Conservation overview of Mediterranean deep-sea biodiversity

a strategic assessment

Yiannis Issaris

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Forewords

To date, a very limited part of the ocean has been explored. Our fragmented information about its biodiversity and ecosystems, especially regarding the deeper areas, makes the development of effective management strategies even more challenging. This situation becomes even clearer in the Mediterranean —a critical region in many regards: not only is it one of the world's greatest biodiversity hotspots, but it is also extremely rich in natural resources. Besides, our *Mare Nostrum* has a strong influence on the climate and weather conditions of Mediterranean countries, and plays a vital role in sequestrating carbon from the atmosphere. On an economical level, it builds the basis for key business activities, including fisheries, coastal and marine tourism or maritime transport. Despite its huge relevance, overexploitation of its natural resources, mismanagement and further increasing pressures are putting the region at serious risk.

The current report, published by the International Union for the Conservation of Nature, Mediterranean Cooperation Centre (IUCN-Med) with the support of MAVA Foundation and scientific experts, is part of IUCN's regular process to assess the state of the Mediterranean marine biodiversity and the available knowledge. This information is intended to provide a comprehensive overview of the current knowledge and threats posed at the Mediterranean deep-sea for policy and technical decision makers, industry and the scientific community. It also attempts to address the causes and effects of major threats, including those resulting from climate change.

Although the deep-sea environment takes up as much as 78 percent of the total Mediterranean marine surface, our knowledge of these ecosystems remains very limited. Enhancing our understanding of the deep-sea environment and effective monitoring are key to promptly detect and mitigate our footprint.

While Mediterranean countries have increased their efforts over the last two decades to conserve and manage the sea, greater action is needed to face the growing challenges and meet the targets under the Sustainable Development Goals, precisely Goal 13 "to take urgent action to combat climate change and its impacts" and Goal 14 "to conserve and sustainably use the oceans, seas and marine resources". Addressing these goals will help us enhance the resilience of marine ecosystem which the Mediterranean society depends on.

Antonio Troya Panduro
Director, IUCN Centre for Mediterranean Cooperation

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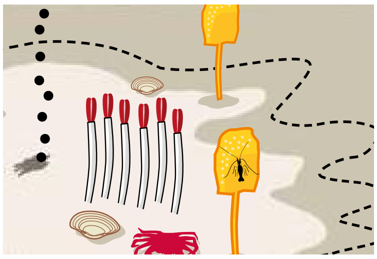

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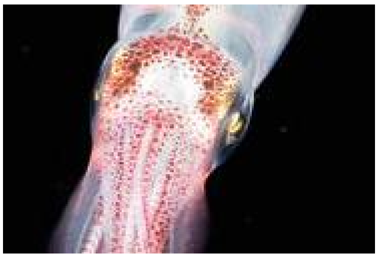

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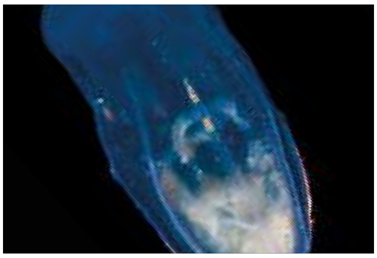

Preliminary notes

The Mediterranean has long been recognised as a global marine conservation priority. However, very little is known of its deep-sea environment, how it functions and how it is affected by the growing impact of humans. This vast area, which lies below 200 m, accounts for close to 78% of the Mediterranean Sea and it shelters a rich and fragile biodiversity. In recent years, scientists, with the aid of emerging technologies, have been exploring new regions and discovering new species which, in turn, has led to the realization that the deep-sea is home to ecosystems found nowhere else on the planet. Yet, conservation planning is still limited with respect to its actions to protect and improve this fragile environment. The objective of this document is to guide and facilitate **the implementation of a deep-sea conservation, research and sustainable management strategy in the Mediterranean region with all relevant partners.**

This document reviews the status of our knowledge of the Mediterranean deep-sea environment, its current regulations and policy instruments, main challenges and opportunities. It is intended to spur a more focused approach to the conservation of the Mediterranean deep-sea environment and to provide guidance where actions are most needed. Actions and areas identified herein can serve as initial components of a portfolio approach as countries move towards compliance with the Convention on Biological Diversity, UNGA resolutions for the deep-sea and other International and national commitments. 9 The strategic orientation draws on the results of the 2015 meeting of deep-sea experts organised by IUCN and which was followed by a series of scoping reviews and discussions in order to compile the most up-to-date information on deep-sea biodiversity as well as international and regional policies.

For the group, this report also indicated where further research is needed in order to understand and identify the following:

a) Major knowledge gaps;

b) Key areas where vulnerable ecosystems and biodiversity hotspots are now known and urgent action to conserve them should be developed.

Before moving ahead with any planning process of the selection of actions and priority sites, however, other stakeholders should be consulted. Since its first draft, this group of experts has contributed to the development of a series of policy actions, and we hope that an increasing number of individuals and organizations continue to collaborate on this effort to understand, protect and improve the sustainable use of the Mediterranean deep-sea ecosystem.

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Introduction to the Deep-Sea Ecosystems

Deep-sea ecosystems include the waters and sediments found approximately 200 m below the surface. They represent the world's largest biome, covering more than 65% of the earth's surface and including more than 95% of the global biosphere[1,2].

Compared globally to more familiar terrestrial or coastal environments, the deep-sea contains many extremes on Earth, with an average depth of ca 4,200 m, lack of sunlight, average temperatures < 4° C (except in the Mediterranean and in the Red Sea where the temperature is close to 13° C and 21.5°C during the whole year, respectively) and average hydrostatic pressure of approximately 400 atm (ranging from 20 to >1,000 atm). The complete darkness avoids the possibility of any photosynthetic primary production deeper than ≈200 m, further challenging the ecological functioning of deep-sea systems.

We now recognize the deep-sea as a highly complex and heterogeneous ecosystem comprised of several different, and contrasting habitats. The deep-sea biosphere also includes the Earth's largest regions partially or completely devoid of free oxygen (i.e., hypoxic and anoxic environments), which include the oxygen minimum zones (expected to expand significantly in tandem with the ongoing global change), the deep hypersaline anoxic basins, and the deep Black Sea (the single largest anoxic region in the world). Until today, researchers have documented life everywhere in the deep-sea, with active metabolic life from -2 to >100 °C, even in sediments at a depth of 10,000 m and microbial life at 1,000 m below the seafloor[3,4].

The global deep-seafloor accounts for a total area of more than 434 million of km^2. This estimate alone increases previous calculations (based upon orthogonal projections from the sea surface to the seafloor) by approximately 20%, but specific smaller-scale topographic features require further upward re-evaluation of the actual extent of deep-seafloor. Habitat mapping of the deep is still in its infancy and improved knowledge of deep-sea topographic features at different spatial scales will facilitate a better understanding of the relevance of these structures in sustaining deep-sea biodiversity as well as provide new insights for defining high-sea areas for the preservation of deep-sea biodiversity and ecosystem functioning.

Despite the huge areas involved, our knowledge of both pelagic and benthic deep-sea diversity is still very scant. In the last decades, an increasing number of studies investigated deep-sea biodiversity in several regions of the world. However, these studies focus on a limited number of taxa and are typically characterized by a limited spatial or temporal scale of investigation due to the high costs of both ship time and the technologies needed to explore the deep-sea[1,5].

Allochthonous and autochthonous energy sources feed deep-sea life from different pathways: active transport with the vertical migration of organisms from shallower depths, passive fall of organic matter from large items such as animal carcasses, rivers inputs and plants, as well as fine particulates of organic matter composed by faecal pellets and phytoplankton[6]. Likewise, chemosynthetic primary production also provides an important contribution to the deep-sea food webs[7].

Deep-water coral framework formed by the white coral, *Madrepora oculata* in Malta. **OCEANA / LIFE BaHAR for N2K**

On the deep-sea floor, organisms depend heavily on the export of organic particles from the euphotic zone. Of ≈48.5 to 54 Pg C y^{-1} (Petagram of carbon per year[1]) marine surface primary production, only around 1% is stored in subsurface marine sediments[8]. Microbes recycle the remaining organic matter and consume most primary production before it reaches the deep-sea floor.

Although an extreme food limitation apparently characterizes the large majority of deep-sea environments, time-lapse photography has demonstrated rapid and massive inputs of plant material from the terrestrial environment to the deep-sea floor, reaching as far as 5 km deep[9].

These events, together with the remains of large marine animals deliver high quality, fresh organic material to this environment and have significant effects on the biomass, biodiversity, metabolism, distribution and abundance of the deep-sea species within it[10].

Moreover, scientific evidence shows that lateral advection (the lateral transport of material along the marine slope), delivers much of the organic matter flux from continental margins[11] with massive and frequent transport to deep areas, a phenomenon especially remarkable down submarine canyons[12]. All these processes, explain the absence of consistent trends in the sedimentation process of organic matter at increasing depths in most deep ecosystems at wide spatial scales, as well as the presence of areas of accumulation of organic matter even in the deepest areas, the Hadal trenches (i.e., > 6,000 m deep). Indeed, despite enormous pressures and low temperatures these environments can support benthic abundances and biomasses of certain taxa (e.g. nematodes) that can exceed those of coastal systems[13,7]. In addition, certain environments such as chemosynthetic hotspots supplied with reduced chemical species emanating from the seafloor at warm hydrothermal vents or cold seepage areas create islands of microbial primary productivity. There, autotrophic CO_2 fixation supports specialized communities of microbial and animal life with exceptionally high local biomasses and abundances for the marine environment[14,15].

The deep ocean harbours several types of ecosystems, and habitats which are subject to specific physicochemical, hydrodynamic and geomorphological conditions[16,17]. Yet, work is still needed to create a clear classification for each of them. The presence of different geomorphologies and habitats, along with temporal variation, supports deep-sea

[1] Pg C = 10^{15} g carbon = 1 billion metric tonnes carbon.

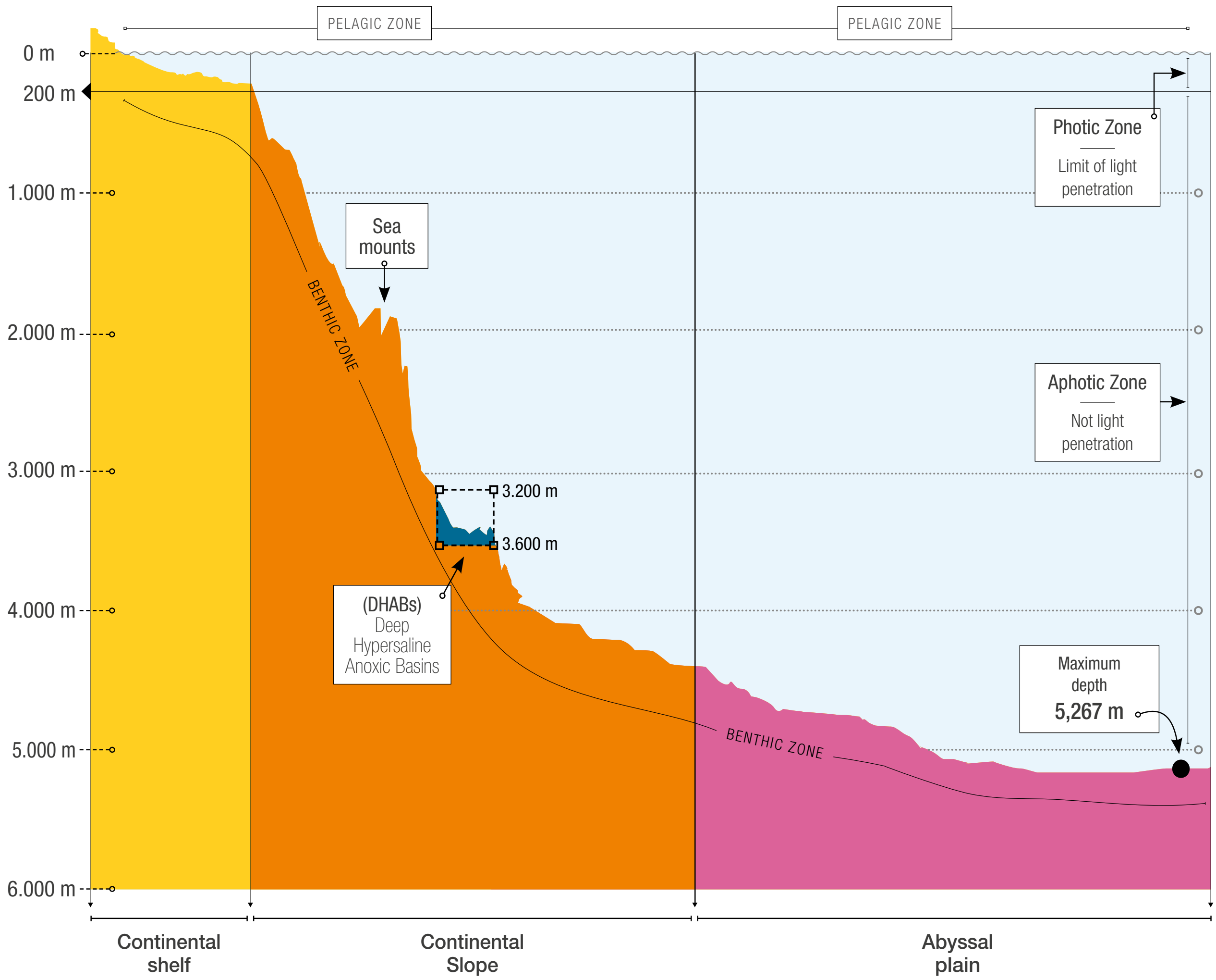

Fig.1. Zonation of the Mediterranean marine environment based on depth and light penetration. Deep-sea is considered to start at the continental shelf-break in the aphotic zone ~200 m water depth.

biodiversity. Moreover, there is also a transition zone among the habitats and ecosystems ranging from the deepest part of the continental shelf to those below the 200m depth contour *(Fig1)*. And there is evidence which supports that some deep-sea communities can also occur in the lower part of the circalitoral zone. Among the already identified geomorphologic features of the deep-sea are:

Open continental slope systems, beyond the shelf break with the deeper part of the continental shelf as a transition zone to the deep areas

Submarine canyons formed by the flow of rivers during past low sea level periods or via other erosional processes. They link the continental shelf to the deep-ocean floor.

Seamounts, pockmarks and volcanic ridges: underwater mountains formed from volcanoes or sunken islands that can form chains and sometimes show vent activity.

Hydrothermal vents resulting from volcanic activity on the ocean floor. These fissures release geothermally heated and mineral-rich water.

Cold seeps and related structures, where fluids rich in methane and H_2S (hydrogen sulphide) or other hydrocarbon-rich fluids diffuse from the seafloor along continental margins. These include habitats of gas hydrates and brine pools (created mostly by the release of fluids charged with mud derived from the subseabed).

Abyssal plains formed by flat areas of seabed nourished by organic debris settling from surface waters.

Deep hypersaline anoxic basins where the water mass, often near the bottom, is depleted in oxygen.

Observations along the canyon of Cassidagne (France). **Agence France pour la Biodiversité / COMEX5**

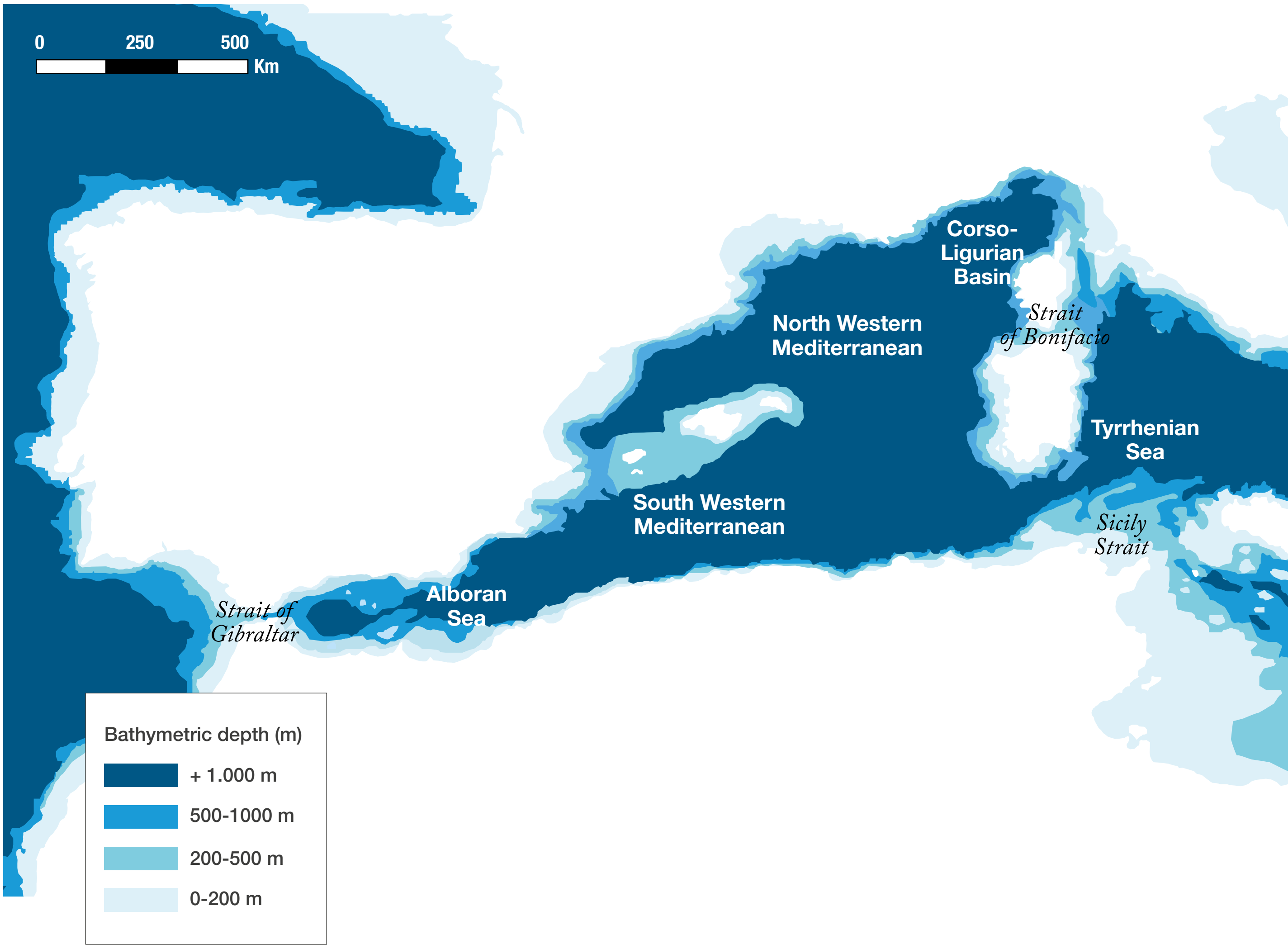

Fig.2. Map of the Mediterranean Sea showing the sub-basin areas and principal straits.

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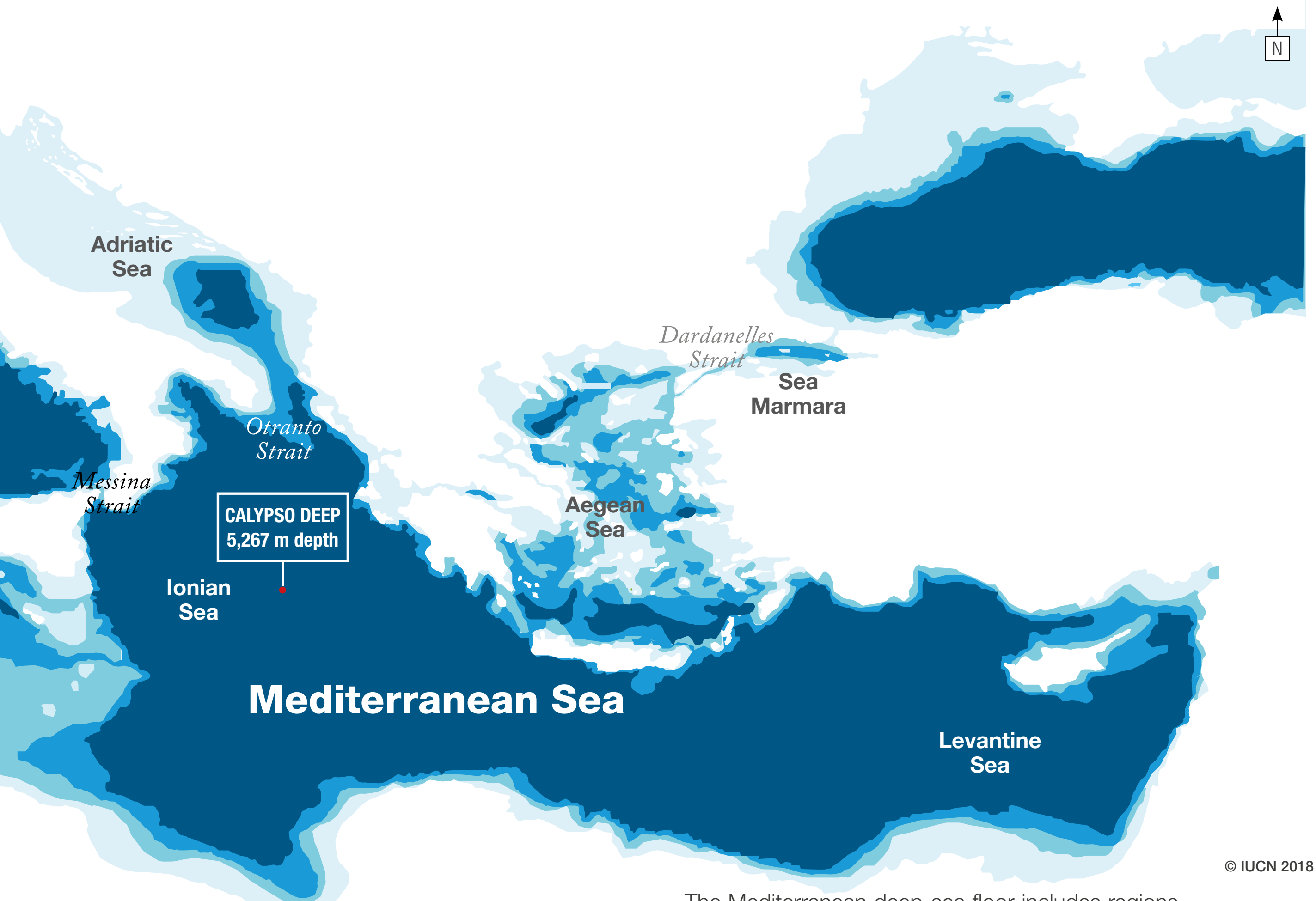


The overall surface area of the Mediterranean basin is approximately 0.82 % of the world ocean surface. The Mediterranean has an average depth of 1,500 m and the deepest recorded point is 5,267 m at the Calypso Deep in the Ionian Sea with more than 1,965,926 km^2 below 200 m depth. The total volume of the Mediterranean is approximately 0.3% of that of the global ocean.

