Geo-biology of Mediterranean Deep-Water Coral Ecosystems

M. Taviani[1], L. Angeletti[1], B. Antolini[2], A. Ceregato[1], C. Froglia[2], M. López Correa[3], P. Montagna[4,1], A. Remia[1], F. Trincardi [5], A. Vertino[1,6]
1, Institute of Marine Sciences, CNR, Bologna, Italy
2, Institute of Marine Sciences, CNR, Ancona, Italy
3, GeoZentrum Nordbayern,Universität Erlangen-Nürnberg, Germany
4, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, U.S.A.
5, Institute of Marine Sciences, CNR, Venezia, Italy
6, Department of Geology and Geotechnologies, University of Milano-Bicocca, Milano, Italy
marco.taviani@bo.ismar.cnr.it

Abstract

Cold (or deep) water corals (CWC) are a spectacular and widespread component of the ocean biota. Highly structured CWC ecosystems serve as biodiversity hotspots suggesting the need for the proper management of these unique habitats. Among the most relevant actors in promoting the growth of conspicuous structures (deep water reefs and mounds) are branching stony corals like *Lophelia pertusa* and *Madrepora oculata*. These widespread frame-builders occur also in the Mediterranean basin and are the backbone of Recent CWC provinces identified thus far in the Ionian Sea (Santa Maria di Leuca), South Adriatic Sea, Strait of Sicily, Catalan-Provençal canyons and Alboran Sea. CWC distribution seem strongly influenced by oceanographic factors coupled with proper substrata, such as steep (canyon heads, seamount walls etc.) or rugged (slumped blocks) topographies. Dead pre-Modern coral assemblages are present in the entire Mediterranean Sea. These submerged fossil assemblages have been mostly U/Th and ^{14}C dated at the latest Pleistocene documenting propitious basin-wide conditions for their successful growth during glacial periods.

1 Introduction

The existence of cold (or deep) water corals (CWC) is known since centuries (overview in [1]). Their capability to construct substantial bio-constructions ('reefs', bioherms, mounds, build-ups), however, has been properly focused mostly in the last decade or so through the implementation of novel technologies to explore the deep ocean and the concomitant launch of a series of international and national multidisciplinary programmes [2, 3, 4, 5, 6, 7]. As evocatively summarized by Freiwald et al. [8], the outcome of such on-going integrated research is that cold-water coral reefs are now 'out of sight - no longer out of mind'. CWC are generally intended as those deep water azooxanthellate colonial scleractinian (stony) corals more commonly distributed between ca. 200-1200 m in a temperature range of ca. 4-14 °C. CWC group taxa with a pronounced frame-building ability (*Lophe-*

lia, Madrepora, Oculina, Goniocorella, Solenosmilia, Enallopsamia, Dendrophyl-ùlia), some of which, such as *Lophelia pertusa*, *Madrepora oculata* and *Solenosmilia variabilis*, presenting a quasi-cosmopolitan geographic distribution [8]. For instance, in the Eastern Atlantic CWC build-ups constitute one of the major features along the NW European continental margin covering, albeit discontinuously, a distance of over 2400 nautical miles from sub-polar latitudes off Scandinavia to temperate settings off Iberia. Highly structured CWC build-ups are clustered in specific regions where the proper mixture of suitable topographic and oceanographic situations do exist [9, 10]. The most efficient frame-builders (mainly *Lophelia* with a growth rate attaining 2.5 cm·year^{-1}: [11]) work in making spectacular carbonate mounds, some encompassing many hundred thousands to millions years of discontinuous coral accretion [9, 12, 13, 14, 4, 5]. CWC mounds and smaller build-ups are documented on both sides of the Atlantic (overview in [5]. Individual giant mounds may reach a few km in diameter and many hundred meters in height and include both active (e.g., Magellan, Darwin, Belgica, Hovland, Porcupine Bank Canyon mounds) and buried examples (e.g., Enya, Viking mounds). In face of their spatio-temporal distribution and volumetric extent, it is evident that CWC are important carbonate producers whose contribution is far from being negligible in the assessment of the carbonate budget [15, 16]. Discrete areas characterized by substantial CWC growth are conveniently recognized as coral provinces whose number is steadily increasing. While one or more such corals often co-act in establishing bio-constructions at depth, a variety of other sessile invertebrates as solitary scleractinians (such as *Desmophyllum* and *Caryophyllia*), octocorals, antipatharians (black corals), sponges and even giant oysters (*Neopycnodonte*), efficiently concur in making CWC habitats true biodiversity hotspots [8, 17, 3, 18, 19, 20, 21]. These coral habitats are significant performers in the economy of the ocean [8, 22, 18] and therefore require proper management and governance [18, 23, 24]. CWC are in fact under aggression by a number of anthropogenic threats [8, 18], above all invasive fishing practices like bottom trawling [25, 26, 27]. The predicted change in seawater chemistry bringing about a progressive acidification of the ocean is also a major concern for the fate of CWC worldwide because of its negative impact on the corals' calcification ability [28].

