

M. ANGIOLILLO¹, M. GIUSTI¹, M. BO^{2, 3, 4}, F. ENRICHETTI^{2, 4}, M. TOMA^{1,2}, F.S. RENDE¹,
L. ROSSI¹, A. IZZI¹, A. PAZZINI¹, L. TUNESI¹

¹Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Via V. Brancati 48, 00144 Roma

²DISTAV, Università degli Studi di Genova, C.so Europa 26, 16132 Genova

³Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa), Piazzale Flaminio 9, 00196 Roma

⁴National Biodiversity Future Centre - NBFC, Piazza Marina 61, 90133 Palermo, Italy
michela.angiolillo@isprambiente.it

THE MARINE STRATEGY FRAMEWORK DIRECTIVE: MONITORING OF MEDITERRANEAN CIRCALITTORAL AND BATHYAL CORAL REEFS

LA DIRETTIVA QUADRO SULLA STRATEGIA PER L'AMBIENTE MARINO: IL MONITORAGGIO DEI CORALLI PROFONDI CIRCALITORALI E BATHIALI DEL MAR MEDITERRANEO

Abstract - *Habitat-forming species are known worldwide to play a key role in structuring benthic ecosystems and enhancing biodiversity and ecosystem functioning. Under the European Marine Strategy Framework Directive, monitoring activities have been carried out in the Italian waters since 2020 (every three years) to assess the ecological and conservation status of coral forests and scleractinian cold-water reefs using diversity, health status, and impact variables. Monitoring was conducted using remotely operated vehicles between 100 and 650 m depth in nine areas and 90 sites of the MSFD Italian subregions. The investigated habitats showed different health conditions, ranging from almost pristine (i.e., Corsica Channel) to severely stressed by marine litter and fishing-related items (i.e., Dohrn Canyon). No extensive habitat destruction was observed. These monitoring activities increase knowledge of vulnerable benthic species and habitats, providing a preliminary baseline assessment of distribution, population structure and conservation status with respect to the main sources of impact.*

Keywords: *Habitat-forming species, ROV-Imaging, Ecological Index, Fishing impact.*

Introduction – Habitat-forming species are known worldwide to play a key role in structuring benthic ecosystems and enhancing biodiversity and ecosystem functioning, but several stressors threaten them (Bo *et al.*, 2014). In deep waters, habitat-forming corals (e.g., stony corals, black corals, and gorgonians) can form bioconstructions or dense assemblages known as coral reefs and gardens (Roberts *et al.*, 2006). In the Mediterranean Sea, considerable effort has been made over the past two decades to unveil the distribution, extent, and ecological role of these habitats (Chimienti *et al.*, 2019). However, quantitative data on their conservation status still need to be improved. Given the importance and vulnerability of some habitat-forming corals, Italy decided to include deep circalittoral coral forests and bathyal scleractinian cold-water coral (CWCs) reefs in the monitoring activities of the Marine Strategy Framework Directive (MSFD, 2008/56/EC), extending its implementation to the deep sea. The MSFD aims to achieve and maintain a Good Environmental Status (GES) of the European marine waters and to protect resources and ecosystem services by adopting a holistic approach based on methodological standards and ecological indicators. An opportunistic approach was adopted in Italy, combining the use of three MSFD Descriptors: Biodiversity - D1, seafloor integrity - D6, and Marine litter - D10. Monitoring activities have been carried out in the Italian waters since 2020 using remotely operated vehicle (ROV) technologies. The aim is to assess the ecological and conservation status of coral forests and scleractinian CWC reefs over time, using diversity, health status, and impact variables.