Despite its limited dimensions, the Mediterranean Sea hosts approximately 7.5 % of all marine species, with a high percentage of endemic species[18]. These unique features are related to the highly complex characteristics of the Mediterranean basin, which is divided into the Western, Central and Eastern basins with the Strait of Sicily constituting the main divide *(Fig.2)*. The Western basin (mean depth roughly 1,600 m) consists of three deep basins: the Algero-Provençal basin, the Tyrrhenian Sea and the Corso-Ligurian Basin. The Central-Eastern Mediterranean consists of three main deep basins: the Ionian, Aegean, and Levantine [5,19]. Here, in the Hadal zone of the Hellenic trench, which ranges from roughly 4,150 metres to 5,300 metres deep, is located in the Calypso Deep—the deepest part of the Mediterranean basin.

The Mediterranean deep-sea floor includes regions which contain complex sedimentological and structural features, such as:

- **Continental slopes**
- **Submarine canyons and landslides**
- **Base-of-slope deposits**
- **Seamounts**
- **Cold seepage (including mud volcanoes and pockmarks)**
- **Hydrothermal vents**
- **Bathyal or abyssal muddy plains**
- **Deep-hypersaline anoxic basins**

Although not technically deep-sea, as it is a transition zone with the upper bathyal, the deep circalitoral zone of the continental shelf also merits consideration as some characteristic habitats and species overlap with those of the shelf break and continental slope.

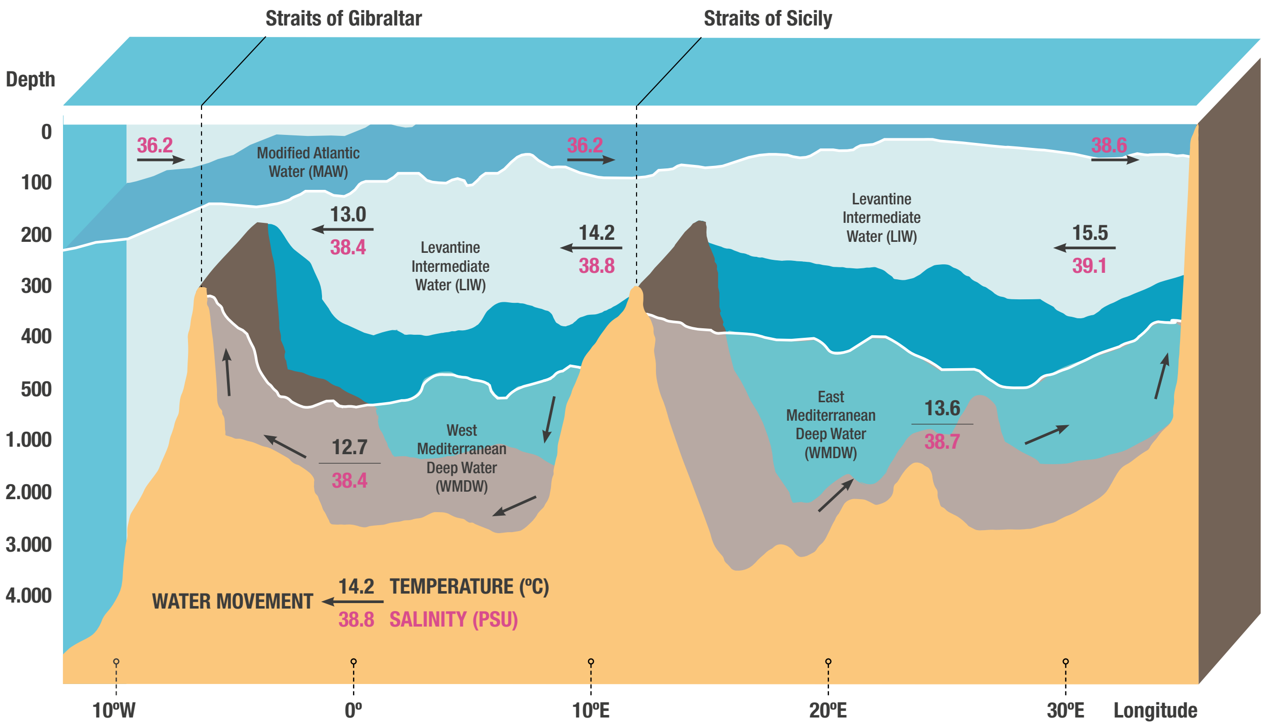


Fig.3. Sea water mass circulation in the Mediterranean Sea.

Sources: Adapted from Zavattarelli, M., and Mellor, G.L., A Numerical Study of the Mediterranean Sea Circulation, American Meteorological Society, 1995. GRID-Arendal.

Environmental Setting of the Mediterranean Deep-Sea

The main environmental features of the deep Mediterranean Sea are:

a) highly constant temperatures from roughly 300–500 m of depth to the bottom, and bottom temperatures of about 12.8°C to 13.5° C in the Western basin and 13.5° C to 15.5° C in the Eastern basin[20],
b) high salinity, from about 38 to 39.5 psu with stratification of the water column,
c) limited freshwater inputs (the freshwater deficit is equivalent to about 0.5–0.9 m y^{-1}, compensated by the Atlantic inflow of surface water, which also influence to a deeper salinity;
d) high oxygen concentrations, and
e) limited food conditions, with strong environmental gradients and low nutrient concentrations in the Eastern basin[21]. Seasonally, during late spring and summer, the whole Western Mediterranean is strongly stratified with a thermocline at 20–50 m of depth. In winter, the water column is more homogeneous, especially in the open sea. Nonetheless, in the Levantine basin, water is stratified during late spring, summer and late fall by a steep seasonal thermocline formed between 35-80 m deep.

Water circulation is, like the sedimentological and structural features, also very complex. The surface waters enter into the Mediterranean Sea from the Atlantic surface and turn into intermediate waters in the Eastern Mediterranean. Low-salinity Atlantic waters enter the Mediterranean, while denser Levantine Intermediate Mediterranean waters flow beneath the Atlantic waters in the opposite direction into the Atlantic Ocean *(Fig.3)*.

Thus, the water circulation on a mesoscale (i.e., within the range of approximately 100 nautical miles) is extremely variable and dynamic in the Mediterranean basin, and it is responsible for the creation of small gyres (eddies) that have implications for the upwelling of deeper waters and its influence on primary productivity. This consequently affects the flux of organic matter transported to the deep-sea floor.

Thus, the deep-sea also represents a complex scenario of geophysical cycles influencing species behaviour and, consequently, their distribution. Currents may represent an important agent in relation to key ecological functions of species, such as low-energy dispersal capacities and feeding [22]. The trajectories of deep and bottom currents are largely unknown, but strong currents with speed up to 1 m s^{-1} have been documented in submarine canyons in relation to meteorologically driven episodic events[12]. Rapid vertical transport of surface waters to great depth also occur as a result of dense water convection, when surface waters become denser as a result of evaporation and cooling. This phenomenon, known as cascading, occurs as short term events[23] and is thought to influence the distribution of the food sources and of the of deep-sea benthos[24].

Given the average depth of the Mediterranean basin, the deep-water turnover is relatively rapid (from 50 to 80 years) when compared with the wider oceanic regions[5,25]. The consequence of this is the rapid transfer of sediments at great depth.

The Levantine region of the Eastern basin is one of the most food-limited deep-sea areas of the world [26,27]. Inputs of organic carbon are 15–80 times lower than in the Western basin and there are extremely low concentrations of chlorophylla in offshore surface waters (about 0.05 µg L^{-1}) [28,29]. In addition, there are low concentrations of food sources that decline sharply with increasing distance from the coast and depth.

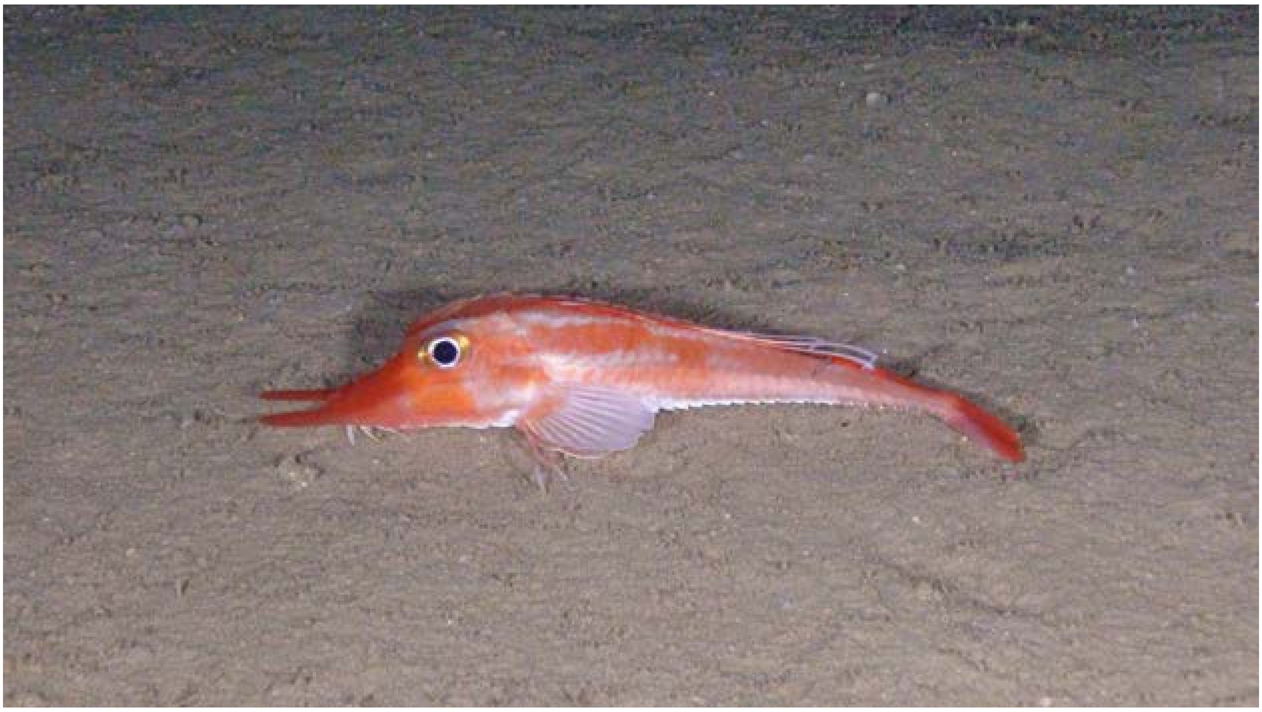
Finally, the deep-sea also represents a complex scenario of geophysical cycles influencing species behaviour and thus their distribution. Currents may represent an important factor in relation to species with key ecological functions, low-energy dispersal and feeding capacities[22].

Mediterranean Deep-Sea biodiversity

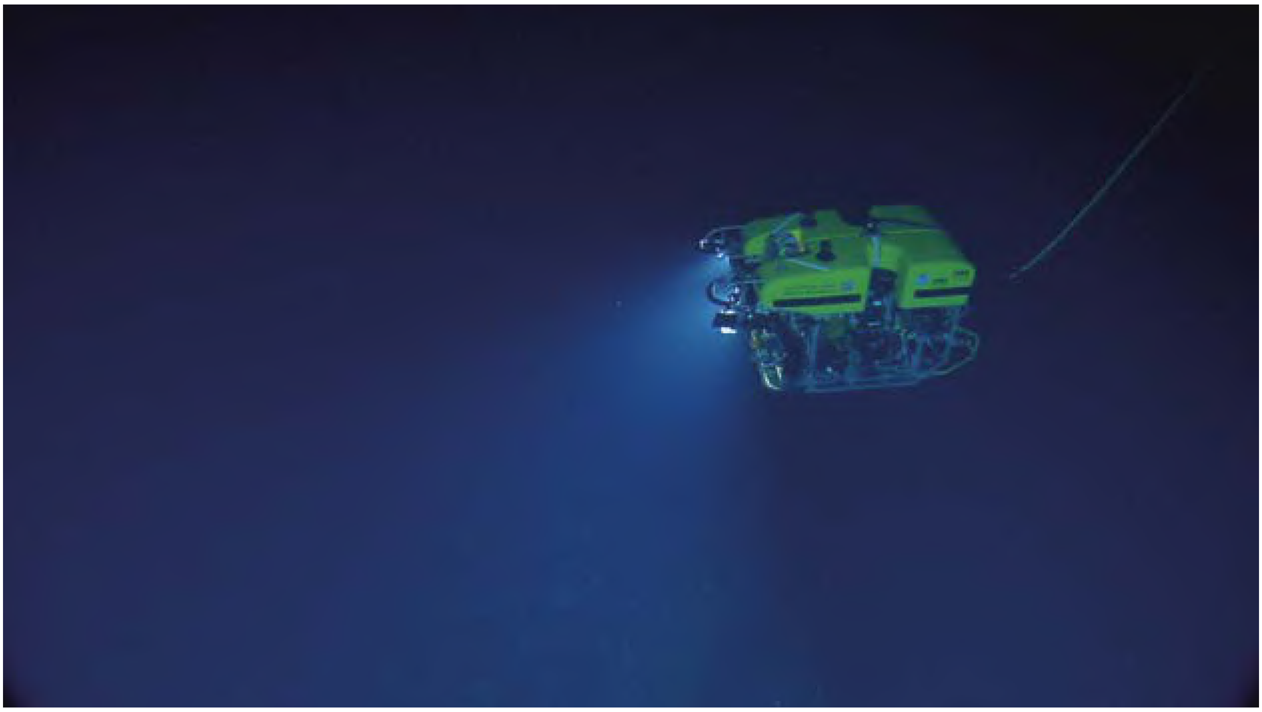
In terms of exploring the Mediterranean marine biodiversity, the first investigations of deep-sea macrobenthos were conducted in the Cretan Sea (Aegean Sea) in 1844, where scientists noted an impoverishment in biodiversity with increasing depth. This observation turned into a general concept that life could be absent at depths of > 300-500 m as the deep-sea environmental conditions seemed to be too harsh to sustain life[30]. Nonetheless, earlier reports[31] already provided evidence of the presence of deep-sea life from the Gulf of Genoa at depths down to 1,000 m. Later, the Washington expedition (1881–83) collected benthic and benthopelagic deep-sea fauna in the Tyrrhenian Sea by trawling at depths of 3,115 m. After this early phase of exploration, knowledge of Mediterranean deep-sea fauna was mainly provided by the Princesse Alice and Hirondelle expeditions (1888–1922) which focused primarily on fish fauna. The most extensive deep-sea faunistic exploration in the Levantine basin of the Mediterranean occurred afterwards during the voyages of the Research Vessel Pola (1890-93). The Danish oceanographic cruises of the research vessels Thor (1908) and Dana (1928–29) also reported deep-sea fish at depths greater than 1,000 m in the Mediterranean. After the Danish oceanographic expeditions, the first noteworthy sampling of deep-sea fishes in the Mediterranean was during the Polymède campaign made with the vessels Jean Charcot (Geistdoerfer and Rannou in 1972) in the Western basin and the German Meteor expedition in the Eastern basin (Klausewitz in 1989).

During the second half of the twentieth century and up to the late '70s limited deep-sea research was conducted. Among such expeditions, however, were the earliest manned submersible investigations exploring depths down to 4,523 m and resulting in various occasional reports on megafauna with the first *in situ* pictures of deep coral forests[32-36].

However, it was only from the late 1980s that specific projects were designed for the systematic investigation of the sea below 1,000 m including the deep Levantine Sea[37-48]. In this period, deep-sea epibenthic dredging (Agassiz trawls and otter trawls) and bottom long-lines were largely in use. This allowed for the collection of several megafaunal species, including the discovery of new species[49], such as four deep-water shark species at depths of 1,330–1,440 m.



African armored searobin, *Peristedion cataphractum*. **OCEANA / LIFE BaHAR for N2K**



Oceanographic cruise expedition. **OET Nautilus Live**

In addition, occasional biological information found in the literature provided hints on some important Mediterranean deep-sea hotspots, or on certain taxonomic groups.

In 2001, a multidisciplinary trans-Mediterranean expedition investigated bathyal and abyssal (600–4,000 m) fauna and provided ground-breaking data on the distribution, biology, and ecology of meio, macro-, and megafauna[47]. A similar sampling strategy was replicated during 2013 by the BIOFUN project. For the first time, it included an analysis from viruses to megafauna in order to better understand the linkages between biodiversity patterns and ecosystem-functioning in relation to environmental conditions along a gradient of increased oligotrophy from the Western to Eastern Mediterranean.

During the second half of the twentieth century and up to the late '70s limited deep-sea research was conducted. Among such expeditions, however, were the earliest manned submersible investigations exploring depths down to 4,523 m and resulting in various occasional reports on megafauna with the first in situ pictures of deep coral forests[32-36].

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In addition, occasional biological information found in the literature provided hints on some important Mediterranean deep-sea hotspots, or on certain taxonomic groups.

A real-turning point for the systematic study of the Mediterranean deep-sea took place through the recent action of European and national large-scale projects on specific deep-sea habitats and ecosystems (e.g., seamounts, canyons, coral reefs, cold seeps etc.), their biodiversity and ecology. Some of these revealed the first discoveries for the Mediterranean Sea. This integrated multinational and on-going effort has provided, now for more than 25 years, a wealth of important information on deep-sea habitats, their biodiversity, functioning, connectivity and ecosystem services.

Within these environments, responses of pelagic and demersal species to intrinsic environmental changes (i.e. geophysical cycles in light intensity and internal tides) modified our perception of community composition and overall biodiversity with the discovery of species affected by activity rhythms. Moreover, seasonal changes of environmental conditions and daily rhythm can directly influence the presence and abundance of species at various depths[50].

Angular rough shark (*Oxynotus centrina*) in Malta's waters. **Sharklab-Malta / Rasmus Loeth Petersen**

02
Current knowledge on mediterranean deep-sea biodiversity

Species and habitats

There are large differences in the knowledge among the different components of deep-sea biodiversity (from microbial to megafaunal components) as well as among the different regions within the Mediterranean Sea. The first and most striking difference arises from a comparison between the knowledge of pelagic *versus* benthic diversity in the deep Mediterranean, the latter being typically much better investigated than the former. The second is the clear difference between the northern and the southern sector of the Mediterranean, as most investigations have been concentrated on the northern portion of the Mediterranean basin. All this is due to the different availability of technologies, funds and investments between the European countries and the countries of North Africa and the Middle East. Such differences have resulted in an unbalanced intensity and frequency of sampling, which poses serious limits on our past and present knowledge and consequently on any future management plans. The third element relates to the different components of deep-sea biodiversity. In fact, thus far, biological research has been primarily focused on meso-zooplankton, meio-fauna (animals smaller than 1 mm that dwell within the sediments) and larger components, benthopelagic fauna (e.g. crustaceans, teleosts, sharks, cetaceans etc.) and mega-benthos (e.g. cold-water corals, sponges) with less emphasis on mega-zooplankton (in particular gelatinous zooplankton).

Overall, our knowledge on benthic macrofaunal and megafaunal diversity of the deep Mediterranean Sea is still rather incomplete, and this is especially true for the Eastern and Southern Mediterranean, in spite of recent contributions published in the last two decades. Nonetheless, thanks to recent technological advances, it is now possible to obtain three dimensional seabed maps which, together with Remotely Operated Vehicle (ROV) footage, facilitate the characterization of sea floor features, allowing for the exploration and mapping of the deep-sea as never before. Additionally, more a up-to-date species list for some deep-sea areas will be procured in the near future by obtaining high-frequency and prolonged time-lapse imaging through the installation of observatory nodes as part of the **European Multidisciplinary Seafloor and water-column Observatory (EMSO) programme**, devoted to the installation of permanent cabled video-observatories.

An interesting trait in biodiversity is suggested by some obvious differences in the role and functions of deep-sea organisms detected along the latitudinal trend in the Mediterranean Sea. Bouchet and Taviani (1998) hypothesized that the shallow Gibraltar Strait acts as an important filter for the deep-sea benthic larvae from the adjacent Atlantic ocean (the Pseudopopulation hypothesis), and also identified a reduction of diversity in bathyal gastropods eastwards in the basin. Recent observations lend support to this theory concerning the role the Strait of Gibraltar plays by claiming that this physical barrier between the Atlantic and Mediterranean waters could be responsible for the genetic isolation of large deep-sea species, such as the Portuguese dogfish (*Centroscymnus coelolepis*), which is a dwarf variant of a more globally distributed species[51]. Moreover, the warmer temperatures of the Mediterranean at depths >500-1000 m (about 10 °C higher than in the Atlantic Ocean at the same depth) could further explain the reduced number of Atlantic species in the deep Mediterranean basin as a whole, with less numbers in the Levantine, in agreement with data on gastropods[52].