2 Cold-water corals of the Mediterranean Sea

In the last 15 years, the Italian National Research Council (CNR) of Bologna has conducted systematic research on CWC in the frame of various national (CNR, FIRB-Aplabes) and European (ESF Moundforce, EU Hermes and Hermione) projects resulting in a sequence of oceanographic missions covering a substantial part of the Mediterranean Sea, from Alboran to the Levantine basin (Figures 1, 2, 3). This interest for deep sea coral research, however, stems from long before since CWC were routinely encountered during marine geological investigations of the deep Mediterranean Sea carried out beginning in the late 60's by the former Laboratory then Institute of Marine Geology (now ISMAR-Bologna) resulting in various publications dealing with corals (e.g., [29, 30, 31, 32]).

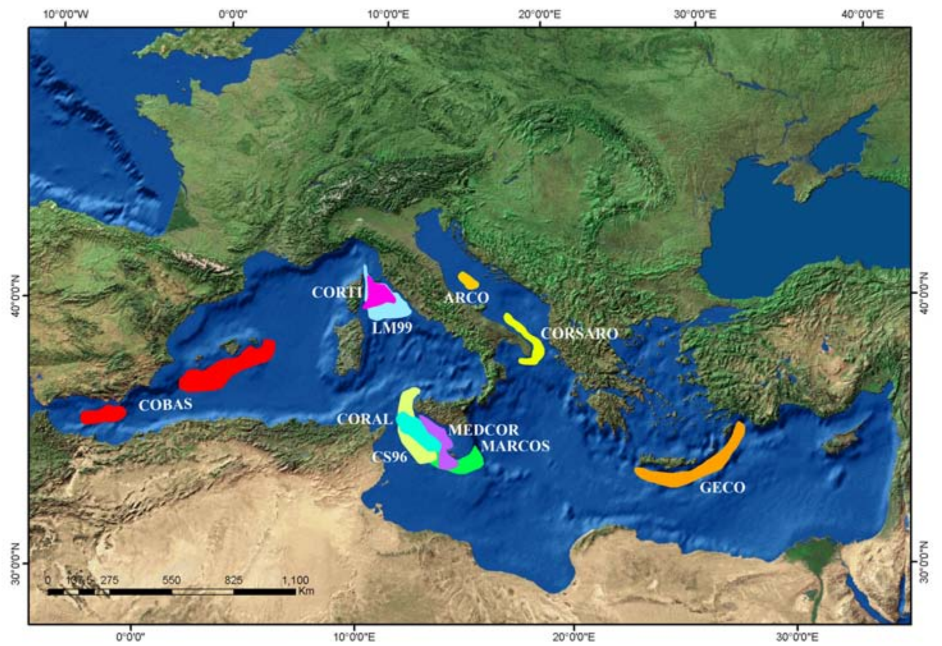

Figure 1: Map showing the location of CNR scientific cruises devoted to the exploration of cold-water corals in the Mediterranean Sea (1996 to present).

Remarkably, CWC have first been reported from the Mediterranean Sea as fouling an electric cable laid between Sardinia and Algeria at depths > 2000 m [33]. Because of its geographic location, the semi-enclosed Mediterranean Sea is inhabited by CWC of strict Atlantic affinity [34, 35, 36].

