



Know the distribution to assess the changes: Mediterranean cold-water coral bioconstructions

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Abstract

Cold-water corals (CWCs) are the main engineers of extensive deep coral frameworks hosting a lush diversity of species in certain areas of the world, including the Mediterranean Sea. In this basin, the most important bioconstructor species are the so-called “white corals”, i.e. the colonial scleractinians *Madrepora oculata* and *Lophelia pertusa* as well as the solitary coral *Desmophyllum dianthus*. Anthropogenic impacts (e.g., fishing pressure) and human-induced changes (e.g., rising temperatures and ocean acidification) are known to affect these important deep-sea bioconstructors. The present paper provides an overview of the horizontal and vertical distribution of white corals in the Mediterranean Sea. The knowledge of the present distribution of living CWCs represents a crucial baseline to understand how anthropogenic and natural changes are affecting these deep Mediterranean habitats.

Keywords Deep sea · White corals · Distribution · Biogeography · Mediterranean Sea

1 Introduction

The deep Mediterranean Sea is patchily populated by reef-forming cold-water corals (CWCs) that, in some places, form significant bioconstructions (Freiwald and Roberts 2005; Freiwald et al. 2009). Under the label of CWCs are commonly grouped those cold-affinity azooxanthellate cnidarians, usually found below 200 m depth in the Mediterranean Sea, acting as habitat formers (Roberts et al. 2006, 2009). This definition includes both stony corals (i.e., Scleractinia) building up durable bioconstructions, as well as forest-making anthozoans thriving on both hard and soft bottoms (i.e., Antipatharia, Alcyonacea, and Pennatulacea). Among CWCs, “white corals” (Pérès and Picard 1964) have

a pronounced frame-building ability, being able to deposit calcium carbonate and build-up conspicuous biogenic substrata able to persist after the death of the coral itself. The Mediterranean white corals are broadly represented by the colonial species *Madrepora oculata* Linnaeus, 1758 and *Lophelia pertusa* (Linnaeus, 1758) as well as the solitary coral *Desmophyllum dianthus* (Esper, 1794). In particular, the branched stony corals *M. oculata* and *L. pertusa*, in certain cases forming colonies exceeding 1 m in height and width, are able to build up large bioconstructions (e.g., Freiwald et al. 2009; Angeletti et al. 2014), promoting the formation of true deep-sea coral frameworks. On the contrary, *D. dianthus* is a pseudo-colonial bank-building coral which can reach local high densities in the Mediterranean Sea and can provide small but spread hard substrata on pre-existent coherent surfaces (e.g., Taviani et al. 2016). CWC bioconstructions host a very high diversity of species and represent a true hotspot of biodiversity (Mastrototaro et al. 2010; Marchese 2015; Rueda et al. 2018). Their framework offers an intricate network of biogenic frames and niches for hundreds of associated species (e.g., Tursi et al. 2004; Rosso et al. 2010; D’Onghia et al. 2015). The bioconstructions provide a suitable ground for both larval settlement and juvenile growth of benthic species, as well as represent an important spawning and nursery area for vagile fauna (D’Onghia et al. 2010, 2012).