A further example of this faunal skewness is also offered by fishes as 48 species of deep-sea fishes have been described in the north-Western Mediterranean at depths between 400 m and 1,500 m, whilst the Levantine basin accounts for only 31 species at similar depths[53]. Among the most abundant deep-sea fish species are the Risso´s smooth-head *Alepocephalus rostratus*, the common mora *Mora moro*, the Mediterranean spiderfish *Bathypterois*

The wreckfish *Polyprion americanus*. **Yiannis Issaris**

mediterraneus and the bluntsnout grenadier *Nezumia spp*. Although much reduced in diversity and richness, as compared with the deep-sea fauna of the Western and central basins of the Mediterranean, the Levantine basin also appears to host some autochthonous (i.e., indigenous), self-sustaining populations of opportunistic and eurybathic species (i.e., species able to live within wide bathymetric ranges).

Decapod crustaceans, together with fishes, are dominant in terms of both biomass and abundance[54]. However, from the Western to the Eastern Mediterranean, both of these population parameters decrease with depth. With the exception of the absence of *Stereomastis sculpta* in the Eastern Mediterranean, the same species of deep-sea decapod crustaceans are found throughout the Mediterranean basin. The deep-water shrimps *Aristaeomorpha foliacea* (giant red shrimp) and *Aristeus antennatus* (blue and red shrimp) are among the most important deep-sea resources of the Mediterranean Sea. For a long time, both species have been the main target of deep bottom fishing trawlers in the Western and central Mediterranean, while in some areas of the Eastern basin, such as the Greek Ionian sea, these fisheries started more recently[55]. Due to the commercial interest in both species, several research projects have been carried out, aimed at gaining knowledge of their biology and ecology. Both shrimps, *A. foliacea* and *A. antennatus*, are mostly caught at depths between 300-400 and 800-900 m, respectively. The blue and red shrimp is distributed deeper than the giant red shrimp[46,56] and it shows associated sexual segregation with females mainly located in the upper part of the depth range (within 800 m) and males more common at greater depths, from 800 to 3,300 m. This ecological feature may serve to protect a part of the population of these shrimps from exploitation, making the species more resistant to fishing carried out within the first 800 m of depth[57]. On the contrary, the full population of the giant red shrimps seems to be entirely exploited, as its depth distribution corresponds with that of the fishing grounds[58, 59].

Meiofauna is a collective name that represents one of the most diversified communities of the marine realm, including small organisms, unicellular protists and multicellular metazoans that live in aquatic sediments. Moreover, meiofauna constitute an important food resource for macrofauna and a variety of juvenile fish while certain communities of meiofauna are also known to modify their environment and promote the degradation of organic matter by stimulating microbial activity and bioturbating the sediment[60].

Recent estimates indicates that the deep Mediterraean Sea can host close to 3,000 species versus the estimated 17,000 species for the entire basin (221).

Within this group, nematodes are the dominant meiofaunal taxon (on average more than 80 % of the entire meiofauna assemblage) and their species richness in the Mediterranean can range from 3 to 159 species (Central and Western Mediterranean Sea[61]). At the basin scale, the highest changes in nematode species composition (percentage of dissimilarity among species assemblages: 84 %) is larger at bathymetric ranges 200–1,000 m than at 3,000–4,000 m, and that diversity seems not to be associated with changes in food availability or organic input to the seafloor but with other variables and ecological conditions. Moreover, several studies have shown that nematodes are good indicators of anthropogenic impacts and there is a strong correlation between diversity and ecosystem functioning, with higher diversity found in the Western Mediterranean than the Eastern basin[62].

When looking at other examples of biodiversity groups, it has been noted that, for example, foraminiferal species richness increases with water depth. Furthermore, it seems to decrease eastwards, with the highest values in the Western part of the Balearic Basin and the lowest values towards the East, in the Rhodes Basin, in accordance with the corresponding decrease in organic matter flux to the seafloor[5]. The biodiversity of these deep-sea Foraminifera groups, while still largely unexplored and not fully understood, may indeed play a relevant role in the functioning of deep-sea ecosystems.

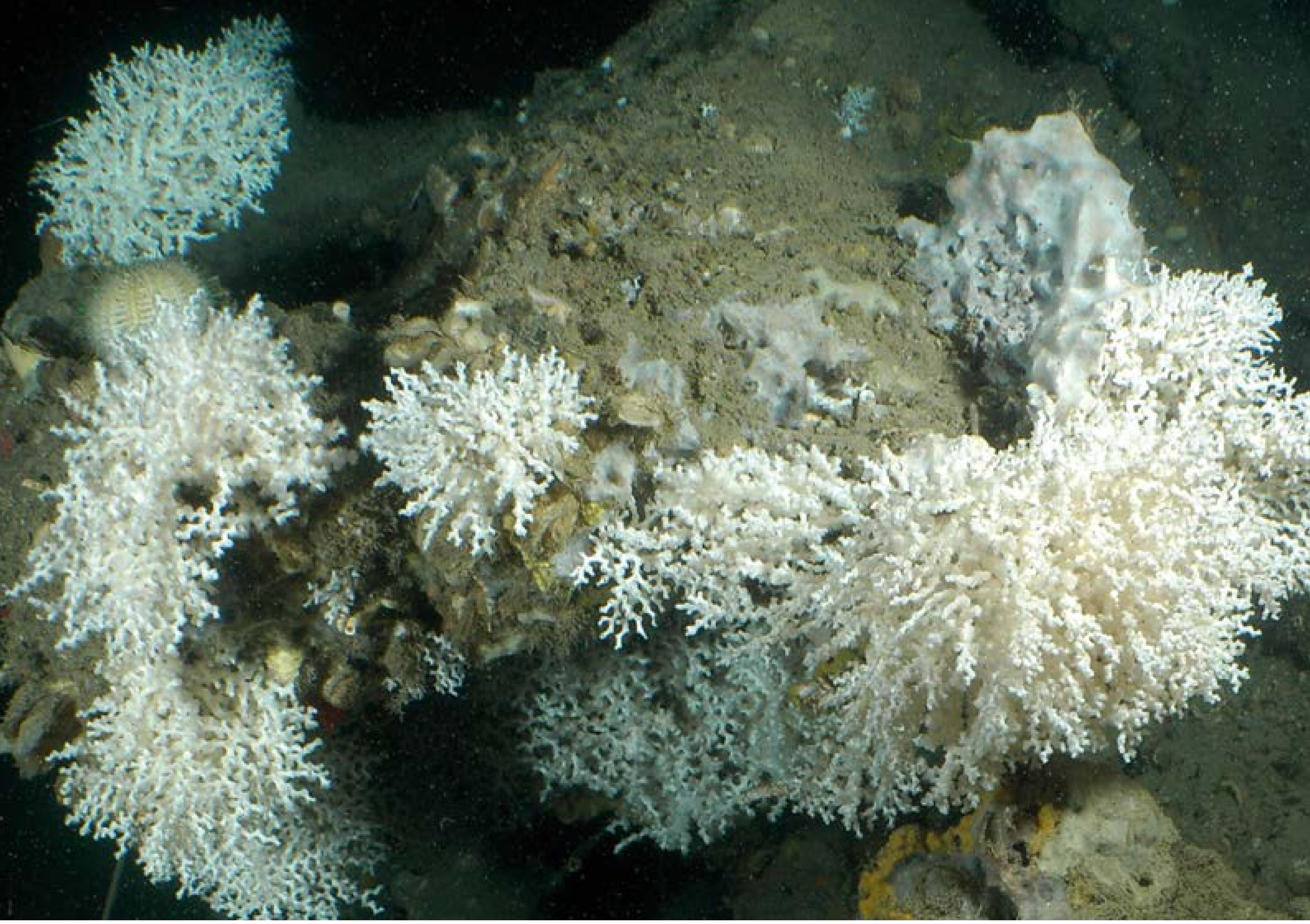
Mediterranean biogenic reefs and other aggregations

Living organisms can alter the marine environmental conditions by enhancing habitat heterogeneity. In particular, reef-forming organisms, such as deep-sea scleractinian corals and sponges, can build biological structures (they are considered ecosystem engineers) and thus provide shelter, nursery habitats and surface area for colonisation by other organisms[63]. And this also holds true in the case of the deep Mediterranean Sea[64,65].

Deep-water sponge fields and coral frameworks and reefs offer internal space, crevices, and rare and firm substrata for sessile organisms (*Astrorhizida, Ampeliscidae, Brachiopoda*, etc.), which seek protection there from strong currents, while simultaneously supplying these organisms with sufficient food of varying characteristics: from zooplankton to detritus. Habitats and communities can be found in mosaics and on relatively small spatial scales. Likewise, it is possible to have characteristic communities of, among others, soft bottoms, rocky areas, coral reefs and deep-sea sponge aggregations.

Deep-Sea Cold-Water Frameworks

Coral species which form deep-sea coral frameworks are important ecosystem engineers. They constitute an elevated secondary hard substrata associated with strong bottom currents that enhance food supply, larval transport and reduce silting. As is the case in the Atlantic Ocean, Mediterranean cold-water corals are preferentially distributed on topographic irregularities, such as escarpments, rocky outcrops, prominent terraces, canyons and seamounts where currents are strong. They are also present on continental shelves and



Deep cold-water coral frameworks of *Madrepora oculata*. **IFM-GEOMAR / ICM-CSIC**

open slopes, inhabiting deep-sea elevated structures (domes, etc) or even settling on semi-lithified or soft sediments[64, 66,67]. Knowledge gained on the distribution of cold-water coral communities in the last two decades, has revealed that its distribution in the deep Mediterranean appears to be much more extensive than previously thought *(Fig.4)*.

Other sessile invertebrates such as scleractinians (e.g., *Desmophyllum dianthus*), colonial octocorals (e.g., *Corallium rubrum*), antipatharians (black corals), sponges, serpulids, specialized gastropods, bivalves and giant oysters (*Neopycnodonte zibrowii*), co-occur making important habitats and biodiversity hotspots[24, 64, 69].

Present knowledge on cold-water corals indicates that these habitats are distributed in several provinces around the Mediterranean Sea[24]:

a) Santa Maria di Leuca
b) The Bari Canyon System
c) The Montenegro Slope
d) The South Malta Coral Province
e) The recently discovered Sardinian Cold Water Coral Province
f) The Gulf of Lion, Provence region, Cassidaigne canyon
g) The Ligurian margin
h) The Alboran sea

As with white coral reefs, well developed populations of the scleractinian orange/pink coral *Dendrophyllia ramea* have recently been discovered in the Levantine basin within Cypriot waters[70].

Mediterranean cold-water corals can survive at the uppermost end of their presumed thermal distribution range[64], at temperatures ranging from 4–13° C, salinities from 38.4 to 38.9 ppm, and dissolved oxygen from 3.75 to 4.54 ml L^{-1}. The temperatures in the deep Mediterranean are close to the upper limit for many cold-water corals living at bathyal depths. However, a recent discovery in the Levantine area adds a new temperature record for the development of *D. ramea*, as it has been found at depths of 155 m and at temperatures of 17 ºC.

Further cold-water coral sites have been recorded along the Apulian margin (Central Mediterranean) improving our knowledge on the species composition and depth distribution of cold-water corals. These findings further support the hypothesis that the distribution of the cold-water coral sites coincides with the course of the dense-water masses that flow between the southern Adriatic and the northern Ionian, connecting the different coral sites[24,71,72].

To the present day, few of the cold-water coral sites in the Mediterranean have been examined by means of Remotely Operated Vehicles (ROV). Cold-water coral communities inha-

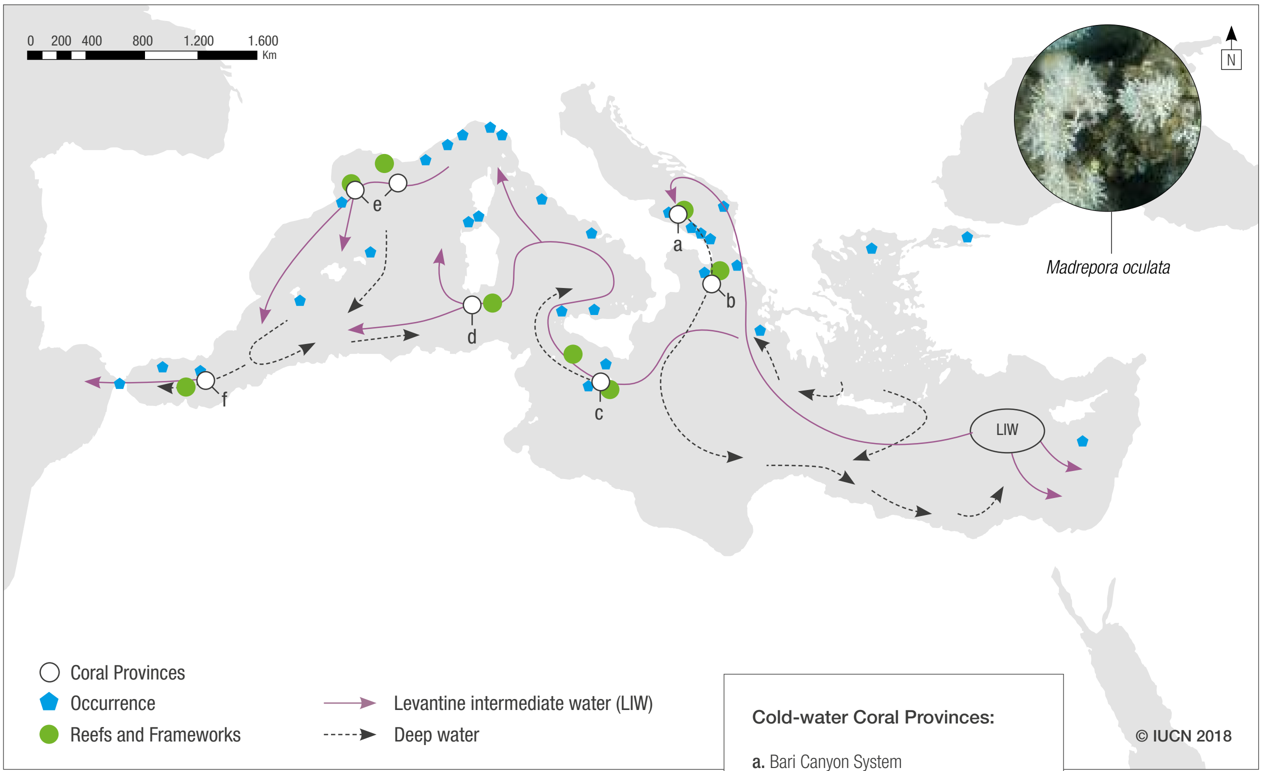


Fig.4. Distribution of living cold-water coral (*Madrepora oculata* and *Lophelia pertusa*) in the Mediterranean, location of six cold-water coral provinces and main paths of flow of the Levantine Intermediate Water (LIW) and deep water masses. See references (65, 158, 71).

Illustration adapted by IUCN.

bit a large bathymetric stretch, as exemplified by the Apulian coral occurrences (Santa Maria di Leuca, northern Ionian Sea; Bari Canyon area, southern Adriatic Sea) where live corals occur from ca. 200m down to 1,200 m.

Cephalopods, crustaceans, and fishes are attracted to the structural complexity of the deep-water coral frameworks, which may act as essential habitats for feeding and spawning, as is the case for the rockfish *Helicolenus dactylopterus*, deep-water sharks (*Etmopterus spinax*) and several other deep-water fish and crustacenan species[73,74]. The colonial stony corals, *Lophelia pertusa* and *Madrepora oculata*, are present in different geographic regions of the Mediterranean deep-sea. The real extent of the distribution of these habitats along Mediterranean margins, however, is far from complete as the explored areas constitute an extremely small section of the seafloor. It is worth mentioning that large portions of the existing coral banks appear damaged, mostly by fishing gear. Likewise, some sites are characterised by a low presence of living colonies and the presence of dead coral frameworks as well as broken coral fragments (coral rubble). Coral graveyards and coral rubble are common occurrences, where dead frames may serve as substratum for a variety of benthic organisms. Recent studies demonstrated that deep-sea bottoms presenting coral rubble accumulations host a different biodiversity from that of adjacent areas, thus still contributing to the enhancement of deep-sea local biodiversity[75].

Cold-water corals (live or as dead frameworks or rubble) can also be found on carbonate mounds. Overall, corals, share the environment with other deep-sea macrofaunal organisms. Besides those previously mentioned above, it is also worth noting the large byssate bivalves (*Acesta excavata*) and the cemented giant oysters (*Neopycnodonte zibrowii*)[76].

Gorgonians and Black Coral Gardens

Knowledge on Mediterranean deep gorgonian and black coral assemblages on the shelf edge and upper slope of the continental shelf is, on the other hand, scarce. For many years their presence was detected due solely to having been netted by fishermen as a bycatch. The use of ROVs, manned submersibles, and video-equipped towed gears, however, has significantly increased accessibility to deeper areas, allowing for non-invasive/quantitative studies of the seabed where they could occur.

Early ecological studies on deep gorgonian assemblages in the Mediterranean Sea revealed high density values for some populations, comparable to those observed in littoral environments[77,78]. Characteristics species found are *Viminella flagellum*, *Acanthogorgia hirsuta*, *Callogorgia verticillata*, *Swiftia pallida*, and *Bebryce mollis*.

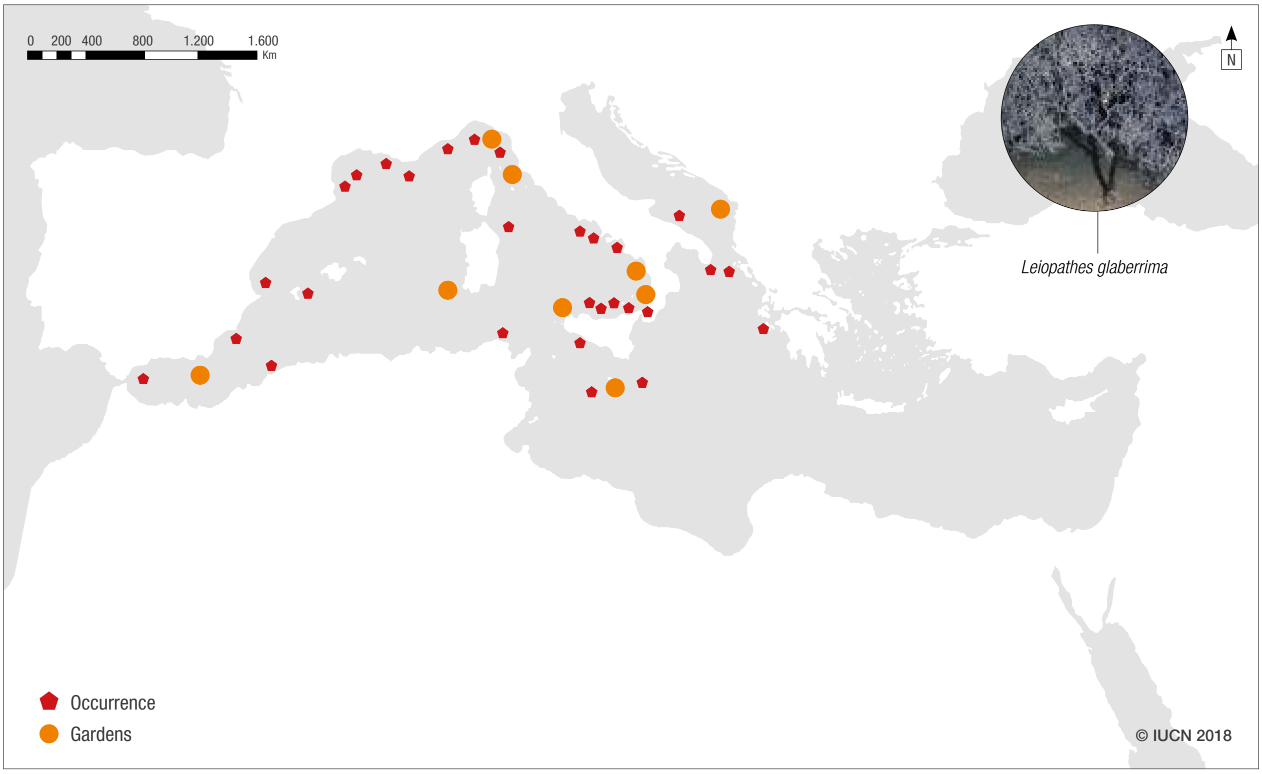


Fig.5. Distribution of Black Coral gardens and occurrence below 200m in the Mediterranean Deep-Sea (*Antipathes dichotoma*, *Leiopathes glaberrima*, *Antipathella subpinnata* and *Parantipathes larix*). See reference (158, 71).

Illustration adapted by IUCN.

One of the most recent studies on deep-sea gorgonians in the Mediterranean[79] characterises the community composition of shallow and deep-sea gorgonian assemblages in the Western Mediterranean (Menorca Channel) and documents the presence of larger populations dominated by medium and large sized colonies in deeper areas. In addition to the reef forming scleractinians *M. oculata* and *L. pertusa*, coral gardens, mostly formed by gorgonians and black corals, are widespread in the mesophotic and bathyal hard bottoms of the Mediterranean Sea. Information on black corals in the Mediterranean Sea had been scarce until a few years ago. New records have increased, particularly in the Western basin, helping to improve our existing knowledge of their biology and ecology **(Fig. 5)**. Mediterranean black corals have never been found at depths shallower than 50 m, and to date four species are known to consistently form coral gardens in the Mediterranean Sea: *Antipathes dichotoma*, *Parantipathes larix*, *Leiopathes glaberrima* and *Antipathella subpinnata*. However, recent findings may add a new family (*Aphanipathidae*) to the already documented black corals in the Mediterrranean (*Bo, M. pers. comm.*).

Rich coral grounds dominated by the black coral *Leiopathes glaberrima*, is being described hosting a highly diverse associated fauna at numerous sites in the Mediterranean. These communities occur along the Italian coasts, the Tyrrhenian seamounts, the Malta-Siracusa escarpment, in the deep portions of the South Malta province, the Montenegrin canyon in the southeastern Adriatic, as well as in the Alboran Sea from 250 m to down to 1,000 meters [80,81,82].