Materials and methods – Nine areas, known for the presence of deep coral forests and scleractinian CWCs and representative of diverse seabed morphologies, environmental conditions, and anthropogenic pressure intensities have been identified to be monitored every three years, starting from 2020 in each of the three subregions bordering Italy (Fig. 1a, Tab. 1). The monitoring activities were carried out on board the R/V *Astrea* of ISPRA between 100 and 650 m depth in 90 sites, following a standardised operative monitoring protocol based on ROV-imaging analysis of i) the diversity, occurrence, and abundance of the megafauna and ii) the vulnerability of coral assemblages to marine litter (Angiolillo *et al.*, 2023a). The ecological status of coral assemblages was assessed using the following metrics, responding to three MSFD descriptors and related indicators: i) species richness; ii) abundance of target species (megabenthic structuring species); iii) population size structure of each target species; iv) health status of the target species; v) distribution and abundance of marine litter; vi) effect of litter on benthic communities (entanglement). The MACS index (Enrichetti *et al.*, 2019) was applied to assess the health status of deep coral forests. A new ecological index, under development (Enrichetti *et al.*, *in preparation*), was used instead for scleractinian CWCs. Both indexes defined five classes of ecological status, ranging from bad to high status (Enrichetti *et al.*, 2019). The indexes integrate the Index of Status (*Is*) and the Index of Impact (*Ii*), providing information about the biocoenotic complexity and impacts affecting the investigated ecosystems and, therefore, depicting the environmental status of the benthic community.

Results – The preliminary results of the first monitoring cycle identified various biodiversity hotspots. Differences in species composition and abundance among the investigated areas were highlighted, showing the peculiarity of each area, the associated megafauna, the exclusive species, and the habitat-structuring population status. The investigated habitats showed different health conditions, ranging from almost pristine, as in the Corsica Channel, to severely stressed by marine litter and fishing-related items, as in the Dohrn Canyon (Tab. 1). No extensive habitat destruction was observed. Monitoring activities confirmed the presence, in the bathyal areas, of significant assemblages of scleractinian CWCs, mainly formed by *Madrepora oculata* Linnaeus, 1758 and associated gorgonian species. The known CWC provinces of Nora and Bari canyons and Santa Maria di Leuca showed mounds with well-developed frameworks of both *M. oculata* and *Desmophyllum pertusum* (Linnaeus, 1758) (Fig. 1b(i)). The Bari Canyon also showed a rich sponge assemblage. The Dohrn Canyon was characterised by sparse colonies, mainly of *M. oculata*, on rocky walls (Fig. 1b(ii)), strongly impacted by fishing activities. Large populations of *Neopycnodonte zibrowii* Gofas, Salas & Taviani, 2009 and *Acesta excavata* (Fabricius, 1779) were also found here. In the Corsica Channel, the two CWC scleractinian species formed extensive mounds with high colony densities (Fig. 1b(iii)), and different rich assemblages of gorgonian and black coral species were observed (Fig. 1b(iv)). Finally, the Monterosso Canyon was characterized by mounds of *M. oculata* impacted by litter and fishing-related items (Fig. 1b(v)). Noteworthy was an interesting facies of bamboo corals (Fig. 1b(vi)). In the shallower and coastal sites along the Siracusa coast (SE Sicily), the soft bottom with scattered boulders revealed a lush population of *Dendrophyllia ramea* (Linnaeus, 1758), strongly impacted by fishing lines, and the presence of several colonies of *Corallium rubrum* (Linnaeus, 1758). The deeper areas were characterised by vulnerable species typical of soft bottoms, such as *Funiculina quadrangularis* (Pallas, 1766) and *Virgularia mirabilis* (Müller, 1776), where several trawl marks were observed.

Tab. 1 – Summary of data collected indicating the ecological status of monitored areas
Riepilogo dei dati raccolti che indicano lo stato ecologico delle aree monitorate

