (VMEs). Recently, the Food and Agriculture Organization (FAO) [40] recommended the establishment of protected areas where such VMEs are known to be or likely to occur in order to put into action an ecosystem-based fishery management of deep-sea ecosystems [27]. Despite the European Commission has now proposed regulations against the use of trawling nets on important ecosystems as coralligenous, seamounts, and white coral mounds [90], in the Mediterranean waters, the interdiction of these deep-sea coral sanctuaries located on trawling routes or within traditional artisanal fishing grounds would raise numerous socio-economic problems [24].

Future research efforts should be paid to better understand the factors driving deep coral biodiversity in the Mediterranean Sea in a more "holistic" key, focused on understanding how, at different spatial scales, the disappearance of animal forests could represent a point of no-return whose consequences are still not clear to the scientific community [15, 24, 37].

Acknowledgements

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