Deep-Sea Sponge Aggregations

Sponges can form aggregations, sometimes in astonishingly high abundances, and thus often become major habitat builders[83,84]. These aggregations of sponges offer substrate for attachment, shelter, and nourishment to other organisms. Moreover, as active suspension feeders, they significantly impact local and regional fluxes of organic carbon and dissolved inorganic nutrients. Reef-building sponges also create habitats for other organisms, provide refuge for adult redfish (*Sebastes sp.*) and nursery habitats for juveniles[85]. Sponges are also among the most important bioeroders of deep-water frameworks.

For example, three species of sponges (*Bubaris sarayi* sp. *nov.*, *Sarcotragus* cf. *muscarum*, and *Ircinia* cf. *retidermata*) were found at 830 m of depth off the Israeli Mediterranean coast[86]. The cavities of these sponges contained a wide variety of organisms including polychaetes (*Harmothoe spinifera, Ceratonereis costae, Leonnates jousseaumei*) and the snapping shrimp (*Synalpheus gambarelloides*).

26

Deep-sea sponges in a chimney forest of columnar carbonates on the Montenegrin margin in the southern Adriatic Sea at a depth of about 450 m. (See reference 215).

Similarly, a monospecific reef-like aggregation built by the lithistid demosponge, *Leiodermatium pfeifferae*, on a 760 m-deep-seamount has been seen to host a wide variety of benthic organisms such as hydroids, the alcyonacean octocoral *Muriceides lepida*, and the scleractinian coral *Desmophyllum dianthus*[84].

Forming discreet sponge grounds, dense assemblages of the sponges *Poecillastra compressa* and *Pachastrella monilifera* have also recently been documented in Southern Italy [83,87,88, 68]. Fields of the large (up to 1 m tall), vase-shaped sponge, *Asconema setubalense*, have been documented on bathyal seamounts in the Alboran Sea and important aggregations of the axinellid *Phakellia ventilabrum* have also been reported in the Mediterranean[83].

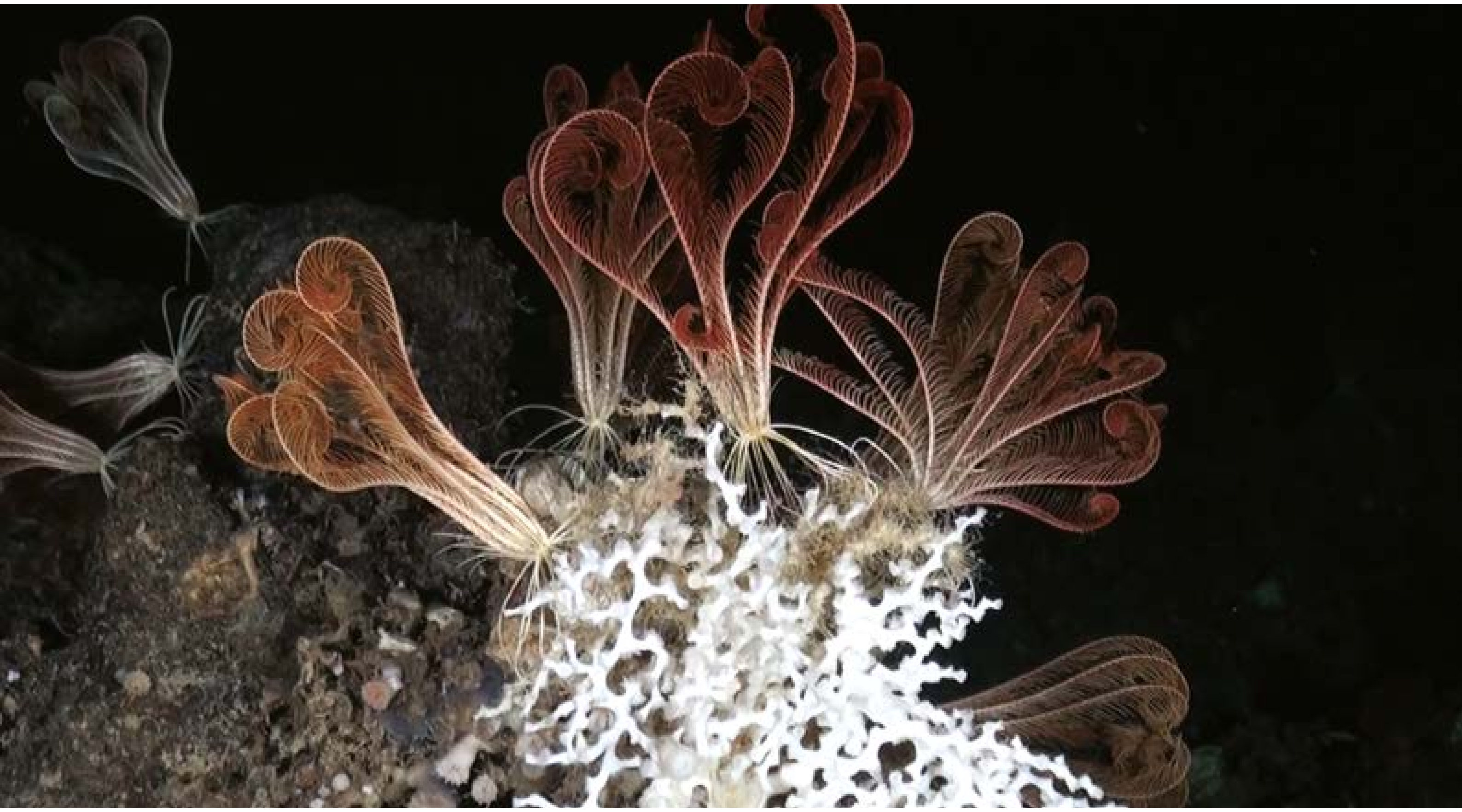
Other Soft Bottom Fauna Aggregations

Other aggregating bathyal fauna can form biogenic habitats or facies of particular relevance. On soft bottoms, the benthic faunal biodiversity is particularly complex as it is shaped by the interaction of numerous environmental and biological processes (e.g., substrate, water-mass properties, productivity regimes, geomorphic features, etc).
Noteworthy among the fauna aggregations in bathyal soft bottoms (sometimes also on the shelf edge or upper slope) are the ones formed by the critically endangered bamboo coral *Isidella elongata*, as well as by certain gorgonians such as *Spinimuricea klavereni*, or the ones with sea-pens such as *Funiculina quadrangularis*, *Kophobelemnon stelliferum*, *Pennatula spp.*, etc.[89].

The fragile bamboo coral grounds formed by *Isidella elongata (Fig.6)* are associated with rich biodiversity and unique epifauna, among them, deep shrimps (*Aristeus antennatus*, *Aristaeomorpha foliacea* and Norway lobsters (*Nephrops* *norvegicus*), sharks (e.g. *Galeus melastomus*) and teleost fishes such as hake (M*erlucius merluccius*), the blue whiting (*Micromesistius poutassou*), the greater fork-beard (*Phycis blennoides*), the flatfish (*Lepidorhombus boscii*), or the blackbelly rosefish (*Helicolenus dactylopterus*) [90].

Large assemblages of mobile crynoids (e.g. *Leptometra phalangium* and *Antedon mediterranea*) and assemblages of the brachiopod (*Gryphus vitreus*) are commonly found on sedimented shelf edges and some open-slopes. *Leptometra* beds are mainly characterised by a high abundance of spawners of commercially important species, such as the red mullet (*Mullus barbatus*) and *Trisopterus minutu*s *capelanus*[91]. Reefs and beds serve as a substratum for several species as bryozoans, sponges, ophiuroids and hydroids.

Fauna assemblages inhabiting soft sediments on slopes, the shelf break and/or canyons along continental margins host either monospecific communities (e.g. sandy muds populated by the mollusc *Thenea muricata*) or mixed assemblages (e.g. bathyal coarse sediments with corals such as *Bebryce mollis* and/or *Villogorgia bebrycoides*). Generally, these communities are still hardly studied[91]. On soft bathyal bottoms, the presence of sponge aggregations is limited to a few species, such as the mushroom-shaped sponge, *Thenea muricata*, and/or the carnivorous sponge *Cladorhiza abyssicola*. They are frequently found with commercial fishes and decapods (e.g. *Gadiculus argenteus*, *Merluccius merluccius*, *Nephrops norvegicus*) as well as with the sponge *Rhizaxinella sp*. [93].



White cold water coral, *Madrepora oculata*, and crinoids, *Leptometra phalangium*. **OCEANA / LIFE BaHAR for N2K**

Life diversity across mediterranean Deep-Sea ecosystems

Over relatively limited spatial scales, the Mediterranean basin contains a number of deep geomorphological features that can represent potential "hotspots" of biodiversity. A tentative, possibly not exhaustive, list of them includes a highly heterogeneous seafloor from:

a) Deep continental shelves and upper slopes
b) Submarine canyons
c) Seamounts and volcanic ridges
d) Carbonate mounds
e) Cold seeps and related structures including gas hydrates, pockmarks, and volcano fields affected by brines;
f) Hydrothermal vents
g) Abyssal plain
h) Hypersaline anoxic basins

Mediterranean continental shelves and upper slopes

The continental slope represents the connection between the shelf and the basin plain, with the shelf break at the edge of the continental shelf *(Fig.1)*. Available studies indicate that there is no one single driver of open slope biodiversity and the species occurrence depends on the "local" ecological and hydrological characteristics as well as the topographic/textural conditions of each area. The complexity of the latter might have a considerable influence on the settlement of a large number of species.

Continental slopes consist of mostly terrigenous sediments and include large areas of soft sediments, boulders and exposed rock faces. Animals on the sediment slope are mainly deposit feeders that feed on the organic matter input from the surface. Upon the deep continental shelf different biocenoses flourish, including those of coastal terrigenous mud, with a dominance of sea pens *Virgularia mirabilis* and

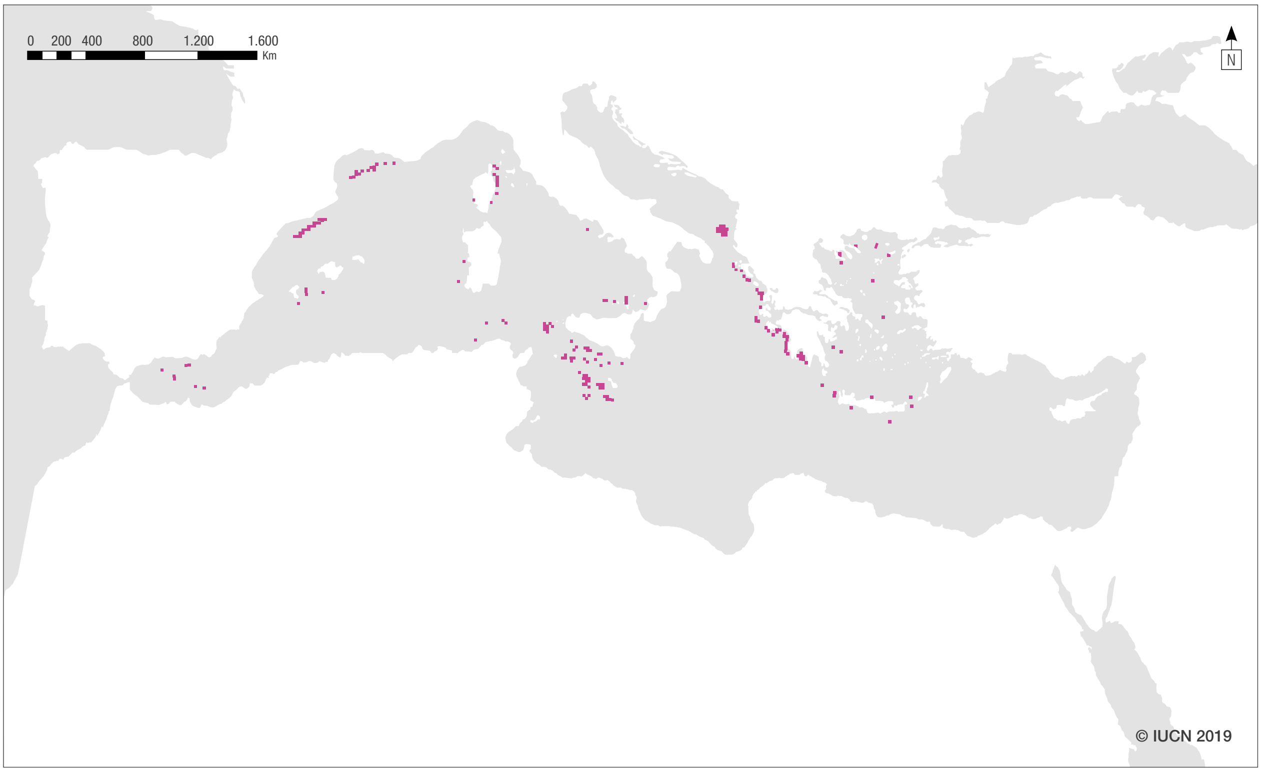


Fig.6. Distribution of the bamboo coral *Isidella elongata* in the Mediterranean Deep-Sea.

Source: IUCN Red List of Threatened Species (2015) and GFCM MPA Working Group, 2019 (157 and references within).

The bamboo coral *Isidella elongata* is listed as Critically Endangered by the IUCN Red list in the Mediterranean. **OCEANA**

Pennatula phosphorea, sticky muds, with soft coral *Alcyonium palmatum* and the holothurian *Parastichopus regalis*, and muddy detritic bottoms, with the brittle star *Ophiothrix quinquemaculata* [91].

Furthermore, the Norway lobster *Nephrops norvegicus*, is one of the most active bioengineering species on deep shelves and upper slopes. Animals dig burrows in the substratum and compete with other burrowing and burying species in muddy areas.

As the slope approach the shelf, the progressive increase of grain size alters the distribution and abundance of the biota of the sediment. Cold-water corals such as *Lophelia pertusa* and *Madrepora oculata* associated with slope features (e.g., canyons, seamounts, and carbonate mounds or cold seeps) could form carbonate frameworks and reefs and sustain high biodiversity. Other structural species such as the bamboo coral *Isidella elongata* also developed here.

On shelf-edge detritic bottoms, crinoid beds of *Leptometra phalangium*, facies of the small echinid *Neolampas rostellata* or large hydroids (*Lytocarpia myriophyllum* and *Nemertesia antennina*), and communities of the ophiuroid *Ophiacantha setosa* and the pectinid bivalve *Clamys clavatus* (in the Aegean Sea) host a biocenosis of great diversity and abundance. The high production of plankton at the shelf break makes it an important feeding ground for large shoals of fish and cetaceans. They also host a high abundance of spawners of commercially important species, e.g. the hake (*Merluccius merluccius*), the blue whiting (*Micromesistius poutassou*), the greater forkbeard hake (*Phycis blennoides*) or the deep water rose shrimp (*Parapenaeus longirostris*)[94].

On shelf-edge rocky areas, the biocenosis could be dominated by large-sized sponges (e.g. *Poecillastra compresa*, *Rhizaxinella pyrifera*, *Phakellia ventilabrum*, *Axinella spp*.), the yellow scleractinian *Dendrophyllia cornigera*, numerosous black corals, many bryozoans, brachiopods, polychaetes and echinoderms[88].

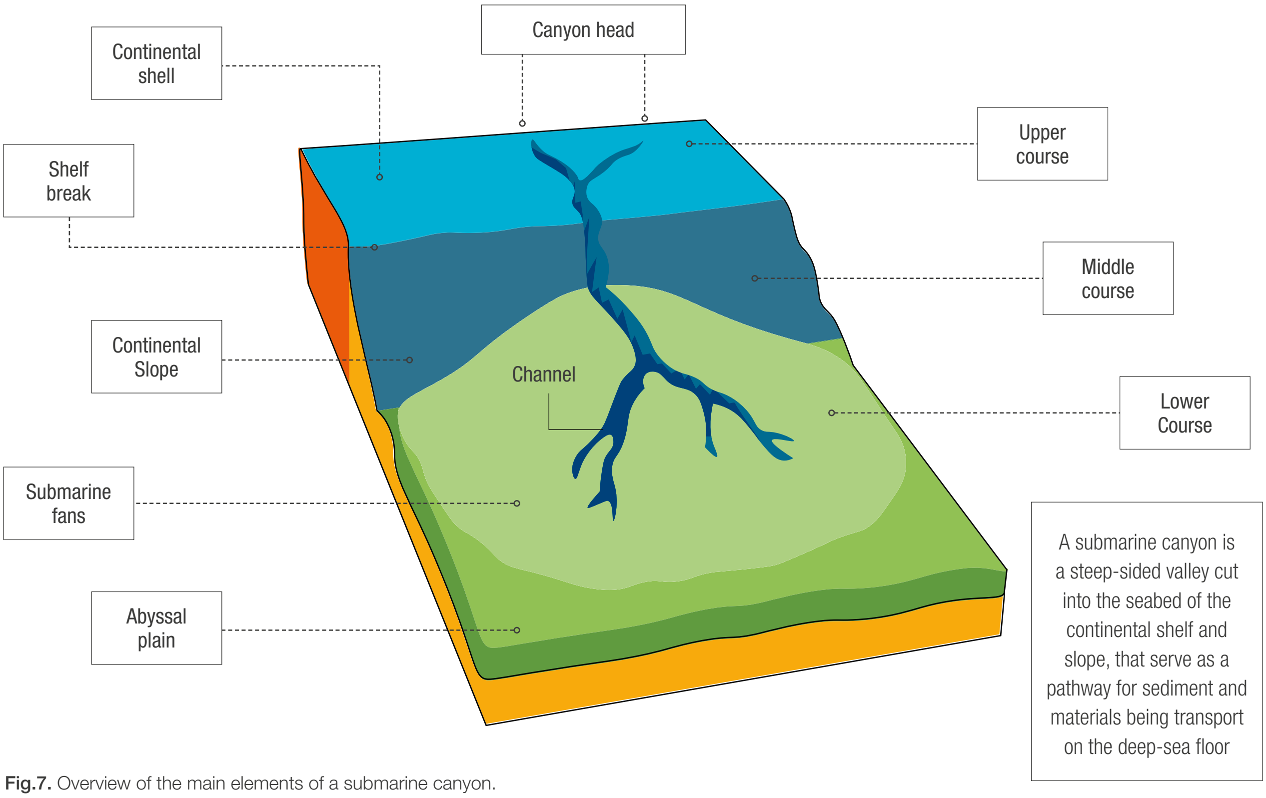


Fig.7. Overview of the main elements of a submarine canyon.

Mediterranean submarine canyons

Submarine canyons are defined as "*steep-walled, sinuous valleys, with V-shaped cross sections, and reliefs comparable to land canyons*"[95] *(Fig.7)*. Submarine canyons are widespread on many continental margins of the Mediterranean basin with complex canyon networks (e.g., the Gulf of Lions), sometimes adjacent to sections of the margin with only linear canyons (e.g., the Catalonia margin) or no canyons at all (e.g., the North Balearic margin)[96].

Overall, more than 500 submarine canyons have been identified previously in the Mediterranean Sea on the basis of morphological criteria applied to the ETOPO1 global relief model and the Mediterranean Science Commission bathymetric dataset[97]. At present, a total of 348 submarine canyons or canyon systems are distributed along the slopes of the Eastern and Western Mediterranean basins, and 237 have being referenced in scientific literature[96]. Submarine canyons play a key role as ocean-continental shelf exchanges, influencing general and local scale water circulation patterns, as major pathways for the transportation and burial of organic carbon, as corridors for material transported from the land to the deep-sea, and as temporary buffers for sediment and carbon storage.

A large number of submarine canyons exist along the continental shelf edge of the Mediterranean region. They are important links transporting sediment, organic carbon and other nutrients between the continental shelf and the deep-sea. Current data suggest that these canyons support unique, highly diverse, and vulnerable habitats. They are complex environments and different commercially important species are found associated to them.

In the oligotrophic Mediterranean Sea, submarine canyons can also play an important role in energy cycling at different spatio-temporal scales[5]. Most Mediterranean canyons, play

European hake, *Merluccius merluccius*. **OCEANA / LIFE BaHAR for N2K**

an important role as habitats for a variety of organisms[65,66,67] and also for species of economic interest[74]. The complex circulation in submarine canyons supports increased biological production; accordingly, these canyons are considered biodiversity "hotspots" due to the high diversity and abundance of pelagic and benthic life [98,99]. This is often related to the increased availability of organic matter due to the enhanced transport of particles from the shelf down to the canyon [100, 101]. For example, in the Blanes Canyon (NW Mediterranean), water layers with significant amounts of suspended sediment are present year-round and act as a nursery area for several shrimp (i.e. *Plesionika heterocarpus, P. edwardsi, P. giglioli and P. martia*) and fish species (*Phycis blennoides, Mora moro, Lepidion lepidion* amongst others)[102].

Enhanced upwelling can occur along canyons attracting a variety of migratory top pelagic predators such as tunas, swordfishes, sharks, turtles and cetaceans. The high concentration of food and abundance of prey trapped within the canyon walls are the biological factors which make the submarine canyon ecosystems so attractive for top-predators and large filter-feeding organisms such as finback whales (*Balaenoptera physalus*)[103].

The hydrodynamics of submarine canyons also influence benthic and nektonic organisms during their active and passive migratory movements from shallow to deeper water and vice-versa. Canyons play an important role in structuring the populations and life cycles of planktonic fauna as well as benthic meio-, macro- and megafauna associated with them. They host[104] biomass and abundance 2- to 15-fold higher than that in the surrounding areas at similar depths (up to 500-m depth). Furthermore, Mediterranean submarine canyons harbour high abundances of planktonic organisms and are "hotspots" of endemism. Moreover, this type of habitat also provides critical nursery areas for a variety of fish species living over continental margins. Canyons along the Mediterranean are also important habitats for commercially exploitable species, such as hake (*Merluccius merluccius*) and shrimps of commercial interest (*Parapenaeus longirostris* and *Aristeus antennatus*). These areas serve as "spawning grounds", where a portion of a heavily exploited stocks remain out of reach of the trawl fishery, and annually sustain recruitment[19]. This, for example, is the case with the canyons of the Western sector of the Ligurian Sea and with those along the Catalan margin[102].