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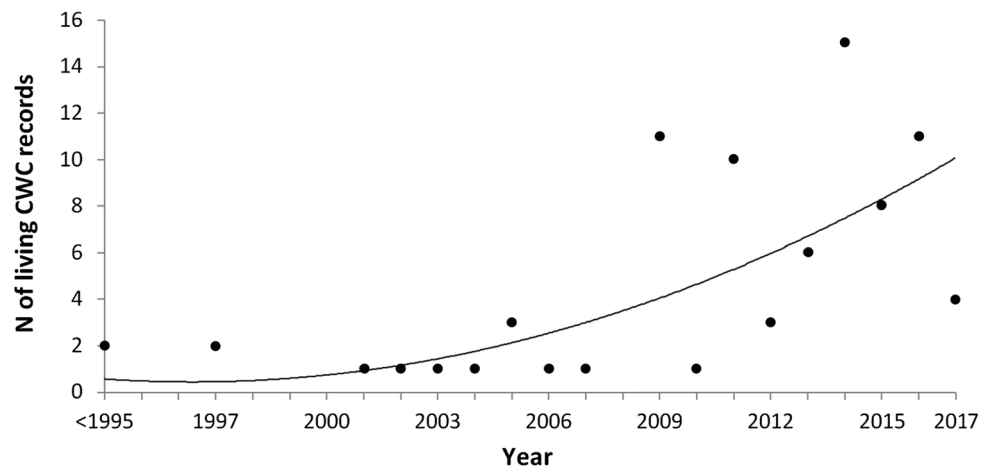
The CWCs *M. oculata*, *L. pertusa*, and *D. dianthus* were mostly recorded as Pleistocene fossils in the first studies of deep Mediterranean communities, with just few records of living specimens (Zibrowius 1980). Limited accidental findings of living CWCs and concomitant discoveries of related frameworks (e.g., Tunesi and Diviacco 1997; Vafidis et al. 1997; Mastrototaro et al. 2002) stimulated targeted oceanographic cruises and intentional coral samplings for the study of CWC sites in the deep Mediterranean Sea. As a result, in the last 20 years, the relentless development of the deep-sea exploration technologies allowed the discovery of several CWC sites characterized by living corals. Large and highly structured CWC communities, characterized by a significant coral growth and colonies density, develop in specific areas with a proper mixture of suitable topographic and oceanographic features. These areas are known in the literature as CWC provinces, only defined so far from a qualitative and somehow arbitrary point of view as discrete geographic units (Taviani et al. 2011a, 2016). According to Taviani et al. (2016), six main CWC provinces have been recognized up to date in the Mediterranean Sea. These areas are located in the northern Ionian Sea (Santa Maria di Leuca), in the Southwestern Adriatic Sea (Bari Canyon), in the Strait of Sicily (South Malta), in the Sardinia Channel (South Sardinia), and in the Gulf of Lions and in the eastern Alboran Sea (see also Orejas and Jiménez, in press). These still little known communities are facing with new emerging anthropogenic-driven changes, mainly represented by fishing impacts and climate changes related to human activities (e.g., Bo et al. 2014; Sweetman et al. 2017). Among fishing impacts, artisanal fishing practices (e.g., longlines) and bottom trawling represent the main threats for Mediterranean CWCs (D’Onghia et al. 2016). Trawl fishing can be occasionally prevented by the occurrence of hard substrates and by coral frameworks themselves, discouraging the use of these gears (Mastrototaro et al. 2013, 2015; Bo et al. 2014, 2015). Despite fishing practices heavily affect CWCs locally,

climate changes exert their action globally (e.g., Sweetman et al. 2017). In particular, the rise of water temperature represents the main threat for CWCs’ survival (Gori et al. 2016), while the water acidification seems to not affect their calcification physiology as it happens for shallower corals (e.g., Rodolfo-Metalpa et al. 2015 and references therein). Despite it is still matter of debate, the combination of rising temperatures and ocean acidification in the next decades may severely affect CWCs (Gori et al. 2016), being one of the responsables of CWC population decline as it probably happened during the Pleistocene (Zibrowius 1980; Taviani et al. 2005; McCulloch et al. 2010; Vertino et al. 2014). The present paper resumes the currently known distribution of CWCs in the Mediterranean Sea. The update of their distribution and further explorative efforts are essential to assess the ongoing and future changes (natural and anthropogenic) affecting the deep Mediterranean Sea. Indeed, still limited knowledge about deep-sea habitats limits our capacity to predict future response of CWCs subject to increasing human pressure and changing global environmental conditions (Yasuhara and Danovaro 2016; Danovaro et al. 2017).

2 Presence and distribution of CWC bioconstructions in the Mediterranean Sea

The development of exploration visual tools, such as remotely operated vehicles and landers, has been decisive to search, find, and observe remote deep-sea habitats such as the one hosting CWCs. In fact, a significant increase of live CWC records can be found in the literature of the last 2 decades (Fig. 1). Extensive bibliographic sources regarding CWC biogeography are provided in Orejas and Jiménez (in press). From the westernmost Alboran Sea to the easternmost Marmara and Levantine basins, the Mediterranean Sea is turned out to be speckled of CWCs. An exception

Fig. 1 Living cold-water coral records published in the literature from 1995 to 2017



is represented by the African coasts, where no records are known apart from the eastern Alboran CWC province (Lo Iacono et al. 2014; Chimienti et al. 2018). The map in Fig. 2 shows the records of living *M. oculata*, *L. pertusa*, and *D. dianthus* occurred to date in the Mediterranean Sea. These species have been observed and/or sampled at more than 30 sites across the basin. The presence of true bioconstructions (i.e., CWC frameworks) has been reported only in a few of these areas, and the majority of the records are included in the CWC provinces. The remaining records are represented by single or isolated finding, mainly of *M. oculata* colonies and/or *D. dianthus* specimens. On the contrary, only a few records concern living *L. pertusa* (Fig. 2).