Although CWC belonging to extant frame-building genera (i.a., *Lophelia, Madrepora, Desmophyllum*) are known from this basin since the Miocene at least, CWC morphologically indistinguishable from Recent *Lophelia pertusa*, *Madrepora Oculata* and *Desmophyllum dianthus* (= *D. crista-galli*) seem to have continuously settled the Mediterranean Sea from the early Pleistocene onwards as documented by fossil assemblages in southern Italy (e.g., [37, 36]), Rhodes [38] and submerged situations (see [36], for a review). The active geodynamic history backing the recent evolution of this basin, results in the exposure of a number of Cenozoic outcrops [39, 40] containing at places deep-sea coral faunas that render the Mediterranean a privileged place where to study major CWC evolutionary and biogeographic patterns [36]. The abundance of still-submerged dead (subfossil) CWC scattered throughout the entire Mediterranean Sea has been considered as an indication that better conditions for the settlement and maintenance of Atlantic-type CWC did exist in the recent past of this basin [30, 35, 36]. Carbon-14 and Uranium-series dating reveal that most subfossil CWC are of late Pleistocene

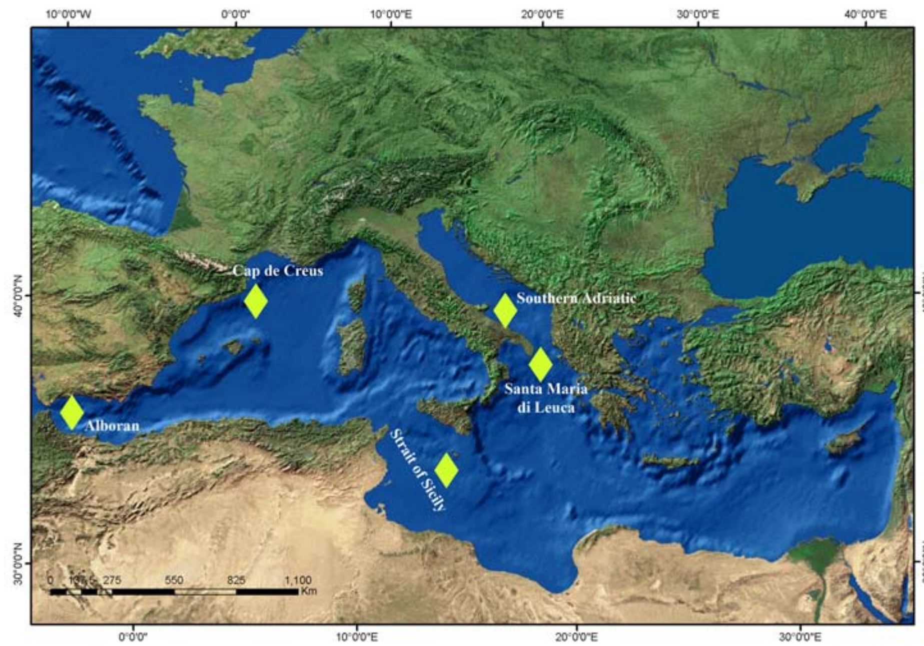

Figure 2: Recent Cold-Water Coral Provinces of the Mediterranean Sea.

age [32, 41, 42, 43, 44], either predating or postdating the last glacial maximum for which no coral evidence has been produced yet. The picture emerging from outcrop and submerged occurrences is that oceanographic conditions during cold phases of the Quaternary are more propitious for CWC to thrive in the Mediterranean when compared to present times whose significant coral growth (especially *Lophelia*) seems highly reduced [35, 32]. In the last decade this vision has been re-dimensioned by the discovery of lush CWC communities containing live *Lophelia, Madrepora* and *Desmophyllum* due to the accidental findings of scientific fishery operations [45, 46, 47, 48] and the large-scale implementation of modern exploration of the deeper reaches of the Mediterranean through remote operating vehicles (ROV) and submersibles [17]. Sites of active coral growth (Figure 2) are mainly located in the Ionian Sea off Apulia (Santa Maria di Leuca: [45, 49, 46, 47, 17, 50, 51], the Southern Adriatic [17], the Strait of Sicily (south of Malta, offshore islands and banks: [48, 17], the Catalan-Provençal canyon system [52] and Alboran [53]. Limited live coral growth is known in the (still poorly investigated) eastern Mediterranean [54, 32, 44]. With respect to the adjacent Atlantic Ocean, the situation of Mediterranean CWC differs because of the lack of substantial coral carbonate mounds in the latter. Most occurrences refer to CWC fouling or fringing canyon heads, precipitous walls and other hardground substrates [36, 44, 55, 17, 52]. The really most de-