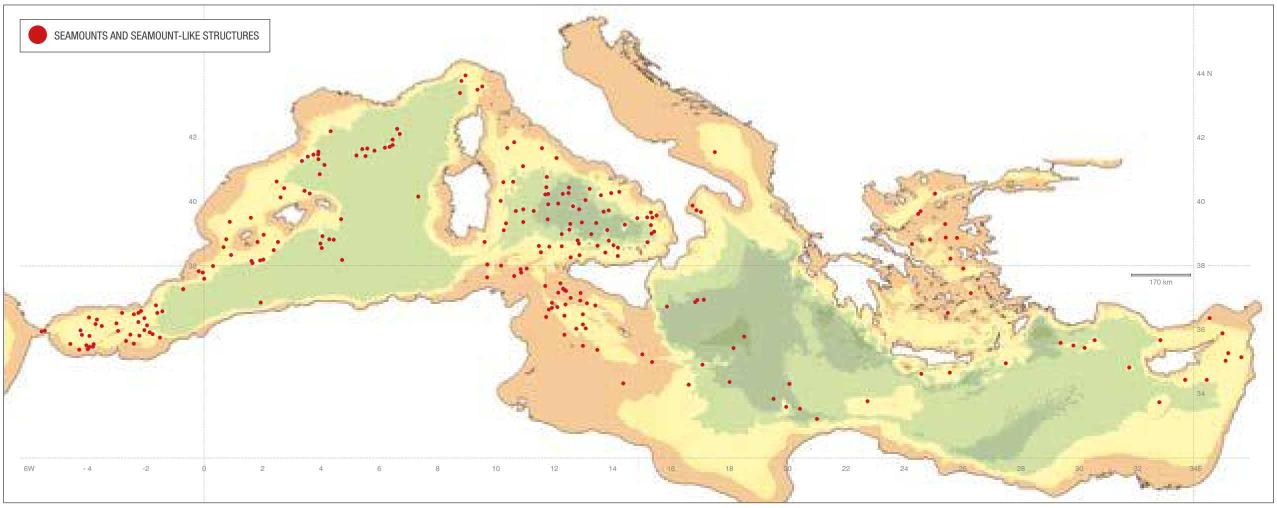


Fig.8. Distribution of Mediterranean Seamounts and Seamount-like structures. See reference (105).

Mediterranean seamounts

Following the definition used in the Mediterranean Atlas of Seamounts by IUCN[105], the term "seamount" refers to seafloor elevations rising at least 100 m from the surrounding deep-seafloor. This definition also follows the recommendations provided by the International Hydrographic Organization (2013).

In the Mediterranean basin, over 242 seamounts, bank rises, highs, hills, spurs and other kinds of sea floor elevations have been identified and described [105] *(Fig.8)*. In the Western Mediterranean, the Tyrrhenian bathyal plain and the Alboran Sea are characterized by the highest concentration of seamounts in the entire basin. Volcanic bodies are either associated with north–south oriented crustal faults (Magnaghi, Vavilov, and Marsili seamounts) or with crescent-shaped bathymetric ridges (e.g., Vercelli and Cassinis). In contrast, the Eastern Mediterranean basin is characterized by a higher topographic heterogeneity than the Western sector and by a large number of seamounts, including the Eratosthenes Seamount—an impressive structure situated in the Levantine Sea with the highest underwater elevation in the Mediterranean.

Seamounts are recognized as highly valuable biological hotspots in the ocean and often host unique communities. Present knowledge on the biodiversity associated with Mediterranean seamounts is mainly focused on benthic habitats and, to a lesser degree, on the pelagic life. Suspension feeders, particularly cold-water corals and sponges, usually dominate the hard-bottom habitats of seamounts. Here, the most important habitat-forming cnidarian taxa of Mediterranean seamounts are alcyonaceans (such as sea fans, soft corals and, sea pens on soft bottoms), antipatharians (black corals, at places forming considerable gardens), and scleractinians (e.g. *Dendrophyllia cornigera, Desmophyllum dianthus*, and the white reef forming corals *Madrepora oculata* and *Lophelia pertusa*—recently suggested to belong to the genus *Desmophyllum* [106]. Moreover, encrusting foraminiferans, poriferans (including carnivorous sponges), bryozoans, annelids, gorgonians, small actiniarians, various bivalves, psoliid holothurians, sipunculids, asteroids and fishes are also found in these environments [21,107,108]. Such a rich benthic biodiversity sustains a complex pelagic and planktonic trophic net dominated by numerous top predators (cetaceans and sharks, *Fig.9*).

The influence of seamounts on the benthic assemblages in the sediments close to these systems has also been shown a remarkable difference in community composition between the adjacent sediments and those typical of the most distant bathyal plain. Seamounts act as obstacles to marine currents, causing local upwelling and eddy formation while lower-relief features such as knolls and pinnacles are unlikely to have the same oceanographic influence [105].

The Mediterranean Sea harbours some impressive seamounts whose biodiversity values are still poorly known. Typical deep-water glass sponges, sea pens, cold-water corals, sea fans and a rich associated fauna attach themselves in dense colonies to seamount slopes. Seamounts can also act as biodiversity hotspots, attracting top pelagic predators and migratory species, such as whales, sharks, tuna or rays.

Fig.9. A representation of a seamount community, showing potential currents and how dispersal and colonization among deep-sea benthic populations may occur.

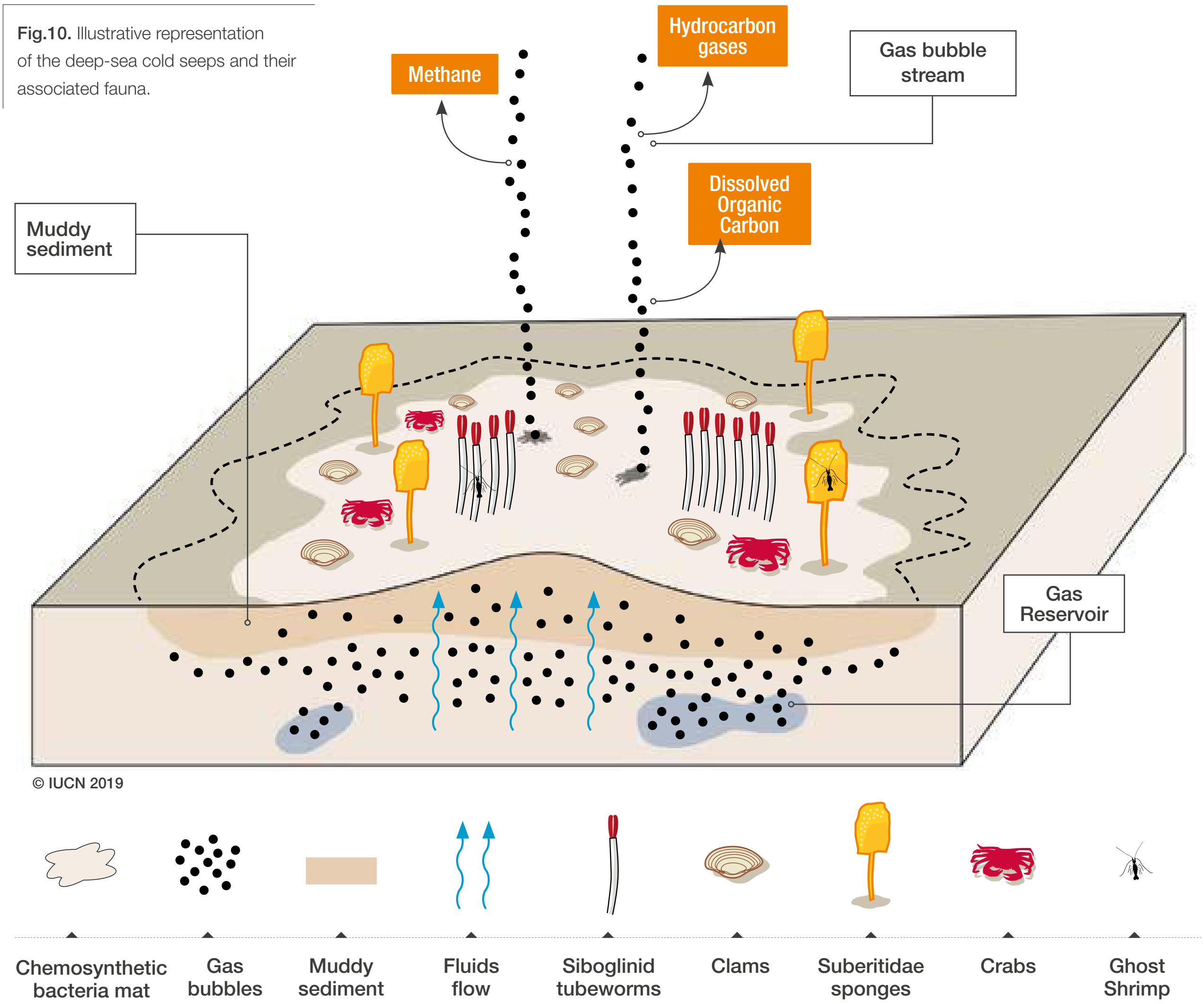
Carbonate mounds

Carbonate mounds are geological elevations of various shapes which may be up to 350 m high and 2 km wide at their base[193]. They have resulted from the growth of carbonate-producing organisms (cold-water corals, bryozoans and sponges), sedimentation, and (bio) erosion processes and are known to be more than 10,000 years old.

Globally, the vast majority of carbonate mounds have been observed from depths between 200 m and 1000 m below the shelf break [109]. Their presence is also confirm in the Mediterranean Sea[64,110]. Live cold-water reef-building corals *Lophelia pertusa* and *Madrepora oculata*, are characteristic on the mound summit and coral debris or mud may also form a significant component of the seafloor substratum. Although very little research has been conducted in the Mediterranean, observations from elsewhere have revealed they can be areas of high species diversity in the deep-sea and, therefore, of particular ecological significance. Giant fields of carbonate pipes and chimneys that have built up large carbonate mounds at depths of more than 1000 m have been discovered in the Gulf of Cadiz (Atlantic side of the Gibraltar Strait). These carbonate mounds have a rich abundance of species and are extensively colonised by sponges, bryozoans, hydroids, soft corals, ascidians, calcareous tube worms, crinoids and bivalves[111].

Chimney forest of columnar carbonates on the Montenegrin margin in the southern Adriatic Sea at a depth of about 450 m. Their age is estimated ca. 250-270,000 yrs. Angeletti et al. (See reference 215).

Fig.10. Illustrative representation of the deep-sea cold seeps and their associated fauna.



Mediterranean cold seeps and related habitats

Cold seeps are marine seafloor ecosystems that develop around hydrocarbon emission pathways from the seabed at ambient or slightly higher temperatures[115]. Also known as cold vents, seeps have a highly fragmented distribution along continental margins around the world and there is not a comprehensive inventory of their distribution in the Mediterranean. They are among the most recently discovered marine environments.

The habitats created by seeps are linked to the chemicals they release (methane, petroleum, other hydrocarbon gasses and gas hydrates), which characterise the presence of chemosynthetic communities fuelled by the chemical energy originated from microbial utilization of these sources.

Chemosymbiotic macrofauna associated with deep seep ecosystems (i.e. hydrogen sulphide, methane, brine and other hydrocarbon-rich fluid seepage) in the deep Mediterranean were first described from the top of the Napoli mud volcano in Crete, at 1,900 m depth[112,113]. Communities from cold seeps are also present along the Catalan margin, the

The biological communities associated with cold seeps are remarkably unique (Fig.10). Specialized bacteria living inside some fauna such as bivalves and tube worms metabolize methane and/or hydrogen sulphide for energy and provide nutrition. The aggregations of these fauna provide the structure and habitat for different associations of benthic animals that are able to cope with the elevated concentrations of chemical compounds and low oxygen levels found at, and below, the sediment in these environments. A large proportion of the species found in these ecosystems are endemic, with only few species commonly occurring at different sites.

Communities of sponges and corals. Agence France pour la Biodiversité. **COMEX**

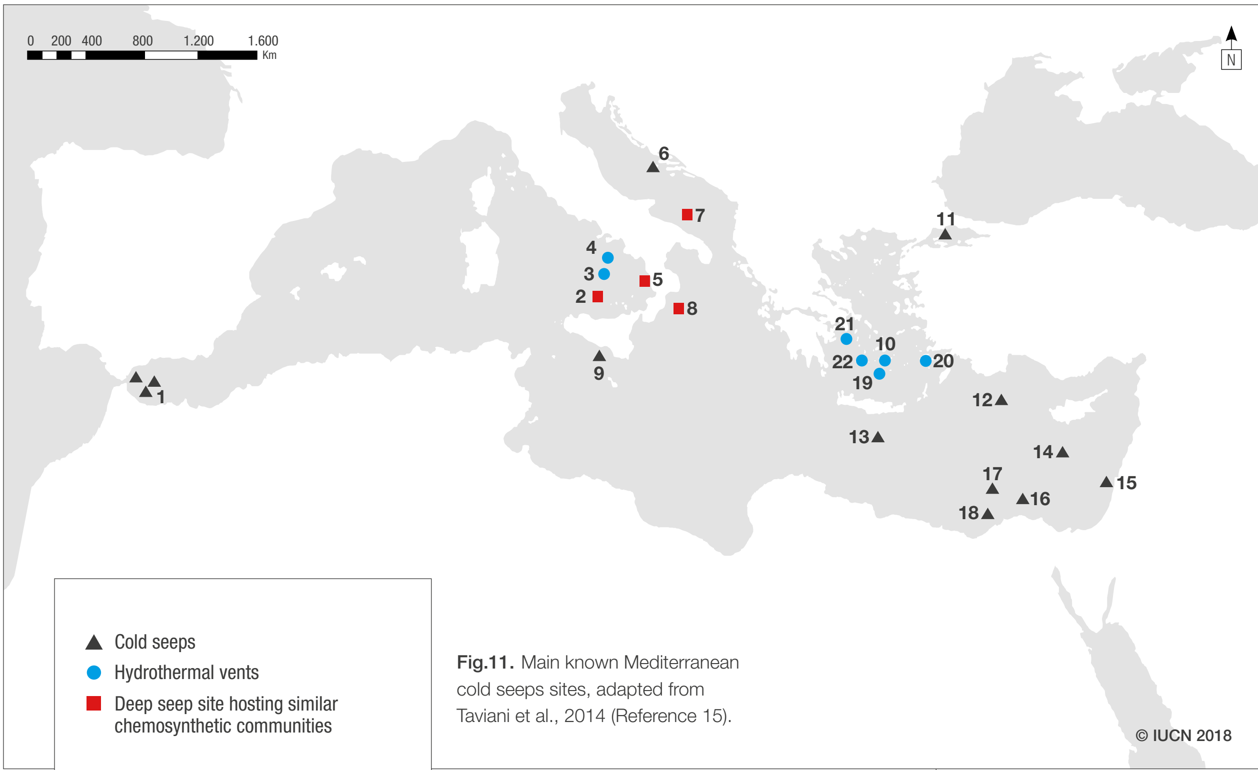


Fig.11. Main known Mediterranean cold seeps sites, adapted from Taviani et al., 2014 (Reference 15).

1. Alboran mud volcanoes
2. Enarete Seamount vents
3. Marsili Seamount vents
4. Palinuro Seamount
5. Paola Basin pockmarks
6. Horseshoe hill pockmarks at Pomo/Jabuka
7. Bari Canyon area
8. Calabrian Arc mud volcanoes and pockmarks
9. Gela Basin pockmark field
10. Kolumbo and Santorini craters
11. Marmara submarine deep fault system
12. Anaximander mud volcano field
13. Olimpi mud volcano field
14. Eratosthenes Seamount
15. Israel continental margin

16,17,18. Nile Deep Sea Fan cluster

19, 20, 21, 22. Greek hot vents

Illustration adapted by IUCN.

Lamellibrachia sp. tube worms at a cold seep.

Pomo/Jabuka Pit (Adriatic Sea), and the Gela Basin (Strait of Sicily, Central Mediterranean [15] **(Fig. 11)**. In the south-Eastern Mediterranean, several seepage areas (seep zones of filtration) have been found in the Nile Deep-Sea fan[114]. The leakage of cold, methane-rich fluids from subsurface reservoirs to the sea floor at these specific sites sustains some of the richest ecosystems on the seabed[115]. In situ observations[116,117] of these living chemosynthetic communities in the Eastern Mediterranean Sea has revealed the presence of aggregations of bivalves, siboglinid tubeworms *Lamellibrachia anaximandri*, large sponges, and endemic fauna along various cold seeps and carbonate crusts at depths of 1,700–2,000 m. Symbiont-bearing invertebrates (Bivalvia, Polychaeta) have also being described[119] off the Egyptian coasts at depths of 500–1,000 m.

Thus, cold seeps appear to host a rich meiofauna and megafauna which are sustained by the symbiotic bacteria that carry out the chemosynthesis. This Mediterranean fauna further includes unusually large specimens of Suberitidae sponges (*Rhizaxinella pyrifera*) and crabs (*Chaceon mediterraneus, Calliax sp.*) as well as some other endemic chemosymbiotic species (e.g. with capacity to host sulfur-oxidizing bacteria) and other associated fauna that are able to form small clusters or spread over large fields in high densities[15]. Cold seeps from the Mediterranean are also characterised by the absence of large size bivalves of the genera *Calyptogena* or *Bathymodiolus* typically associated with similar habitats in other regions of the world. Nonetheless, smaller bivalve taxa from the vent and seep such as deep-sea mussels (*Bathymodiolins*) and vesicomyid clams are found aggregating at some seeps, together

Dense aggregate of live siboglinids and an octopus at cold seep environments, Eratosthenes Seamount, Levantine Basin; Pictures taken by the ROV Hercules during the 2010 Field Season of E/V Nautilus. **Ocean Exploration Trust / Institute for Exploration**

A chaceon crab below methane hydrate and on top of large mussels. Image taken from **NOAA OKEANOS explorer program**

with lucinids, thyasirids and solemyids[15,117], while the callianassid ghost shrimp *Calliax* seems almost ubiquitous in all Mediterranean cold seeps.

Different geological features are formed at cold seep sites. Bubbles escaping from the seabed, pockmarks, mud volcanoes, brine pools and precipitates of gas hydrates are present in different deep Mediterranean regions.

Pockmarks

Pockmarks are common features on continental margins worldwide and have also been reported at bathyal depths in the Mediterranean Sea[119,120]. Pockmarks are topographic depressions that occur in areas of fluid discharge and they need fine-grained sediments to form and retain their structure over longer periods of time. They originate by the expulsion of gas from over-pressured gas pockets or by the continuous hydrocarbon fluid discharge which prevents sediment deposition around the seep **(Fig.12)**. They vary in size from 1 m to more than a few hundred meters across with depths of less than 1 to more than 10 m.

Mediterranean pockmarks have been reported from the Catalan margin, Aegean, Levantine and Ioanian seas[119,121]. Pockmark fields may be important hotspots of microbial biodiversity regulated by the intensity of the methane flux which sustains rich chemosymbiotic life[15]. As described above, these invertebrate organisms are "thiotrophic" (i.e., with a capacity to host sulphur-oxidizing bacteria) and can be found as aggregations of lucinid bibalves (e.g. *Lucinoma kazani, Myrtea amorpha*), vesicomyid bibalves (*Isorropodon perplexum*), and sibloginids or beard worms (*Lamellibrachia*), together with callianassid ghost shrimps (*Calliax*) burrowing into reduced sediment. Moreover, several provinces of the Nile deep-sea fan have been observed with the formation of pockmarks in the central area along mid- and lower slopes[122,216]. Polychaetes (*Sabellidae*) associated with gastropods (*Lurifax vitreus*) and cnidarians (*Zoantharia*) have been shown to be the dominant macrofauna taxa. Here, macrofauna communities reaching hundreds to thousands of individuals have been documented on these pockmarks, with variable diversity and distinct associated dominant taxa[123].

Pockmarks in the Western Mediterranean, ranging in width from < 10 to 700 m and with reliefs of 2 to 55 m, occurring in the Ibiza Channel and off the Balearic Promontory, have been documented by ROV[124,125]. In the same area, have identified at ca. 500 m of depth, a non-chemosymbiotic fauna represented by sessile cnidarians, including bamboo corals (*Isidella elongata*) and seapens (*Funiculina quadrangularis*), as well as fishes and crustaceans of commercial interest (*Merluccius merluccius, Micromesistius poutassou, Eledone moschata, Nephrops norvegicus* and *Palinurus mauritanicus*).