These corals occur in the Mediterranean Sea within a wide bathymetric range, from 180 to 1100 m depth (Fig. 3). *Madrepora oculata* and *D. dianthus* are usually dominant in shallower areas respect to *L. pertusa* (e.g., Zibrowius 1980; Gori et al. 2013; Mastrototaro et al. 2010 and references therein), despite showing almost the same bathymetric range of presence within the basin (Fig. 3). In particular, *M. oculata* has been observed from ca. 200–600 m depth in the Alboran, Balearic, and Ligurian seas, and between 300–400 m depth in the Sardinia Channel and in the Aegean Sea (Orejas and Jiménez, in press). Wider bathymetric ranges and deeper occurrences have been recorded in the Adriatic Sea (200–1000 m), the Sicily Channel (200–1000 m) and the Ionian Sea (400–1100 m). *Lophelia pertusa* shows more or less the same bathymetric ranges as *M. oculata*, being usually present below 300 m depth and becoming more present typically deeper than 600 m (Freiwald et al. 2009, 2011;

Mastrototaro et al. 2010; Chimienti et al. 2018). Despite *L. pertusa* results less common than *M. oculata* in the Mediterranean Sea, the current majority of *Madrepora*-dominated communities in the basin may be biased by the fact that *L. pertusa* generally develops in deeper and still scarcely explored waters (e.g., Gori et al. 2013).

Nevertheless, the picture of CWC distribution in the Mediterranean Sea is still not complete and more explorative efforts need to be carried out. Understanding CWC horizontal and vertical distribution patterns, and their causes, is fundamental to assess ongoing and future changes occurring in the deep-sea, using corals as bioindicators. Several studies already tried to address this important point, although without getting a solution (e.g., Fink et al. 2012, 2013, 2015; Taviani et al. 2015, 2016; Wienberg and Titschack 2017). Even though the mosaic of the CWC distribution is still incomplete, the effects of short-time changes (e.g., a few decades) on small-scales (e.g., single CWC site) could be evaluated in the early future thanks to the comparison with the present situation. These visual proofs of the effects could help in turn to better understand the causes, such as the governing factors setting CWC presence and demise. The presence of CWCs seems to be related to vertical or rugged topographies coupled with certain environmental conditions such as high productivity, cold temperature, and enhanced water mass circulation (e.g., Fink et al. 2015). These conditions are subjected to changes in large enough time scales, as it already happened in the past. In fact, the occurrence of living CWCs does not completely overlap with the findings of subfossil ones, particularly in the eastern