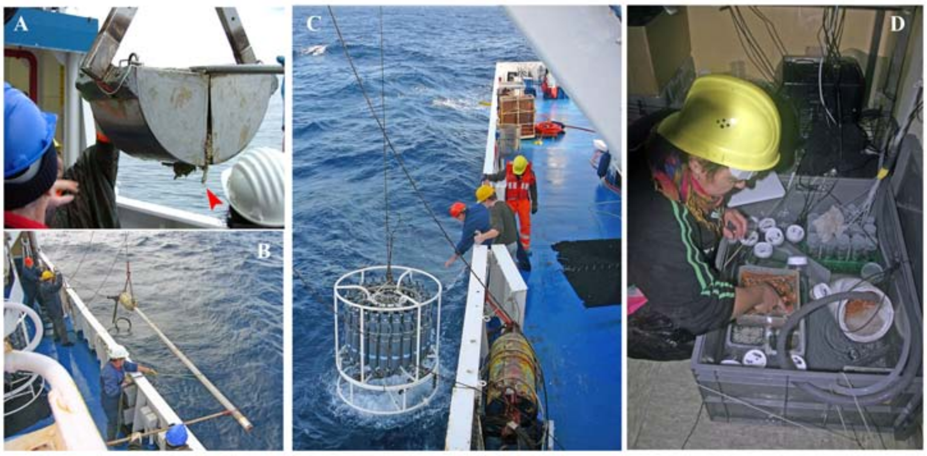

Figure 3: Examples of scientific operations related to CWC research carried out onboard RV Urania. A) Large volume grab sample taken during Cruise CORTI (Tuscan Archipelago, Tyrrhenian Sea, winter 2003); the arrow points subfossil corals embedded in mud (ca -400 m) whose age was later proved to be latest Pleistocene. B) Gravity core operation during MEDCOR cruise (winter 2009) to assess the stratigraphy of CWC south of Malta (Strait of Sicily). C) CTD-Rosette recovery during MEDCOR in the Strait of Sicily to collect oceanographic data on the coral sites, and water samples for geochemical and ocean acidification studies. D) Experiments related to the effects of ocean acidification on live deep water corals conducted during MEDCOR cruise in the Strait of Sicily.

veloped coral provinces, i.e., Santa Maria di Leuca (SML), Southern Adriatic and Strait of Sicily, exploit contrasting topographic scenarios. Vigorous coral growth at SML is favoured by a dramatic seascape generated by the emplacement of gravity mass transported sediment as proposed by Taviani et al. [47] and documented by [50]. A partly similar scenario is found in the Southern Adriatic where also some of the CWC grow on slumped sedimentary blocks [56, 57, 17]. The rich CWC grounds south of Malta [48] take advantage of a submarine escarpment possibly related to regional tectonics of this sector of the Strait of Sicily ([17], Taviani et al. work in progress). Whenever present Pleistocene to Recent coral mounds are small structures, rarely metrical, often representing a single or few episodes of coral growth (e.g., [58, 59]). A case in point are the last glacial buried CWC mounds of the eastern Tyrrhenian described by Remia & Taviani [58]. These small metrical mounds located on tops of a seaward-facing complex relief [59] are made up by *Lophelia, Madrepora and Desmophyllum* corals. These last glacial mounds were eventually oversilted and buried at the end of the Younger Dryas [58, 43]. A similar situation has been recently identified in the Middle Adriatic, near the edge of the Pomo/Jabuka Pit/ Depression where lush *Lophelia, Madrepora* and *Dendrophyllia*