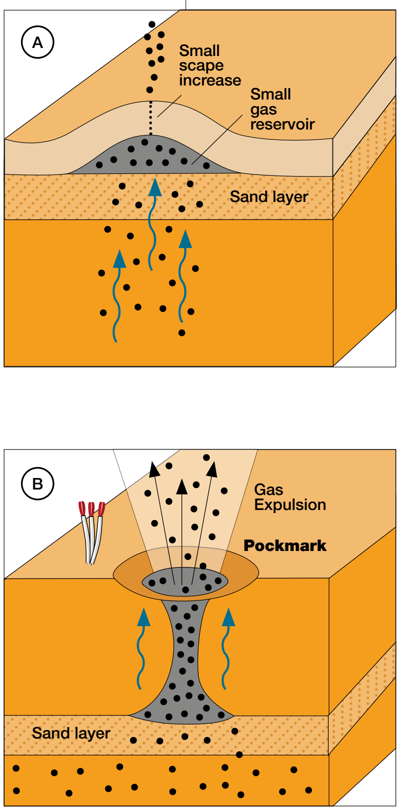
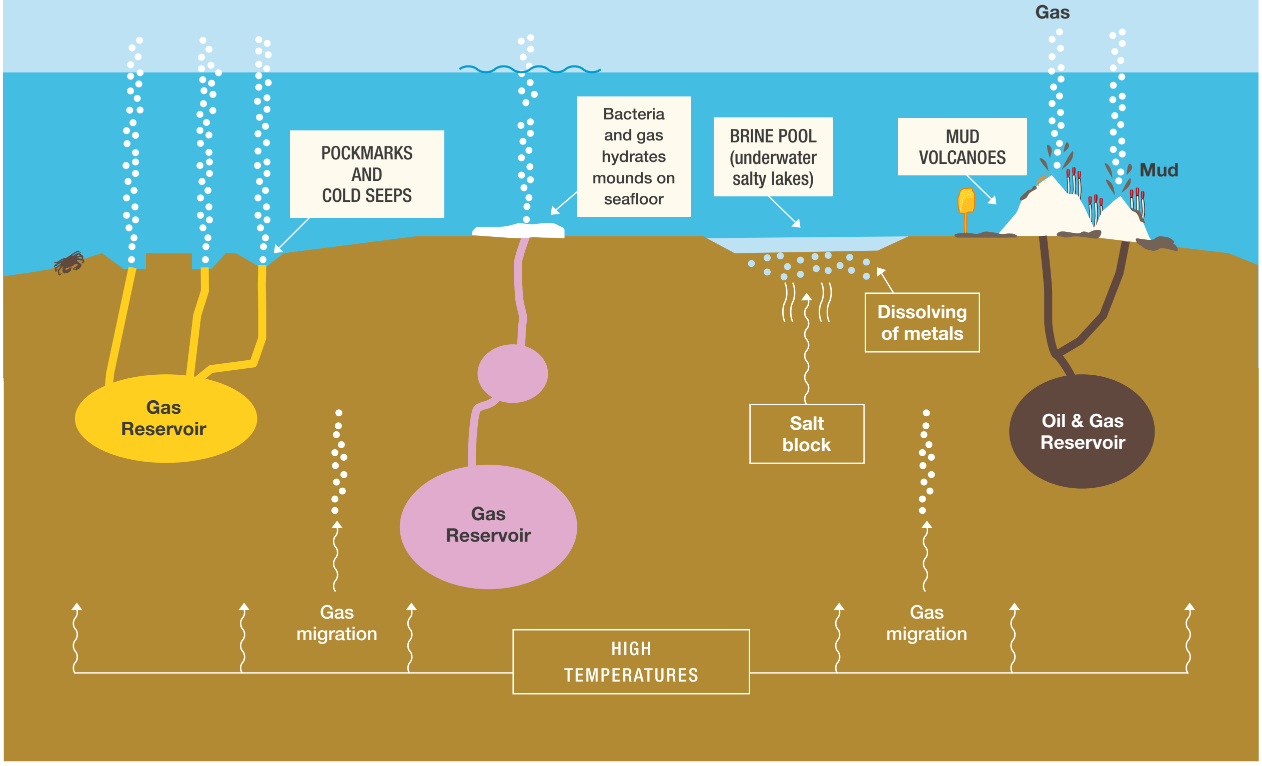


Fig. 12. Envisioned process of pockmark formation. **A)** Gas generated at depth migrates upward and is trapped beneath fine-grained sediment layers, escaping slowly by cracks to the water. **B)** The strong gas pressure enlarge the cracks and culminates into a burst of escaping gas producing the pockmark.

Fig.13. Schematic representation showing typical gas seep related processes. Adapted from *Mienert et al., 2007. The deep-sea frontier*. **European Communities, 2007.**



Mud volcanoes

Mud volcanoes are points of slow (seepage) or vigorous (vent) emissions onto the seafloor of fluids often enriched in hydrocarbons and other compounds that might be linked to natural gas or oil reservoirs. The escape of gas and fluids associated with mud around these sites creates the 3-D bottom volcano structures that enhance the spatial heterogeneity and potentially influence the functioning of the surrounding benthic ecosystems *(Fig.13)*.

Mud volcanoes are abundant in the Mediterranean Sea, particularly in its Eastern basin. They occur in two geodynamic settings: (1) along the Africa-Eurasia subduction zone, particularly in the central and Eastern Mediterranean basins and its Western most boundary, the Gulf of Cádiz; (2) along the continental margins that border Africa from Eastern Tunisia to the Levantine coasts, particularly off Egypt in the Nile deep-sea fan[119]. Here, mud volcanoes are related to the thick sedimentary cone built by the river Nile. Locally, mud volcanoes have also been found in some areas of the Western Mediterranean[126] (e.g., Alboran Sea, south-Eastern Tyrrhenian margin of Calabria).

A recent investigation conducted in the Sicily Channel reveals that mud volcanoes are hotspots for exclusive meiobenthic species. According to these surveys, the most abundant families in mud volcanoes belong to nematodes (Comesomatidae, Chromadoridae, Desmodoridae, Xyalidae) followed by copepods[127]. However, in mud volcanoes located in the Western Alboran Basin (e.g. Dhaka, Al Idrisi and Maya mud volcanoes) off Moroccan coasts, cold-water corals can also appear[128]. Other non-chemosymbiotic fauna is also recorded to be abundant around seeps in the Eastern Mediterranean, and includes unusually large specimens of the Suberitidae sponge *Rhizaxinella pyrifera* (found on Napoli mud volcano), decapod crustaceans (galatheids, *Chaceon* crabs) and large abundances of *Echinus* sea urchin species, possibly influenced by the seepage environment[117].

As in other cold seep structures, the characteristic chemosymbiotic fauna has also been documented on the summit of these mud volcanos, including large siboglinid tubeworm aggregations and infaunal communities dominated by thiotropic small bivalves (Solemyidae, Mytilidae, Lucinidae, Thyasiridae, Vesicomyidae)[117].

In sedimentary basins, seepage may be associated with highly concentrated brines and might appear as "lakes" or "pools" in the seabed due to the high density of the brine (up to 4 times the salinity of seawater) and the slow interaction with the sea above. The **brine pools** often contain high concentrations of methane. Within the basin, seafloor brines have been reported mainly along the Mediterranean

Tubeworm aggregations of *Lamellibrachia* sp. Frequently associated with these chemosynthetic communities are filter-feeding species such as hydroids, coral, sponges and many species that live on them. **NOAA Okeanos Explorer Program 2012**

Ridge, though a few sites in the Nile deep-sea fan have also been documented [129,130].

Mud volcano sites containing brine lakes and pools (with hypersaline fluids) are very rare, only known so far in the Gulf of Mexico and the Eastern Mediterranean. In the Mediterranean, these rare features have been identified only at the Napoli and Milano mud volcanoes, Urania and the Maidstone mud volcanoes. The Anaximander seamounts (Eastern Mediterranean) off the coasts of Turkey are also an important area for active mud volcanism -Amsterdam, Kazan and Kula mud volcanoes[131]. Two active mud volcanoes (i.e. sites of gas seepage and mud extrusion) have also been found in the Western province of the Nile deep-sea fan off north-western Egypt. Here, the active Cheops and Chephren mud volcanoes are filled with methane-rich muddy brines with temperatures reaching 42 °C and 57 °C respectively[132]. Abundant polychaete populations were also reported around the Napoli brine lakes and on the active sites on Amsterdam mud volcano consistent with the high microbial productivity of these environments fuelled by methane fluxes[115].

Chemosymbiotic communities are usually found associated with mud volcano fields and dominated, as usual, by cold-seep thiotrophic bivalves and siboglinid polychaetes[117]. These habitats might also be important for marine mammals since they have a rich and diverse feeding ecology. Indeed, the gouge marks that were found on some mud volcanoes have been suggested to have been made by Cuvier's beaked whales, *Ziphius cavirostris* while on foraging dives[133].

Cold seeps are often found above deposits of gas hydrates. These are ice-like substances that form in deep-sea sediments, usually by water molecules encaging methane (CH_4). Gas hydrates have been sampled at the Amsterdam and Kazan mud volcanoes (located in the Eastern Mediterranean Sea) where high methane levels have been recorded above the seafloor[134].

Cuvier's beaked whales, *Ziphius cavirostris*. **Izanbar / Dreamstime.com**

Mediterranean hydrothermal vents

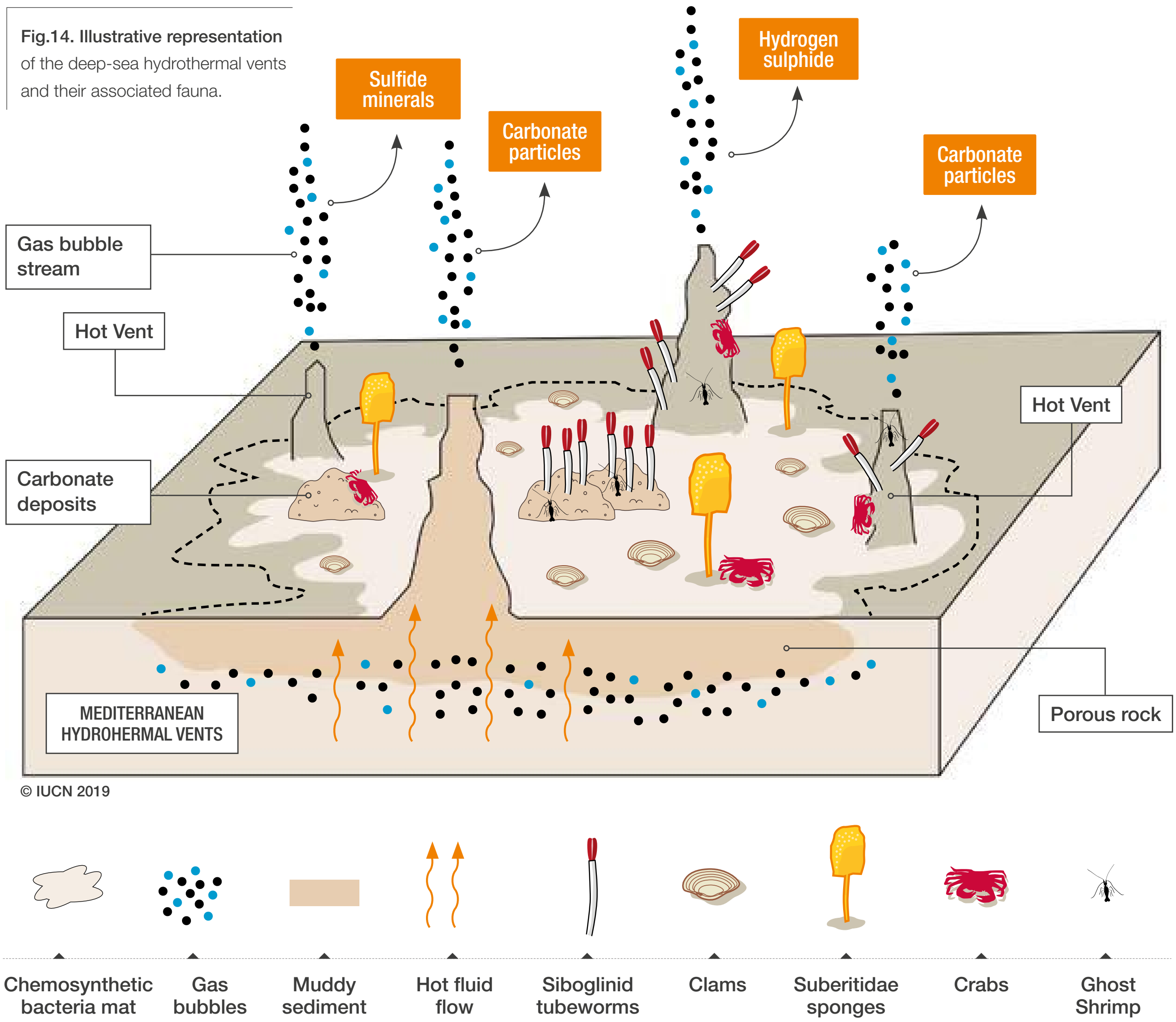
Deep-sea hydrothermal vents occur in volcanically active areas where seawater circulates through the seafloor and transforms into an anoxic and sulfidic heated fluid, which is often enriched in metals, silica, CO_2, hydrogen or methane. The hottest vents can reach temperatures of up to 400 °C, although fluids also frequently diffuse out of the seafloor after mixing with the cold seawater. Here, specialized chemolithoautotrophic bacteria use the reduced form of sulphur, hydrogen or iron to convert inorganic carbon and methane into organic compounds, ultimately providing food and energy to a range of species.

Despite volcanic activity being widespread in the Mediterranean Sea, deep-sea hydrothermal settings have been poorly explored and most of the vents of the Mediterranean Sea are distributed at shallow depths (less than 100 m). At present, the deepest vent fields are known to occur at 300-500 m depth, but there are likely to be much deeper ones[15]. Furthermore, massive sulphide deposits of hydrothermal origin, consisting of pyrite, hematite, sphalerite, galena and baryte have been recovered from the Aeolian Island Arc at 400–680 m at the Palinuro seamount[135,136]. Manganese crusts of hydrothermal origin have also been recovered from the Palinuro and Enarete Seamounts[137] in the Tyrrhenian Sea and from the Santorini hydrothermal field[138].

Hydrothermal vents are oases of life with surprisingly diverse ecosystems. Specialized species have adapted to life in these extreme environments and developed amazing endosymbiotic relationships with the chemosynthetic bacteria. Many of the species described to date in the Mediterranean are endemic to these habitats and cold seeps.

Deep-sea hydrothermalism in the Mediterranean has been documented in the Marsili Seamount (Tyrrhenian Basin) at about 450 m of depth[139]. There, for the first time, a dual symbiosis of beard worms (Siboglinidae) associated to the hydrothermal vents has been reported[140]. These systems very likely show significant differences with respect to the typical high-temperature deep-sea vents known from Atlantic and Pacific mid-ocean ridges

Fig.14. Illustrative representation of the deep-sea hydrothermal vents and their associated fauna.



and are likely closer to back-arc or volcanic hydrothermal systems such as those of the Western Pacific. Such differences are related to the nature and intensity of the venting (i.e. the slow escape of a liquid or gas through porous material or small orifices *Fig.15*), the depth of the vents (much shallower in the Mediterranean Sea than on most mid-ocean ridge vent fields and to the characteristics of its associated fauna.

Like cold seeps, hydrothermal vents are chemosynthetic habitats and host unique ecosystems that depend on chemical energy sources emitted from the seafloor rather than on photosynthesis *(Fig.14)*. Their unique functioning and peculiar fauna are particularly interesting from the ecological, biological, and geological (evolutionary) points of view, but are still largely unexplored in the deep Mediterranean Sea. The described vent fauna assemblages are currently limited to Siboglinidae tubeworm clusters and bacterial mats surrounding hot vents along the flank of the Palinuro seamount [15, 141]. Siboglinid tubeworms are typical species that can be found in both vent and seep environments. For example, the tubeworm species from the Palinuro vents, *Lamellibrachia anaximandri*, is also found on the methane seeps of the Nile deep-sea fan and Anaximander mound[142]. This is, in itself, a rare occurrence of a species occupying both habitats, even though related species at genus levels are commonly found in a variety of sulfidic habitats including whale carcasses. Apart from this species, the reported organisms described from vents are microbes forming thick mats on the bottom of submarine caldera from the Kolumbo volcano and associated with tubeworm bushes at the Palinuro and Marsili seamounts.

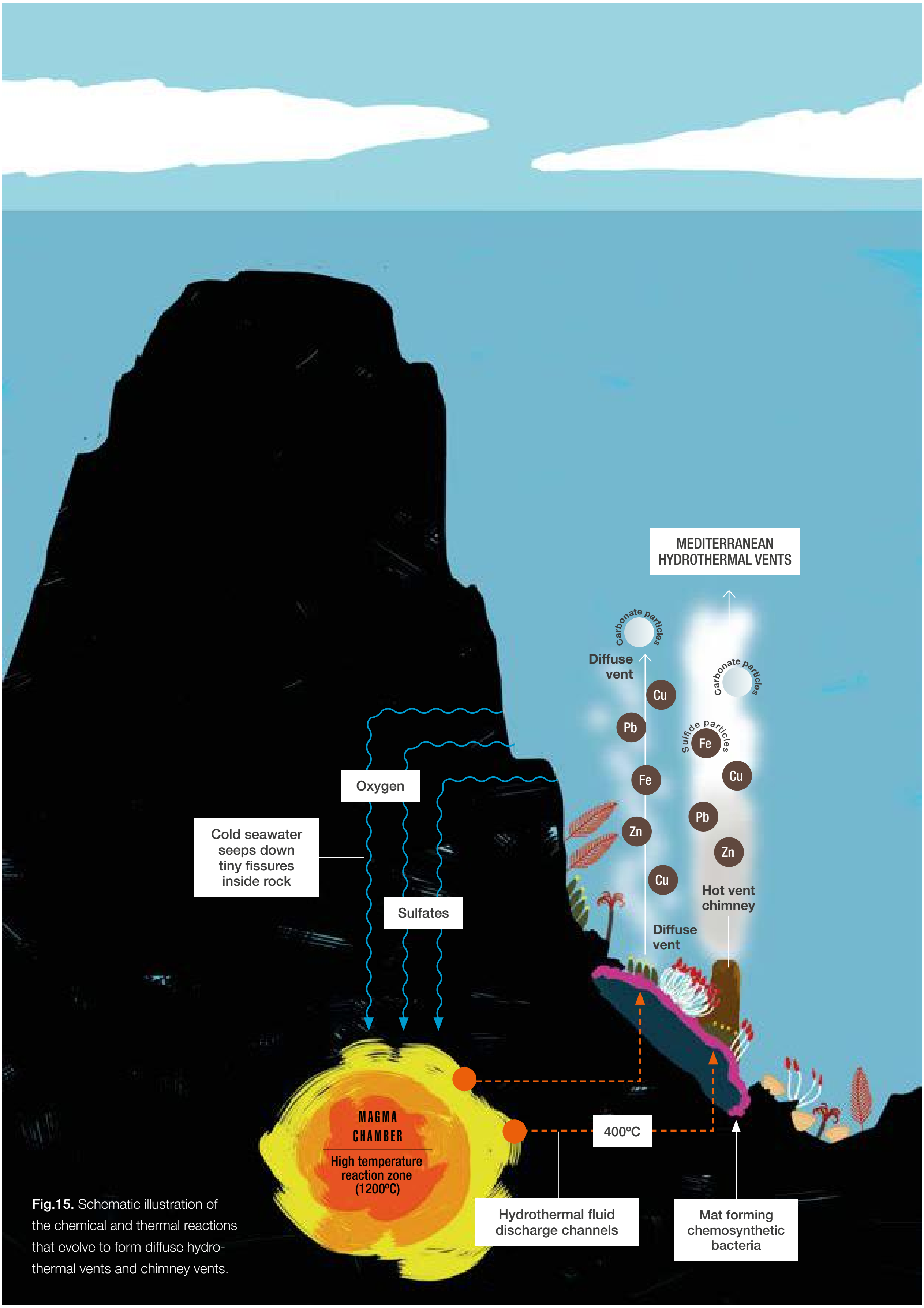


Fig.15. Schematic illustration of the chemical and thermal reactions that evolve to form diffuse hydrothermal vents and chimney vents.

Special substrates in the mediterranean

Special types of reducing habitats in the deep-sea which share many functional traits with cold seeps are:

- **a)** Whale fall (carcasses).
- **b)** Sunken wood.
- **c)** Shipwrecks.
- **d)** Other unusual organic substrates.

Such habitats in the ocean have been reported and their biological relevance highlighted[143]. They do occur in the Mediterranean but little about them is known thus far[14], apart from the occurrences of the chemosymbiotic fauna specialists such as the tubeworm *sibloginid Lamellibrachia*[144].

Mediterranean abyssal plain

The deep-sea basin of the Mediterranean Sea has been defined as either bathyal or abyssal, on the basis of the different depth limits and conditions of the two systems. The bathyal zone is generally described as lying between 200 and 2,000 m below the surface extending down from the edge of the continental shelf to the depth at which the water temperature is 4 °C. Given that the upper boundary between the abyssal zone and the overlying bathyal zone can vary with the environmental conditions, the Tyrrhenian Plain in the Mediterranean has been defined as bathyal, even though the deepest part of the Basin exceeds 3,600 m depth. The abyssal zone, usually below 2,000m, is delimited by the 2,600 / 2,700 m isobaths in the Western basin.

These plains cover a large portion of the deep Western Mediterranean Basin with an overall area of about 240,000 km^2, with water temperatures at 4,000 m around 14 °C (rather than 4 °C or colder as in other deep oceanic basins).This entire benthic environment is as warm as the water around many diffuse hydrothermal vents.

The Mediterranean Sea also differs from other deep-sea ecosystems in the species composition on the abyssal plain, notably the absence of the deep-water grenadier fish *Coryphaenoides armatus* and the amphipod *Eurythenes gryllus* and the presence of scavenging crustacean *Acanthephyra eximia*. Typical deep-water faunal groups, such as echinoderms, glass sponges, and macroscopic foraminifera (Xenophyophora), are also scarce or entirely absent; while other groups (i.e., fishes, decapod crustaceans, mysids, and gastropods) appear much less abundant in the deep abyssal plain of the Mediterranean than in the north-Eastern Atlantic plains.

Deep hypersaline anoxic basins

Deep Hypersaline Anoxic Basins, or **DHABs**, are depressions, valleys, or irregular bowl-shaped features in the seafloor filled with hypersaline, non-oxygenated water more than 2 km below the surface of the ocean. These characteristics make these habitats unique in the world.