Year	MSFD Subregion	Area	Depth range (m)	Main habitat	Status
2020	MWE	Dohrn Canyon	322–452	Scleractinian CWCs on rocky walls	Poor
2020	MWE	Corsica Channel	341–457	Scleractinian CWC mounds	High
2021	MIC	Linosa Island	80–345	Lower circalittoral coralligenous	<i>In progress</i>
2021	MIC	Siracusa	76–358	Lower circalittoral coralligenous	Moderate
2021	MWE	Pontine Archipelago	100–270	Black corals forests	Moderate
2022	MWE	Monterosso Canyon	470–590	Scleractinian CWC mounds and bamboo coral <i>facies</i>	Moderate
2022	MAD	Bari Canyon	180–575	Scleractinian CWC mounds	<i>In progress</i>
2023	MWE	Nora Canyon	345–492	Coral mounds and sparse colonies on horizontal muddy bottom	<i>In progress</i>
2023	MAD	Santa Maria di Leuca	328–689	Scleractinian CWC mounds	<i>In progress</i>

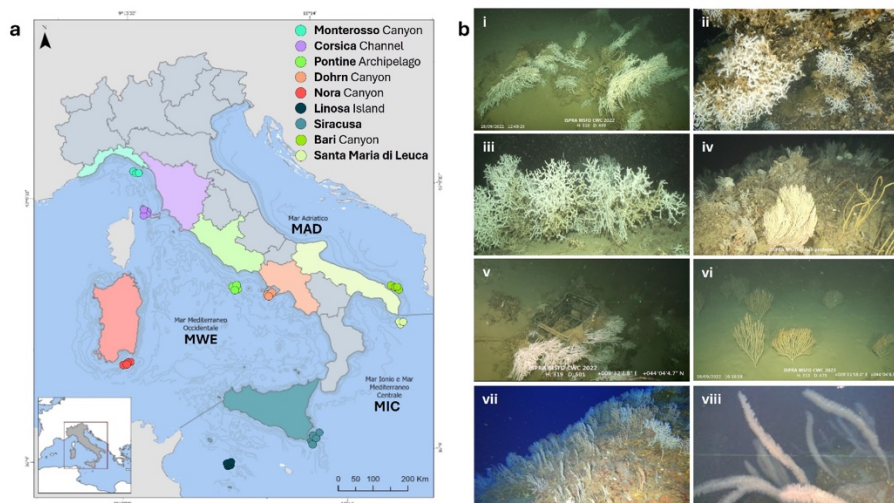


Fig. 1 - (a) Map of the monitored areas (coloured circles) in the three MSFD Italian sub-regions: Western Mediterranean Sea (MWE), Ionian and Central Mediterranean Sea (MIC), and Adriatic Sea (MAD); (b) Habitat-forming corals in the monitored areas: i-ii) *Madrepora oculata*; iii) *M. oculata* and *Desmophyllum pertusum*; iv) deep coral forest; v) *M. oculata* impacted by fishing-related litter and plastic items; vi) Bamboo coral forest; vii) *Eunicella cavolini* and *Antipathella subpinnata*; viii) *Parantipathes larix* forest.

(a) Mappa delle aree monitorate (cerchi colorati) nelle tre sottoregioni italiane della MSFD: Mar Mediterraneo occidentale (MWE), Mar Mediterraneo centrale e Ionio (MIC) e Mar Adriatico (MAD); (b) Specie strutturanti nelle aree monitorate: i-ii) *Madrepora oculata*; (iii) *M. oculata* e *Desmophyllum pertusum*; (iv) Foreste di coralli e gorgonie profonde; (v) *M. oculata* impattata da rifiuti derivanti dalla pesca e da oggetti di plastica; (vi) *Facies di coralli bambù*; (vii) *Eunicella cavolini* e *Antipathella subpinnata*; (viii) Foresta di *Parantipathes larix*.

Data collected in the Linosa area confirmed the presence of a rich benthic community dominated by black corals and small gorgonians (i.e., *Antipathella subpinnata* (Ellis & Solander, 1786) and *Eunicella cavolini* (Koch, 1887), Fig. 1b (vii)). Noteworthy were the rich black coral forests of *Parantipathes larix* (Esper, 1788) in the Pontine Archipelago (Fig. 1b (viii)).