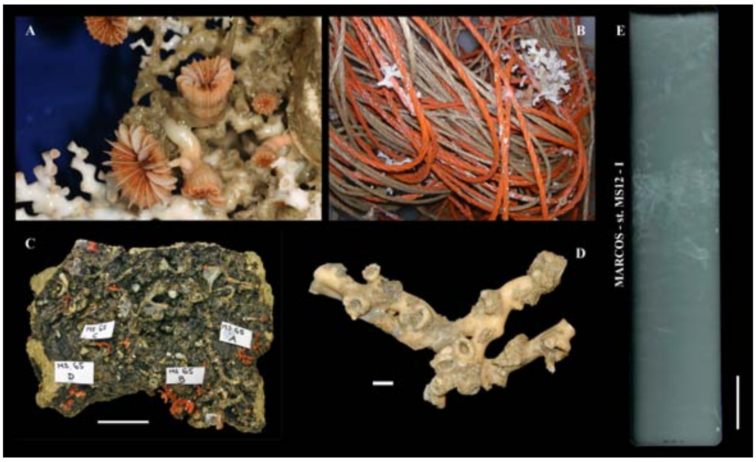

Figure 4: Examples of deep-water coral occurences in the Mediterranean Sea. A) Living *Desmophyllum dianthus* and *Madrepora oculata* from Santa Maria di Leuca coral province, Ionian Sea (CORSARO cruise, Station CR73, ca -670 m). B) Nylon fishing shreds trawled in the Strait of Sicily, offshore Gela (MEDCOR Cruise, Station MEDCOR 74, ca -800 m) fouled by living colonies of *Lophelia pertusa* (the biggest colony on the top-right is up to 5 cm) and the solitary coral *D. dianthus*. C) Fe-Mn-coated hardground collected in the Strait of Sicily at ca -600 m during MARCOS Cruise (Station MS 75), note the occurrence of *Corallium rubrum*, one of the deepest occurrence known so far (up to -600 m); scale bar is 5 cm. D) Very large and thick morphotype of *Lophelia pertusa* from the Southern Adriatic coral province (SETE06 Cruise, Station SE06-13, ca -300 m); scale bar is 1 cm. E) Radiograph of a gravity core obtained from CWC grounds in the Strait of Sicily during MARCOS Cruise (Station MS12, ca -600 m); scale bar is 5 cm.

mounds active up to medieval times have been draped by an important mud influx [55]. Both situations document the importance of fine particle flow, in turn likely controlled by climatic factors [58, 43], in regulating the presence and ultimate fate of deep coral occurrences [31].

Only a few comprehensive studies have been so far devoted to the study of the ecology, biodiversity and functioning of CWC sites in the Mediterranean. By far, SML is at present the CWC province for which most information is available having been the target of many oceanographic missions e.g. RV Urania cruises CORSARO in 2006; RV Universitatis cruises APLABES 1-3 in 2003-2006; RV Meteor cruise M70-1 in 2006 (ROV Quest); RV Pourquoi-pas? cruise MEDECO in 2007 (ROV Victor 6000). Prosperous coral growth here is best between 500-700 m [17, 60, 51] and is controlled by oceanographic factors, above all the influx of Adriatic Deep Water [47, 17, 61]. The area is a site of active coral growth since the latest Pleistocene [47, 42]. Its biodiversity is relatively high [62, 49, 63], with references therein) but somewhat lower than counterparts in the Eastern Atlantic. The trophic web has been recently discussed by Carlier et al. [64] and the beneficial function exerted by CWC on meiofaunal diversity underlined by Bongiorni et al. [65]. Other CWC sites are scrutinized for understanding functioning and main characteristics, among which worth mentioning are the Strait of Sicily [17] and the Catalan-Provençal canyons [52]. In the Strait of Sicily, increasing information is paid to the coral grounds south of Malta [48]. This site is in fact located in a critical sector of the Mediterranean Sea under the dominant influx of two major water masses, the superficial inflow of Modified Atlantic Water and the deep counterflow of the Levantine Intermediate Water, the latter directly impinging onto the area of active coral growth centred at ca. 450-600 m. A complete swath bathymetric mapping of the area covered by active coral growth mostly limited to a submarine escarpment [17] has been recently completed through CNR cruises CORAL (2002), MARCOS (2007) and MEDCOR (2009). The south Malta site in the Strait of Sicily is particularly interesting since, besides the usual frame building 'white corals' *Lophelia* and *Madrepora*, a variety of species co-occur to its biodiversity including solitary scleractinians (*Desmophyllum, Caryophyllia*), yellow corals (*Dendrophyllia*), antipatharians (*Leiopathes*), octocorals (the calcified gorgonacean *Corallium rubrum*, here in the Strait of Sicily at the known deepest range), bivalves, serpulids, sponges, cirripeds (the large barnacle *Pachylasma giganteum*) and coral-predatory gastropods [66, 60, 67, 68]. Overall, coral habitats support or share the environment with other deep-sea macrofaunal elements besides those mentioned above, among which worth-mentioning are large limids (*Acesta excavata*: [69]) and giant oysters (*Neopycnodonte zibrowii*: [70, 20, 62]).