Numerous DHABs have been discovered in the Eastern Mediterranean Sea *(Fig.16)*. The six DHABs of the Eastern Mediterranean (L'Atalante, Urania, Bannock, Discovery, Tyro, and La Médée) are located on the Mediterranean Ridge. The Mediterranean DHABs lie at depths ranging from 3,200m to 3,600 m and contain salt brines, the origin of which has been attributed to the dissolution of 5.9- to 5.3-million-

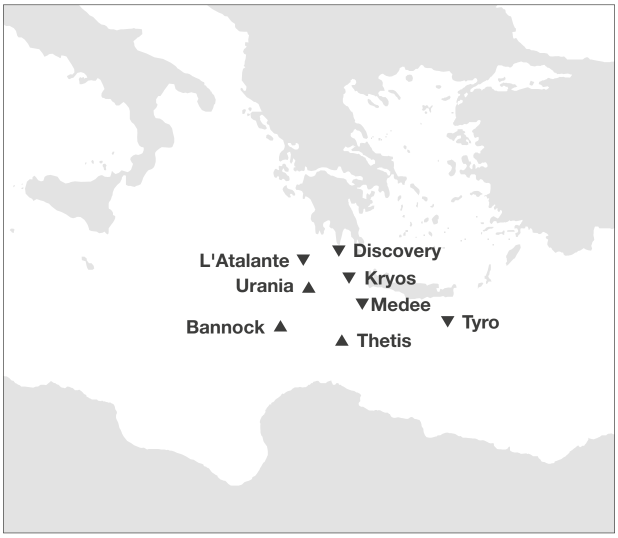


Fig.16. Location of the Deep Hypersaline Anoxic Basins (DHABs) at depths ranging from 3,200m to 3,600 m along the Ridge of the Eastern Mediterranean.

Adapted from *Stoeck et al, 2014. Hindawi Publishing Corporation. Advances in Ecology, Article ID 532687.*

year-old Messinian evaporite minerals[145]. The brines enclosed in these basins are characterized by high salinity and density, a sharp chemocline (i.e., a thin, strong and vertical chemical gradient) and anoxic conditions.

As habitats without dissolved oxygen, DHABs represent some of the most extreme environments where adaptation and evolution of life is unique and of extreme interest for understanding fundamental biological processes of life and potential implications for the use of bioresources. At the same time, their extent is extremely limited and they are particularly fragile environments, as their separation from the surrounding oxygenated deep-sea regions can be easily compromised by any mechanical disturbance that causes mixing.

Different species of bacteria, archaea, and protists have been found living in these environments. For example, studies of prokaryotic life in the Discovery, L'Atalante, Urania, and Bannock DHABs have revealed the presence of novel metabolically active bacterial and archaeal communities[146,147]. Metazoa have been found in the permanently anoxic conditions of the L'Atalante basin[148] along with new faunal species (*Spinoloricus nov. sp., Rugiloricus nov. sp.* and *Pliciloricus nov. sp.*).

Hotspots of biodiversity

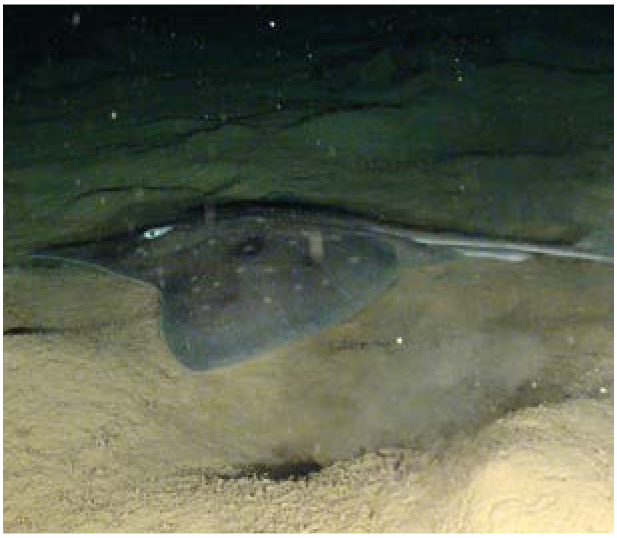
The presence of several peculiar, heterogeneous and diversified habitats and seascapes through the Mediterranean Sea, including submarine canyons, seamounts, and cold seeps, influence the abundance and distribution of deep-sea species. However, a comparative analysis of the deep-sea benthic diversity across different ecosystem types is difficult because of: a) the use of different sampling methodologies; b) different types and amount of data collected; c) the diverse dominance of animal groups in each system. It is not possible to compare values of, for instance, abundance or biomass of meiofauna living in sedimentary environments with megafauna living on hard substrates. Furthermore, research efforts have been not the same in different areas; for example, submarine canyons and seamounts in the Western Mediterranean have been investigated more than those in the Eastern basin.

Today, available studies based from small to large faunal diversity components indicate that deep-sea canyons, for instance, can act as essential habitats for certain species, including both planktonic and benthic species. Moreover, higher sessile diversity have been reported in several deep-sea canyons of the Mediterranean when compared to its adjacent open slopes. This pattern apparently does not hold for smaller sized fauna.

Cold-water corals thrive on different types of seabed (e.g. boulders, gravel, sand). In addition, other deep-water coral forests and sponge fields contribute to the heterogeneity of the deep-sea habitats. Their characterisation and mapping are in progress but it is already evident that these ecosystem engineers provide an important contribution to the overall deep-sea biodiversity by hosting exclusive species or contributing to the diversity of the area [65,88,149]. As an example, during an oceanographic cruise carried out in May-June 2012 and followed by an experimental fishing survey conducted in November 2013 in the Bari Canyon, eighty-five living benthic and bentho-pelagic species were recorded: 29 Porifera, 1 Cnidaria, 2 Mollusca, 11 Annelida, 1 Arthropoda, 19 Bryozoa, 3 Echinodermata, and 19 Chordata. A total of six Mediterranean endemic species were identified, (4 Porifera and 2 Annelida) with 51 newly recorded species for the Bari Canyon and 29 newly recorded species for the Adriatic Sea. Among them included the first ever confirmed record of living specimens of the bryozoan *Crisia tenella longinodata*[150].

In cold seeps and other associated structures, the trophic structure is unique, as primary production from chemoautotrophic bacteria fuels the benthic community with a supplementary and continuous food source not found in heterotrophic deep-sea ecosystems.

The pink spiny lobster, *Palinurus mauritanicus* in the marine canyon of Pruvost, France. **Agence France pour la Biodiversité / COMEX programme**



The Near Threatened Longnosed Skate, *Dipturus oxyrinchus,* observed in the Lebanese sea canyons. **OCEANA Deep Sea Lebanon Project with IUCN & UNEP/MAP-RAC/SPA**

An overall map of the biodiversity found in different deep-sea environments and the identifications of hotspots (as KBA, Key Biodiversity Areas) is still needed. Information to achieve this has been compiled by different initiatives such as the process for identifying Ecologically or Biologically Significant Marine Areas (EBSAs) in need of protection in the Mediterranean *(Fig.20)*, along with other regional and subregional projects.

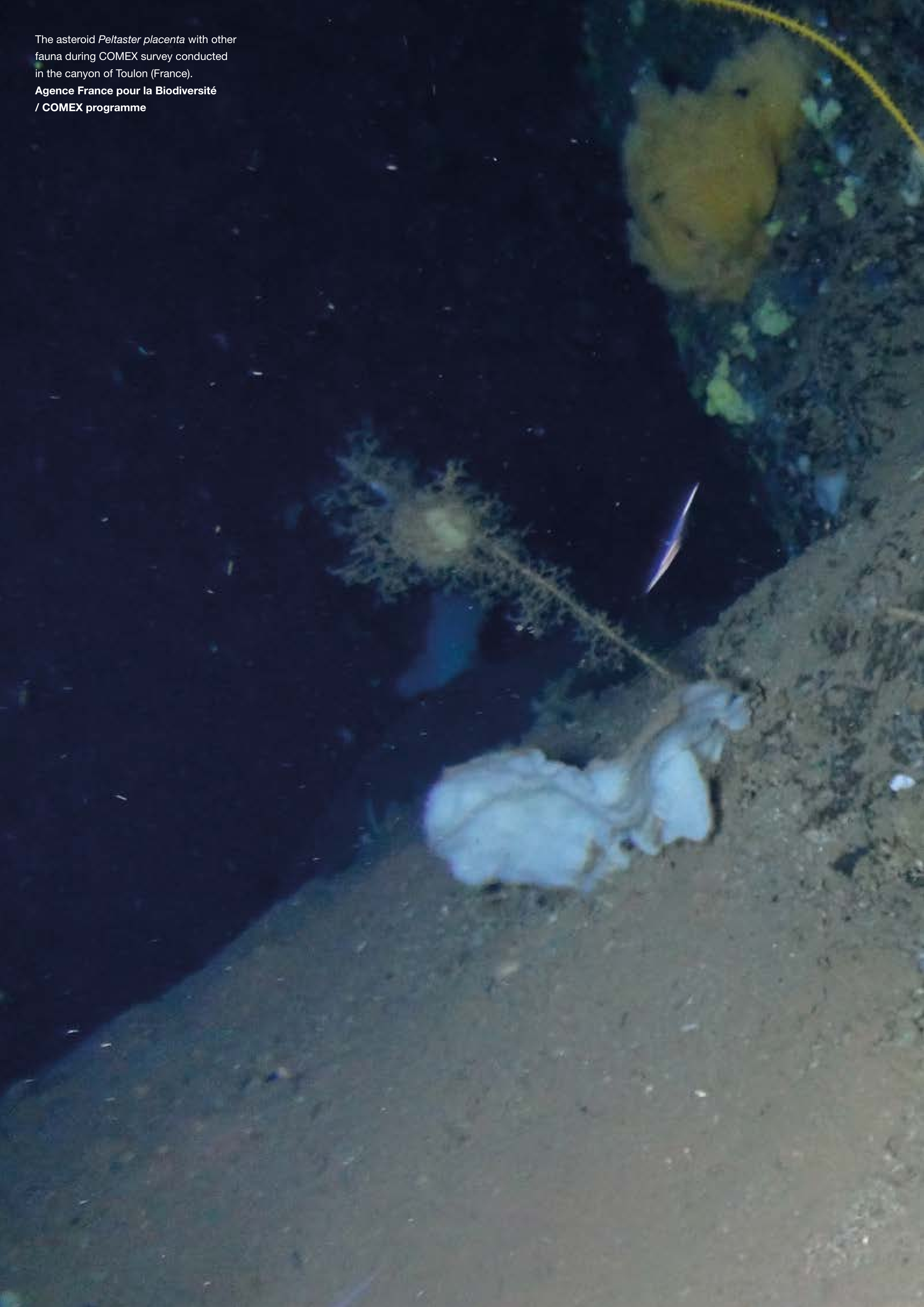
Conservation status of deep-sea species and main threats

Data on the conservation status of many marine species in the Mediterranean Sea is quite limited, and, in most cases, we do not know which deep-sea species are endangered. This is due, in part, to far fewer investigations conducted on offshore and deep-water species than on species found in shallower environments.

Deep-sea sharks, rays, and chimaeras are extremely vulnerable to overfishing and to being captured as bycatch. Indeed, many of them are considered endangered or under threat of disappearing in Mediterranean basin and possibly even of global extinction[151]. The Maltese ray (*Leucoraja melitensis*), for example, an endemic species most commonly found at depths of 400-800 m, is currently classified as "Critically Endangered". Equally, some Mediterranean angel sharks (*Squatina spp.*) are currently listed as critically endangered or endangered at a global level, and at least one, the sawback angelshark, *Squatina aculeata* is considered disappeared from large areas of the Mediterranean.

The study of sharks and rays in the deep-sea appears particularly challenging and is compounded by the fact that very little is known about their ecology and population status[152]. Even less is known about the potential impact of human activities. Many of these slow-growing, long-living species are impacted by the increase of shark fisheries and by the harmful fishing practices that have become more widespread over the past few decades in the Mediterranean. Larger and more powerful vessels and improved technology (more accurate navigation and fish detection equipment) represent a risk for shark and ray populations, as such technological advances have made it possible to fish in deeper waters. For example, the spiny dogfish *Squalus acanthias*, is a small demersal shark that swims towards deeper waters as it grows. It is impacted by gillnets, trammel nets and offshore longline fishing because it gets caught as bycatch or as a secondary target species. This shark is presently listed as "Endangered" in the Mediterranean[153]. Moreover, given the lack of management mitigation measures to reduce the strain caused by fishing bycatch, other deep-sea shark species, such as the rare Kitefin shark (*Dalatias licha*) have been recently listed as "Vulnerable".

The conservation status of cetaceans in the Mediterranean Seas is a source of concern. Many cetacean species live in waters on the continental shelf/slope or in the open sea, beyond the continental slope [154,155]. Species such as Risso's dolphin (*Grampus griseus*), pilot whale (*Globicephala melas*), and sperm whale (*Physeter macrocephalus*) occur mainly around the shelf edge preferable on highly productive areas with nutrient upwellings. This productivity leads to high densities of phyto and zooplankton and thus prey fish species. Submarine canyons and seamounts have also been reported to be important hotspots for Mediterranean cetaceans[96]. Species such as the fin whale (*Balaenoptera physalus*), striped dolphin, and Cuvier's beaked whale prefer the deep waters off the continental shelf where there is also high productivity of deep-sea squids such as in the central Tyrrhenian Sea, Sardinian Sea and the Spanish continental shelf. Other cetacean species occur on both coastal and pelagic waters.



The asteroid *Peltaster placenta* with other fauna during COMEX survey conducted in the canyon of Toulon (France).
Agence France pour la Biodiversité / COMEX programme

The preference of these cetaceans for deep-sea waters off the continental shelf underscores the crucial role deep-sea ecosystems play in the ecology of Mediterranean marine mammals; while the impacts and main threats related to habitat loss and degradation (including climate change), overexploitation (food resource depletion), human disturbance (e.g. ship and boat collisions), entanglement of animals in fishing gear (bycatch), and different types of marine pollution make the need to provide recommendations and actions for conservation and management in the Mediterranean urgent.

The Mediterranean sperm whale subpopulation is listed as Endangered in IUCN Red list (2019) as it is estimated to have a population of less than 2,500 mature individuals in continuous decline. While the fin whale, with a population probably exceeding no more than 5,000 individuals, is listed as "Vulnerable" in the region. Common deep water cetacean species like Risso's dolphin (*Grampus griseus*), the long-finned pilot whale (*Globicephala melas*), and Cuvier's beaked whales (*Ziphius cavirostris*), are listed as "Data Deficient" due to the lack of information regarding their population and trends in the Mediterranean[156].

The Mediterranean region also hosts a variety of deep-sea anthozoan species. The bamboo coral (*Isidella elongata*) found from 150 m to bathyal depths, is almost exclusively restricted to the Mediterranean Sea. The species was listed as "Critically Endangered" on the IUCN Red list but no specific management measures are yet in place to protect its declining population[157]. Other cnidarians species such as the cold-water corals *Madrepora oculata* and *Lophelia pertusa*, black corals (e.g. *Leiopathes glaberrima*) or red coral (*Corallium rubrum*), whose populations can be found as deep as 1000m, are considered "Endangered" or "Near Threatened" on the IUCN Mediterranean Red list and thus require further, appropriate measures to ensure the species are brought back into a good environmental status[158].

Despite their important role in ecosystem functioning, deep-sea coral frameworks are not sufficiently protected by the existing Mediterranean MPA network, which is weak on its coverage of deep-sea benthic habitats[72,158,159].

To date, the status of other habitat-forming species such as sponges, bryozoans, and bivalves has not been assessed, though it is likely that the information to do so is insufficient. Nevertheless, bottom fishing has been shown to deeply affect their populations.

In order to improve the protection of deep-sea biodiversity, it is crucial to consider the deep-sea environment and its key habitats as well as the species within existing regulations and policies. In this sense, it is essential to further expand the current lists of threatened species on both regional and national level regulations so as to include them (e.g. anthozoans, sponges, molluscs). In parallel, the establishment of a coherent and comprehensive network of MPAs by identifying potential new and open sea MPAs or sites where other spatial management measures which include deep-sea benthic habitats should be implemented would also contribute to deep-sea conservation. From a fisheries perspective, collaboration between regional and national bodies is also important in order to eliminate significant adverse impacts of deep-sea fishing through effective management measures.

Services from the deep

Deep-sea habitats commonly receive much less attention than coastal habitats, as they are inhospitable to humans, remote and present numerous challenges associated with their study. As a result, the analysis of what deep-sea ecosystem functions and services provide to humans and its importance has been largely neglected. There is an urgent need to understand the ecosystem functioning and services of the deep-sea ecosystems in order to be able to establish a management plan to use and preserve the deep-sea resources[160]; these ecosystems are already under great pressure from fishing, hydrocarbon extraction, and mining—which are all expanding.

Classification of services provided by deep-sea employed the Millennium Ecosystem Assessment includes supporting, provisioning, regulating, and cultural services. Supporting services are those that are necessary to produce other ecosystem services; provisioning services are products used by humans that are obtained from ecosystems; regulating services are the benefits obtained from the regulation of ecosystem processes; and cultural services are the non-material benefits people obtain from habitats and ecosystems. Although this approach has been criticized as reducing the focus on mechanisms underpinning the system, the ecosystem function and services assessment framework gives decision makers bases to identify management options.

Among supporting and regulating services, it is important to mention the role of deep-sea ecosystems in carbon storage. The ocean absorbs almost a quarter of our annual emissions of CO_2, and much more in terms of absorbing excess heat resulting from the greenhouse effect[161]. The storage of CO_2 also influences climate and many deep-sea functions and services. Similarly, the sequestration of methane, another powerful greenhouse gas, into carbonates is largely driven by seafloor microbial communities interacting with specialized fauna.

The deep-sea also represents an area where waste products are stored and detoxified through biotic and abiotic processes. For example, persistent organic pollutants, macro- and micro-plastics, sewage, and oil can be removed through bioremediation, facilitated by bioturbation (the process regulating the decomposition and/or sequestration of waste by biogenic mixing of sediments performed by organisms).

Among the provisioning services, fish stocks are one of the most tangible ecosystem services provided by the deep-sea. Currently at least 27 deep-sea stocks are under the total allowable catch (TAC) regulation in European waters. However, the Mediterranean fisheries are mostly managed by input controls[2] rather than scientific based output controls, that is, direct limits based on the amount of fish coming out of the fishery. Furthermore, the mean depth of fishing activities is increasing at a rate of ca 62.5 m per decade, from 200 m down to 1,000 m. Fisheries for some deep-sea fish stocks have also collapsed—the result of heavy fishing pressure on species whose slow life histories do not make them well-suited to intensive industrialised fishing activity[162,217].

Other crucial provisioning services for human activities are represented by oil and gas reserves stored in the deep-seabed. In recent years, we have witnessed the development of new technology for offshore drilling and large reserves of hydrocarbons have been found. As a result, the oil and gas industry has moved from land to deep waters.

Besides oil and gas, deep-sea beds are also characterized by reserves of metals including Rare Earth elements. Mining is not limited to resources such as metals but also supplies "ornamental" raw materials, such as the exploitation of some species for jewellery (e.g., red coral and black corals).
The deep-sea can also be a source of genetic resources. The deep-sea is a particularly interesting target for bio-discovery because the specific physical conditions driving unique physiological and cellular adaptations of the fauna.

Finally, deep-sea ecosystems also offer a variety of aesthetic and inspirational services, including literature, entertainment, ethical considerations, tourism, and spiritual wealth and well-being. Some of the main cultural services are important for education and science. As can been seen, deep-sea ecosystems play a tremendously important role, as they not only provide a number of necessary services to support and sustain *our* current way of life and overall human wellbeing but also to support and sustain the entire functioning of the oceans. Moreover, the importance of intangible values of deep-sea ecosystems makes it extremely difficult to fully assess their global value[163].

[2] http://www.fao.org/docrep/005/y3427e/y3427e06.htm

03

A mediterranean with a growing human presence

The increasing anthropogenic inputs of materials and contaminants into the ocean are extending the direct human impacts at a global scale and even reaching down into the deep-sea. As previously mentioned, the deep-sea is characterised by the presence of many slow growing species, which makes them very vulnerable to overexploitation and disturbance.

A paradigmatic example of human impact in the deep ocean is represented by deep-sea fisheries and the evident resource depletion and environmental damage they cause. Wide unregulated fishing in the deep-sea has led to the loss of vulnerable marine habitats on the seafloor, such as cold-water coral frameworks, transforming them into fields of coral rubble.

Dumping of sewage, mining waste, dredge spoil, pharmaceuticals and radioactive waste in the deep-sea, although reduced over the past years (apart from illegal dumping), still represents a major threat to deep-sea Mediterranean ecosystems. Moreover, chemical contaminants (organic pollutants, heavy metals, radionuclides, pesticides, herbicides and pharmaceuticals) accumulate in the deep Mediterranean. Their chemical components are taken up by deep-sea organisms and biomagnified (i.e., increasing the concentration of contaminants per unit of biomass at the higher trophic levels).

The deep ocean was historically a repository for litter from shipping, waste, and dumping. This is still present and estimated to be in the order of > 636,000 tonnes per year of litter discarded into the ocean from shipping, including illegal dumping. Plastic debris is very frequently observed in the deep-sea. Recent evidence indicates that the deep-sea is the major sink for microplastics and microplastic fibres[164,165], and this is even more evident in

The increasing anthropogenic inputs of materials and contaminants into the ocean are extending the direct human impacts at a global scale and even reaching down into the deep-sea. Today, billions of litter items float above or cover the sea bottom in the Mediterranean Sea, of which 70-80% is estimated to be plastic waste as well as lost and dumped fishing gear.

JoyfulCrete / Pixabay

regions where there are submarine canyons. In the MedSEASCAN campaign conducted from the French coastline to the coast of Monaco (2008-2010) countless bits of lost fishing gear could be observed in every canyon of the Ligurian Sea and in five canyons of the Gulf of Lions. Microplastics have severe physical impacts on marine organisms and are associated with the transport of other pollutants. Chronic inputs of litter from terrestrial sources are another major issue, particularly for plastics and persistent pollutants. An illustrative example of this is the plastic bag particles which have been found in the stomachs of several sharks and rays[166].