Conclusions - These monitoring activities increased knowledge of key and vulnerable benthic species and habitats, providing a preliminary baseline assessment of distribution, population structure and conservation status with respect to the main sources of impact. In all areas, the dominant species create complex three-dimensional habitats, including carbonate frameworks and animal forests, showing the different effects of anthropogenic impact on the considered vulnerable habitats (Angiolillo *et al.*, 2022, 2023a,b; Bo *et al.*, 2023). The main pressure is marine litter (mainly lost fishing gear) and the consequent entanglement of structuring species. Only one area results in a high condition status, but several areas are in a moderate or poor status due to the strong impact of lost fishing gear. In these years of sampling, monitoring was carried out in different areas; therefore, the lack of temporal replicability meant that data could only be used as a baseline for the next implementation cycle. The use and development of multiparametric indexes, integrating status and pressure, provided a more robust and structured numeric method to assess the status of scleractinian CWCs reefs and deep coral forests over time. This approach improved scientific knowledge and confirmed the presence of habitats of special conservation interest, enabling the definition of threshold values that help compare data on a large scale. All this information is pivotal for assessing the effectiveness of measures implemented by the MSFD and evaluating the need for additional specific conservation initiatives.

References

- ANGIOLILLO M., BO M., TOMA M., GIUSTI M., SALVATI E., GIOVA A., LAGUDI A., ROSSI L., COLLINA M., BRUNO F., CANESE S., TUNESI L. (2023a) - A baseline for the monitoring of Mediterranean upper bathyal biogenic reefs within the Marine Strategy Framework Directive objectives. *Deep-sea Res. I*, **194**: 103963. doi:10.1016/j.dsr.2023.103963.
- ANGIOLILLO M., BERTASI F., GROSSI L., LOIA M., VANI D., RENDE S.F., GIUSTI M., TUNESI L. (2023b) - Deep Aggregations of the Polychaete *Amage adspersa* (Grube, 1863) in the Ionian Sea (Central Mediterranean Sea) as Revealed via ROV Observations. *Diversity*, **15**: 906. doi:10.3390/d15080906.
- ANGIOLILLO M., GIUSTI M., ROSSI L., TUNESI L. (2022) - A *Dendrophyllia ramea* Population in the Ionian Sea (Central Mediterranean Sea) Threatened by Anthropogenic Impacts. *Front. Mar. Sci.*, **9**: 838274. doi: 10.3389/fmars.2022.838274
- BO M., ENRICHETTI F., BETTI F., GAY G., QUARTA G., CALCAGNILE L., BAVESTRELLO G. (2023) - The cold-water coral province of the eastern Ligurian Sea (NW Mediterranean Sea): historical and novel evidences. *Front. Mar. Sci.*, **10**:1114417. doi: 10.3389/fmars.2023.1114417
- BO M., BAVA S., CANESE S., ANGIOLILLO M., CATTANEO-VIETTI R., BAVESTRELLO G. (2014) - Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. *Biol. Conserv.*, **171**: 167–176.
- CHIMIANTI G., BO M., TAVIANI M., MASTROTOTARO F. (2019) Occurrence and biogeography of Mediterranean cold-water corals. In: Orejas C., Jiménez C., (eds), *Mediterranean Cold-Water Corals: Past, Present and Future, Coral Reefs of the World 9*. Springer, Cham: 213–243 https://doi.org/10.1007/978-3-319-91608-8_19.
- ENRICHETTI F., BO M., MORRI C., MONTEFALCONE M., TOMA M., BAVESTRELLO G., TUNESI L., CANESE S., GIUSTI M., SALVATI E., BERTOLOTTI R.M., BIANCHI C.N. (2019) - Assessing the environmental status of temperate mesophotic reefs: a new, integrated methodological approach. *Ecol. Indic.*, **102**: 218–229.
- ENRICHETTI F., GIUSTI M., TOMA M., TUNESI L., BO M., ANGIOLILLO M., *in preparation* - A new multiparametric index to assess the scleractinian cold-water coral status.
- ROBERTS J.M., WHEELER A.J., FREIWALD A. (2006) - Reefs of the Deep: The Biology and Geology of Cold-Water Coral Ecosystems. *Science*, **312**: 543–547.