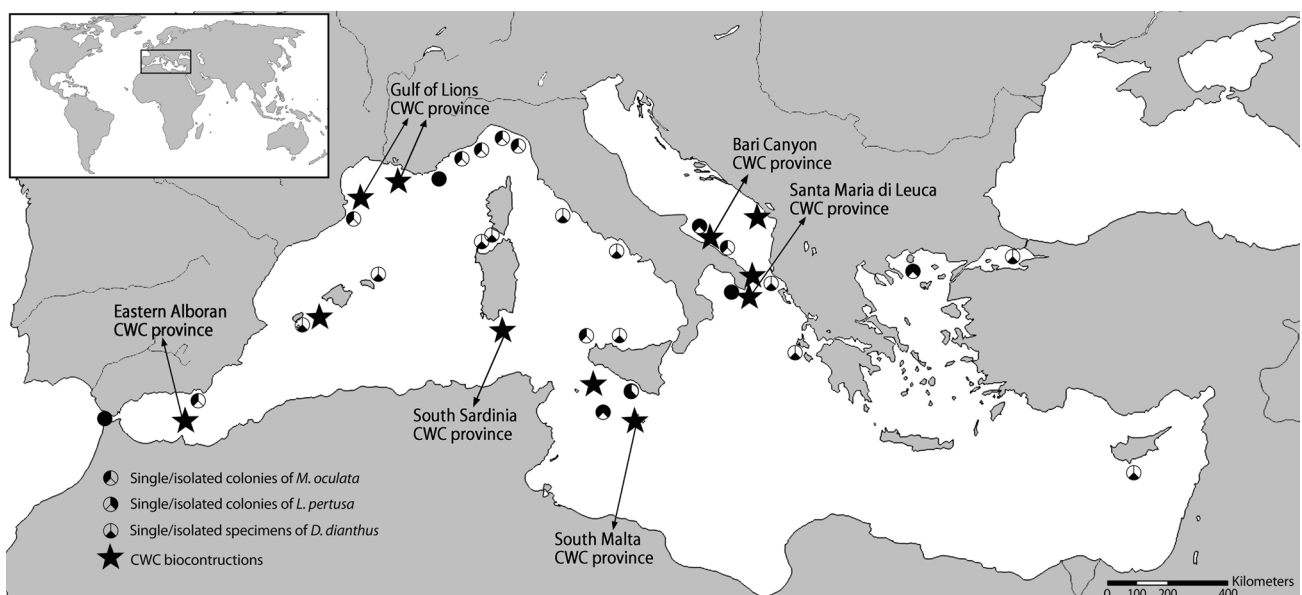


Fig. 2 Distribution of the cold-water corals (CWCs) *Madrepora oculata*, *Lophelia pertusa*, and *Desmophyllum dianthus* in the Mediterranean Sea with indication of the occurrence of single or isolated speci-

mens/colonies or the occurrence of true bioconstructions. The CWC provinces listed in the text are also indicated