3 Conclusive remarks

As for the past exploratory research should be continued since many sectors of the Mediterranean Sea are little known or totally unexplored for potential CWC occurrences. This action necessarily implies that the public research should have availability or certain access to opportune technologies such as ROV (Remote Operating Vehicle), AUV(Automatic Underwater Vehicle), gliders and landers what is not the case at present. Confidential industry information indicates that many living coral stocks do exist offshore Sicily, particularly along the Ionian margin and in the Strait of Sicily. The southern side of the Mediterranean Sea (entire North African margin and Levant) is equally highly promising as being colonized by CWC ecosystems. Further exploration should also be conducted in the Ligurian Sea, an area characterized by winter deep-water production, possibly housing prosperous coral growth [71], like the Catalan-Provençal canyons. The newly discovered CWC site in the Marmara Sea is also a strong indication that further research should be carried out there [44]. A search for CWC should be definitely done in the eastern side of the central Adriatic Sea. Chances are that such Adriatic CWC stocks are prominent in controlling coral dispersal and successful settlement in the Southern Adriatic, Ionian Sea and Strait of Sicily following hydrologic pathways linked to North Adriatic Deep Water production and cascading events (e.g. [72]).

With few exceptions, most Mediterranean CWC sites are still little known for their biodiversity and functional aspects, requiring additional studies on invertebrate and microbial communities, trophic webs and CWC impact on nekton. Regrettably, habitat mapping of main Mediterranean CWC provinces is still in its infancy, with preliminary work mostly limited at Cap de Creus [52] and SML [51]. The connectivity of disjointed CWC sites is also a major target for research to be pursued at the short term. A number of live-collected scleractinians (*Lophelia, Madrepora* and *Desmophyllum*) have been collected to be scrutinized for genetics (including degraded DNA on subfossil corals) to help unveiling their links [70]. In fact, no evidence yet exists regarding intra-Mediterranean source and dispersal pathways of CWC larval flows what should be really considered a major gap in understanding Atlantic-Mediterranean cold-water coral biogeography and evolution.

Relevance should be paid to the usefulness of CWC and associated invertebrates (e.g., *Corallium*, antipatharians, bivalves etc.) as climatic tools. Increasing evidence is produced about the relevance of extracting geochemical signals of valuable paleoceanographic (therefore paleoclimatic) significance out of the carbonate and organic skeletons (e.g., [73, 74], and this volume for a revision). As a conclusive remark, it must be brought to public and political awareness that CWC habitats in Mediterranean as elsewhere are threatened by natural and, more commonly, anthropogenic causes (fishing malpractices, dumping, littering, ocean pollution and acidification). There is an unprocrastinable urgence not only for conducting basic scientific studies but also for concomitant political action capable of ensuring a future to such complex and important marine habitats.

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Consiglio Nazionale delle Ricerche
Dipartimento Terra e Ambiente
P.le Aldo Moro, 7
00185 Roma
tel. 06 4993 3886 fax 06 4993 3887
email: direttore.dta@cnr.it
web: www.dta.cnr.it