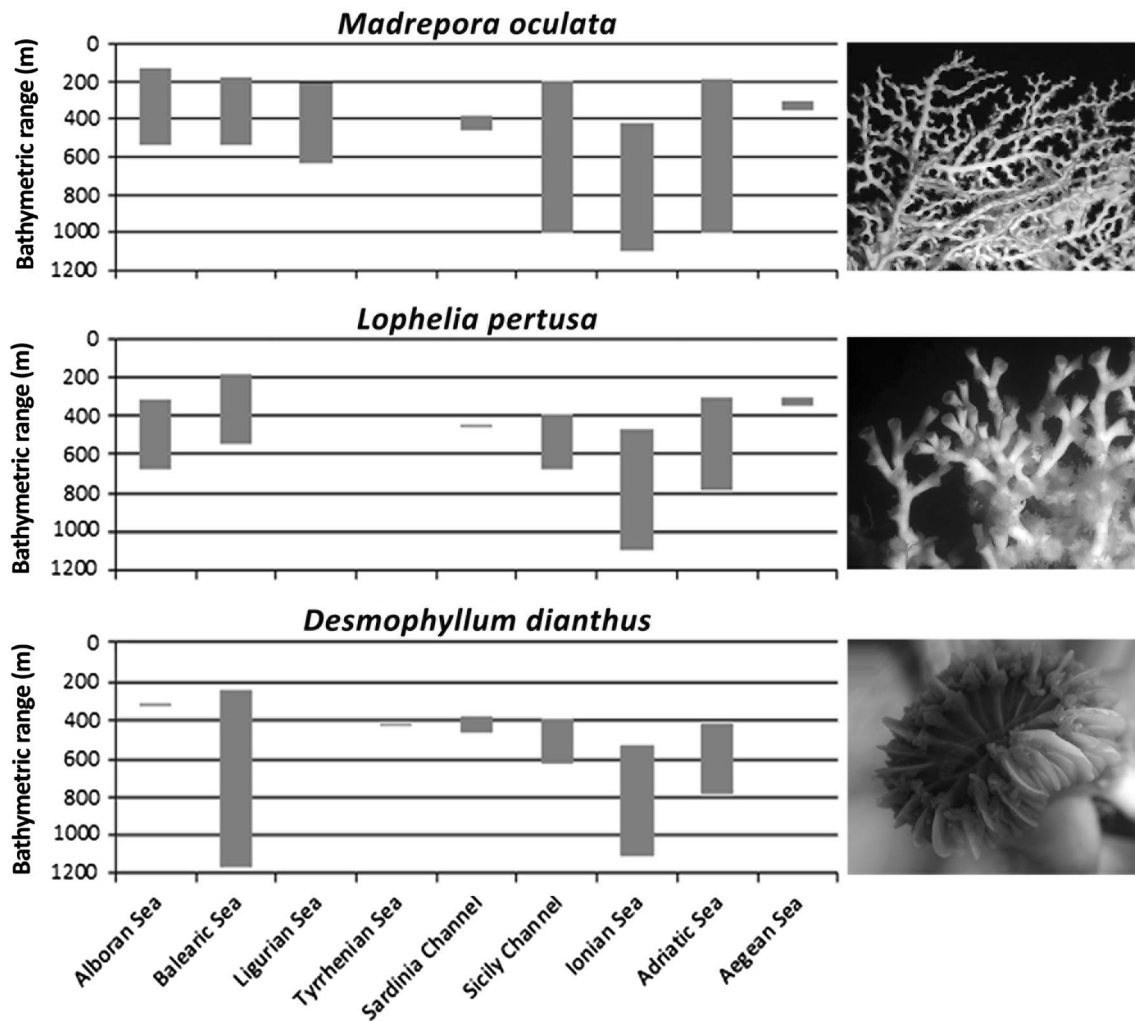


Fig. 3 Bathymetric range of distribution of the white corals *Madrepora oculata*, *Lophelia pertusa*, and *Desmophyllum dianthus* in the Mediterranean Sea. Modified from Chimienti et al. (2018)

Mediterranean basin (Taviani et al. 2011a, b). The water flow regime represents one of the main governing factors in CWCs distribution, preventing burial by fine sediment deposition and providing food transport to coral polyps (e.g., Thiem et al. 2006; Kiriakoulakis et al. 2007; Roberts et al. 2009; Fink et al. 2015). The current CWC distribution in the Mediterranean Sea seems to be mainly influenced by the Levantine Intermediate Water (LIW) and deep waters (i.e., Aegean Deep Waters, Adriatic Deep Waters, Tyrrhenian Deep Waters, and Western Mediterranean Deep Waters) (Millot and Taupier-Letage 2005; Fink et al. 2015; Taviani et al. 2016). LIW is the largest water mass moving in the basin, formed in the northern portion of the eastern Mediterranean Sea and flowing westward, while deep waters are denser and colder masses that generally follow the circulation of LIW and contribute in oxygen and trophic transport for deeper CWC communities (Millot and Taupier-Letage 2005). These water masses also represent a possible vector

for larval dispersal, connecting the different coral sites and provinces of the basin. The resulting distribution patterns derive from the combination of several abiotic factors such as appropriate hard bottoms, low temperature, and strong enough water flow regimes.

3 Future perspectives

CWCs presence and distribution can be considered a needed background that may assist the evaluation about CWC biogeography, calling for the investigation of possible/probable factors, including oceanographic/climatic ones, governing their onset and demise. This would represent a baseline to evaluate the role of anthropogenic changes and impacts in driving ecologic and biologic dynamic balances also in the deep-sea. The increasing in new coral sites discoveries is going to produce a comprehensible mosaic of CWCs'

distribution in the Mediterranean Sea. Knowledge gaps could be filled in different ways. First, by exploring the current CWC sites boundaries and the deeper environs to assess the presence of continuous CWC belts, as the one located along the Apulian margin from Bari Canyon to Santa Maria di Leuca CWC provinces (Angeletti et al. 2014) (Fig. 2). Moreover, other feasible CWC sites could be found in the future following the LIW main path on continental margins, seamounts, and canyons (Freiwald et al. 2009; Fink et al. 2015; Taviani et al. 2016; Chimienti et al. 2018).

CWC bioconstructions represent Vulnerable Marine Ecosystems (FAO 2009, 2011) whose mapping is considered the first and indispensable step in the framework of the environmental protection, according to the European Marine Strategy Framework Directive (EC Reg. 2008/56). Highly structured and extended CWC habitats, recognized as CWC provinces, represent also an essential fish habitat for several species of commercial or conservation interest (D’Onghia et al. 2010, 2012). However, exploring efforts need to be followed with proper governance strategies. For this reason, the General Fisheries Commission for the Mediterranean established the legal category of ‘Deep-sea Fisheries Restricted Area’ where the use of towed fishing gears and dredges is forbidden, as it happened in the Santa Maria di Leuca CWC province (GFCM 2006). How CWCs will react to the ongoing environmental changes cannot be exactly predicted, although the knowledge of the present distribution of living CWCs and the study of their fossils represent a baseline to work on. This would represent an important step for a proper management and a threshold line to understand ecosystems’ response to changes in a short time span also in a stable environment as the deep sea.

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