Moreover, maritime accidents, such as industrial accidents from oil platforms and the sinking of oil tankers, could release vast amounts of hydrocarbons to deep waters, impacting the water column and the deep benthos communities. Oil tankers are not the only vessels that contaminate the sea with petroleum hydrocarbons. The increasing of cargo and passenger vessels, fishing boats, leisure craft,and naval vessels also discharge oily waste, adding more tons of oil into the sea each year *(Fig.22)*.

It is clear that the deep-sea has the potential to be an important area for maritime growth or "blue growth" on both a global and Mediterranean scale. Overall, it has been estimated that the annual income coming from deep resources could reach €10 billion by 2030, supplying as much as 10 % of the world's minerals[167]. Yet, the actual estimates of the economic potential of these activities in the deep-sea are still largely unknown. Such activities, however, might have a huge impact on the marine environment and the costs for deep-sea habitat restoration will be orders of magnitude higher than in terrestrial systems or in shallow waters. There is, therefore, a need to ensure that there is sufficient technology to minimize the impacts and to recover degraded/exploited systems in order to guarantee the sustainability of these activities in the future.

Main sources of direct impacts

In recent decades, the number of commercial vessels sailing in the Mediterranean has increased dramatically, and the number of tourists, estimated at more than 100 million per year is expected to double in the next few years. As a result, it is reasonable to suppose that contamination, sewage, and litter input from vessels and the coast will increase as well.

Marine litter and waste

Three billion items of litter float above or cover the sea bottom in the Mediterranean Sea, of which 70-80% is plastic waste (CIESM, 2014). Marine litter is a major issue in the Mediterranean deep-sea, as demonstrated by different surveys of seabed debris on the continental shelf, slope, and bathyal plain[168]. Some reports highlight the presence of accumulation zones related to the proximity to large cities, areas of high sedimentation rates, and topographic features such as canyons or depressions that may act as a channel for the passage of marine debris into the deep-sea and current gyres. Due to their ubiquitous use and poor degradability, most studies show that plastic items account for most of the debris, sometimes as much as 90% or more. Over 92% of all plastic items found at sea are microplastics (items smaller than 5 mm) and the Mediterranean is nowadays considered one of the most impacted regions of the world[169].

A survey of seabed litter in the Mediterranean at depths ranging from 194m to 4,614m showed that the most common litter items were paint chips (44%) and plastics (36%), mostly originating from shipping[170].

Another example[171] provided values where litter density is slightly higher in deep-sea basins (1.55 ± 0.57 kg per hectare) compared to continental slopes (1.36 ± 0.34 kg per hectare) and submarine canyons (0.71 ± 0.25 kg per hectare). The highest value was found south of Palma de Mallorca (Western Mediterranean) with a mean (± SE) of 4.0 ± 1.8 kg of litter ha^{-1}. Sites located in deep basins and on continental slopes are dominated by clinker, the residue of burnt coal. In the Mediterranean Sea, clinker occurrence on the deep-seafloor has been shown to coincide with shipping routes[164].

In addition, there are more than 30 known wrecks that could contain toxic or radioactive waste[172], but no studies are available on their potential effects on Mediterranean deep-sea ecosystems or on the ocean in general. During World War II, numerous structures for the transport of missiles and mines were sunken in the Ligurian Sea and a number of unexploded mines are believed to still be present in the deep. From World War I to the military operations of the Kosovo war, munitions and explosives have been discharged in the southern Adriatic and northern Ionian Seas, and their dumping in open waters is well known to cause seafloor contamination[173]. The majority of these dump sites are situated on the continental slope, although there has been significant dumping in the deep ocean (e.g. Southern Adriatic Sea as result of the Balkan war) and other unknown sites. Today, there are no declared sites for radioactive waste disposal in the deep Mediterranean, but the presence of a number of sunken vessels carrying unknown materials raise the question of whether radioactive wastes are currently present in the deep.

With regards to deep-sea pollution, a well-known case is represented by bauxite red mud waste in the Marseilles area[174]. From 1967 to 2015, the aluminium plants in this area had been discharging the mineral residue, which results from the alkaline processing of bauxite, into the submarine Cassidaigne canyon through pipes situated at 320–330 m of depth. This has resulted into various degrees of changes to the meiofaunal and macrofaunal communities around this area and the canyon.

Another major threat to benthic and demersal fauna from litter comes from lost or abandoned fishing gear, such as nets and longlines, which continue ghost fishing and can damage fragile ecosystems such as cold-water corals. Recent studies[72,175] highlight the presence of extensive damage on very fragile coral forests caused by fishing activities and by the presence of a large number of lost or abandoned fishing gear in deep areas of the Mediterranean. In these studies, fishing gear was found on virtually every hard ground location investigated and accounted for the high majority of the recorded waste[176]. Given the concentration of fishing vessels and the intensity of fisheries, this problem in the Mediterranean is likely unrivalled worldwide.

Marine debris on Mediterranean Sea. **Yiannis Issaris**

Fishing

The Mediterranean Sea supports important and growing commercial fishing activities, which are gradually extending to deeper waters as shallower resources are becoming or scarce depleted. For example, the commercial fleet in the Catalan Sea has exploited the deep rose shrimp *Aristeus antennatus* for over six decades and is now fishing at depths from 550 to ca. 900 m.

Trawling have myriad impacts on the sea bottom, including stock impoverishment, alterations to the sea-bottom morphology, sediment resuspension and increased bottom-water turbidity, altered organic matter content, and damage and death of benthic biodiversity[177,178]. Due to its lower resilience and higher vulnerability, the impact trawling has on deep-sea benthic ecosystems is more severe and longer-lasting than on shallow-water areas. Trawling along the canyon flanks can increase the sediment load and accumulation rates (in some canyons by 3-4 orders of magnitude since the fishing started in 60s-70s) in the lower sector of the canyon and appears to have severe impacts on hard-bottom fauna[179,180].

Trawling is practised by little more than 8% of the estimated 74,748 fishing vessels in the Mediterranean[162, 217]. Trawling is usually characterized by high and variable discard values: from 15 to 65.5 percent and a mean value of 33%. Economically, this fishing activity brings in roughly a little more than cambiar a 46% of the entire catch, which underscores its importance. Mediterranean trawlers operate from coastal waters to depths down to 800 metres, though most of them limit their hauling activities to depths of less than 300 metres[162, 217]. The deep bottom fisheries of Spain, Italy, Algeria and Tunisia target the Norway lobster (*Nephrops norvegicus*) or red shrimp (*Aristeus antennatus and Aristeomorpha foliacea*), at depths close to 1,000 m.

Benthic assemblages in deep waters are often extremely vulnerable to physical disturbance and their recovery from the impacts of trawling will likely take a long time[177, 181]. Trawling and longlining take place in the proximity of or directly in these fragile ecosystems, as, for example, in Santa Maria di Leuca Cold Water Coral Province (Central Mediterranean). Part of this area was designated as a

Konstantinos
Papaioannou
/ Dreamstime


NEU 231

Trawl fishing vessel. **Pixabay**

Fisheries Restricted Area in 2006 by the General Fisheries Commission for the Mediterranean (GFCM), which banned the use of towed gears and dredges to protect the habitats and enhance the catches and sizes of fish/crustacean species which find refuge and grow larger in the coral area[179].

Estimates from La Fonera Canyon (Balearic Sea, Western Mediterranean), indicate that the organic carbon removed daily by trawling can be from 60 % to 100 % of the input of organic material. Recent evidence for the impact of trawling at depths > 600 m, reveals that trawled sediments display a decrease in organic matter content and in the abundance and biodiversity of benthic assemblages[177,180]. Intensive and repetitive bottom trawling in some areas can transform large portions of the deep continental slope into faunal deserts and highly degraded seascapes. Accordingly, we urgently need to revise the depth limit for trawling and other fishing gear. This is especially true and vitally important for particular regions and areas that are inhabited by species characterized by slow growth, late maturity, and low reproductive capacities.

Recent ROV as well as experimental fishing surveys carried out along the deepest part of the continental shelf and along the canyons have demonstrated that not only trawling, but also artisanal fishing (e.g. long-line bottom fishing) is a major concern for the Mediterranean Sea, especially for hard-bottom communities and the nearby soft bottom surroundings[66,182,183]. A plurennial ROV exploration plan carried out in Italy revealed the occurrence of lost fishing gear and signs of damage throughout the entirety of the explored areas[175].

Effects of fishing (direct and indirect effects) are probably the most important threats to longstanding, slow growing cold-water coral species. Artisanal fishing is generally practiced in areas that are good habitats for coral gardens and reefs, thus increasing the probability of coral bycatch by this gear, especially for large, arborescent species. Arborescent anthozoans and massive sponges represent a major component of the fishing bycatch, but almost no quantitative studies are available. Researchers[183] found that during experimental long-line fishing carried out between 500-600 m of depth in the Eastern Mediterranean Sea using hooks targeting hake and blackspot seabream, a major coral bycatch occurred, particularly black corals (approx. 30-130 colonies per fisherman per year). Similarly, cold-water corals were found in 72% of long lines and these findings have also been estimated in the Italian cold-water coral region of Santa Maria di Leuca[179]. Moreover, recent fishing surveys carried out along the Western Mediterranean Sea in Italy, Tunisia, and Spain

Fishing impacts on benthic fauna. **Yiannis Issaris**

(ENPI-ECOSAFIMED) have provided a detailed description of the benthic bycatch of professional trammel nets, gillnets, and longlines on various types of marine communities where all the bycatch was on structuring species thriving both on hard and soft bottoms. The relationship between fishing activity and health status of the benthic communities remains a very complex scenario, difficult to attribute to only one parameter. Various factors are involved:

a) Environment (topography of the bottom, currents influencing the position and movements of the gears underwater).

b) Biological communities (the aggregation ability of the species, their size and shape, skeletal flexibility, which may influence the entity of the mechanical damage).

c) Fishing characteristics (technical characteristics of the gear that may influence the probability of the organisms to remain entangled such as length, number of hooks and size, soaking time).

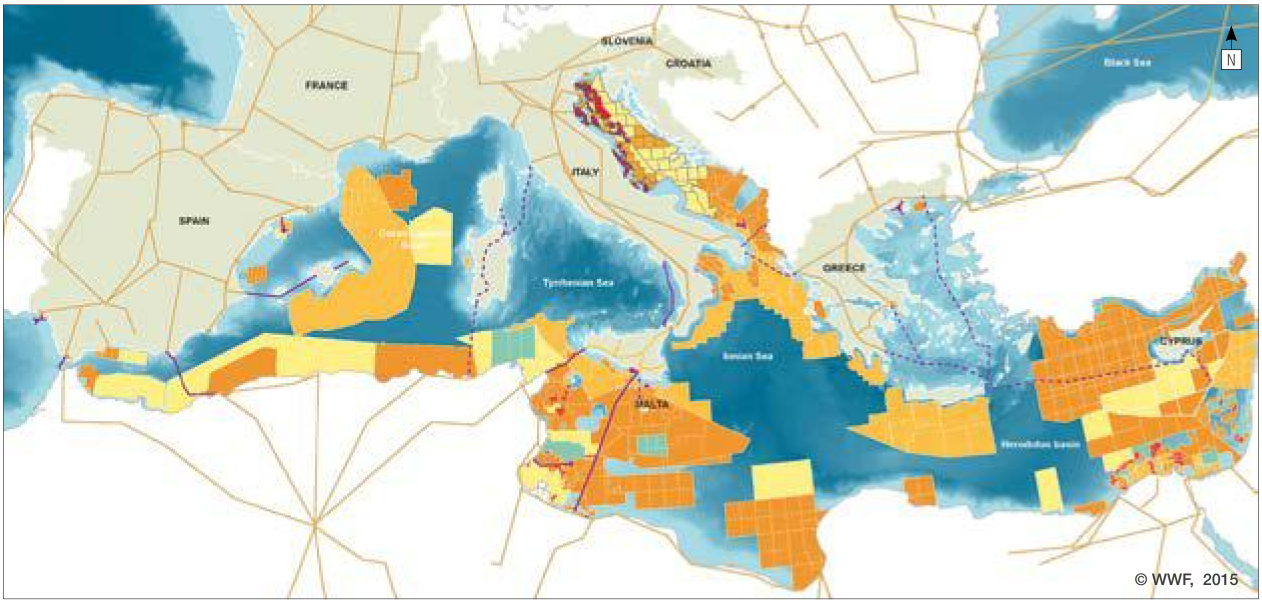
d) Social factors (number of fishermen, number of vessels, fishing culture, technological equipment, existence of specific bans that may influence the benthic populations over a long period of time)[175].

The most significate impact on the benthic coral communities is the removal of the colonies and their mechanical damage along with being clogged by the resuspension of nearby soft sediments[184]. Damaged colonies are also more susceptible to the colonization of epibiont organisms that slowly increase coral mortality[185]. Over a long-term temporal scale, indirect impacts on coral forests are correlated to a decrease in the benthic richness (both at meio, macro and megafaunal scale) and the removal of critical three-dimensional habitats that may constitute important feeding or nursery areas[18,149,186].

In this context, no data are available on the impact of recreational fishing activities which sometimes occur below 200 m, and which is often carried out in artisanal fishing grounds with numerous demersal techniques, occasionally with similar, if not higher intensity.

Mediterranean jellyfish,
Cotylorhiza tuberculata.
Max Kleinen/ Unsplash

Oil gas drilling rig.
kbinvestimentos / Pixabay



OIL AND GAS CONTRACTS

MEDITERRANEAN EU COUNTRY
OPEN AREA
BIDBLOCK AREA
EXPLORATION AREA
DEVELOPMENT AREA
PRODUCTION AREA
RELINQUISHED AREA

NARURAL GAS INFRASTRUCTURES

MARINE GAS PIPELINE - ACTIVE
MARINE GAS PIPELINE - PROJECT
TERRESTIAL GAS PIPELINE

Fig.17. Oil and gas contracts, natural gas infrastructures and sites of seismic events.

Source: Reference 187. MedTrends Project. WWF-France (http://medtrends.org/)

Oil and gas exploration, drilling and transportation

The impacts of deep-sea exploration (e.g. hydrocarbon extraction, mining, bioprospecting) on the seabed remains unclear and depends on the target resource, its associated ecosystems, and the technology used for extraction.

To date, the oil and gas extraction/exploration has been the main activity located in the deep waters of the continental Mediterranean margins *(Fig.17)*. This is likely to continue with a trend for oil wells to be located in increasingly deep water. Current offshore oil and gas production in the Mediterranean takes place mainly in Italy with facilities in the Adriatic Sea, the Ionian Sea and in the Sicily Channel, and, though to a lesser extent, in Spain. Offshore oil and gas exploration and exploitation activities also take place in the waters of other North African states[187]. And in Israel, the first ultra-deep gas field at a depth below 1,500 m depth started to produce in 2013. Impacts resulting from accidental or operational oil spills have occurred between 1970 and 2009 in the Mediterranean basin, but the potential impacts on deep-sea ecosystems have not yet been studied. Oil spills are more frequently observed along the major shipping routes, particularly in the Ligurian Sea and the Gulf of Lion as well as very close to the Eastern coast of Corsica and in the Strait of Sicily[188].

Deep-sea communication cables and pipelines

At the global level, millions of kilometres of communications cables have been placed on the seafloor over the last century; few studies, however, have investigated the effects of cables on marine life. Several gas pipelines are also operational in the Mediterranean Sea *(Fig.18)*. New gas pipelines, such as the Trans-Adriatic Pipeline or the projected pipeline between Cyprus and Greece, are also planned in the Mediterranean Sea in response to the need for an increased gas supply to Europe[187].

Due to the different characteristics of cables (e.g. fibre optic cables) and pipelines such as, diameter, rigidity and function, their placement on or in the seafloor requires different techniques and tools, and their impacts may also be different. However, previous studies[189] made outside the Mediterranean region (e.g., Central California coast), demonstrated that the

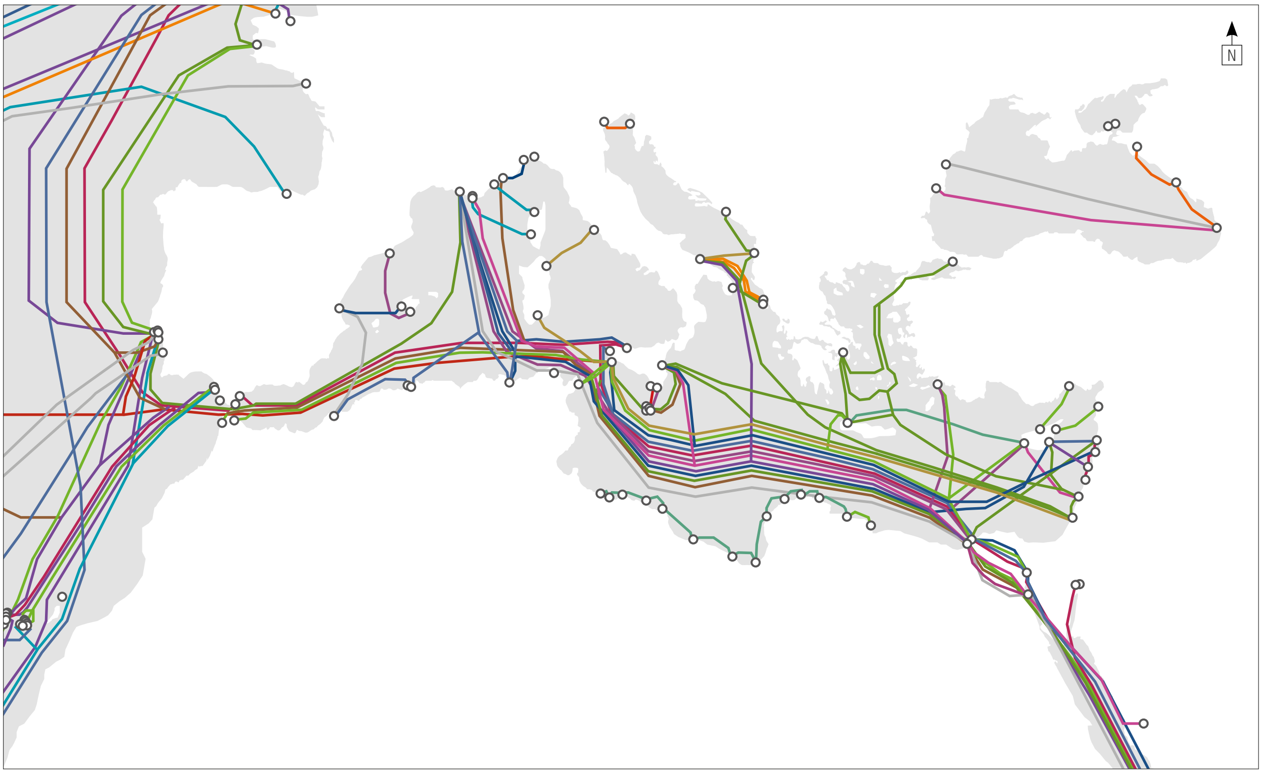


Fig.18. Mediterranean Submarine Cable Map (www.submarinecablemap.com) **2019 PriMetrica, Inc.**

direct impact of pipelines and cables is generally limited, as it occurs mainly during the laying operations, whereas once the pipe or cable is installed the direct physical impact is restricted to a narrow corridor[190,191].

Further research is needed to understand the potential impact of cables and pipelines (grounded and above the seafloor) on deep-sea environments in the Mediterranean Sea. Until such information becomes available, it would be a valuable safeguard for the cable and pipeline industries to agree to avoid routes through areas hosting sensitive deep-sea ecosystems or areas of scientific or historic interest[192].

Mining for deep-sea minerals

There are currently no ongoing operations in the Mediterranean Sea but potential areas for seabed mining for sulphide deposits have been identified along the Italian and Greek coastlines[187]. It is expected that in the near future this new industrial activity in the deep ocean will likely supply 5% of the global mineral needs by 2020. Areas in which massive sulphide deposits occur are usually on hydrothermal vents but may also be a mosaic of rocky surfaces and sedimented areas. Deep-sea mining can potentially affect extensive areas of seabed and will likely produce sediment plumes, give rise to noise pollution, emit toxic materials, and discharge fine particulate material that can smother benthic communities and vulnerable habitats. Direct impacts by mining at one depth may have a significant effect to vent fauna, including vent endemic species and different assemblages of other species. The long term impacts of this type of activities are still unknown[167].

Combined effects with climate change and ocean acidification

The small size of the Mediterranean and its enclosed nature between continents renders this "miniature ocean" particularly sensitive to changes in climate. Indeed, recent studies indicate the Mediterranean to be one of the most responsive areas to climate change[194].

Global change and cumulative stressors leading, at least in the Mediterranean Sea, to surface and deep water warming and acidification already significantly impact deep and intermediate waters of the two basins[195]. Mediterranean deep-water temperatures have increased by ca. 0.12 °C in the past 30 years[214] a consequence of the increased stratification of marine waters, **deoxygenation*** is another potentially serious threat to the deep-sea. Although, globally, the impact will not be homogeneous and some areas are already being impacted.

Using the Intergovernmental Panel on Climate Change (IPCC) scenarios and the projected changes in temperature, oxygen, pH, and primary food supply, it has been predicted that the smallest projected changes in biogeochemical parameters will occur in deep-sea habitats (e.g. soft- and hard-bottom benthos, seamounts and vents), whereas the largest changes will be in shallow-water habitats like coral and rocky reefs, seagrass beds and shallow soft-bottom benthos[196, 214]. Even deep-sea ecosystems, for which the magnitude of biogeochemical shifts will be smaller, will undergo substantial biological responses, mainly because the deep ocean is much more stable and thus its fauna is adapted to narrower ranges of environmental variation than those in shallow marine habitats[4]. Yet, the limited accuracy of these projections and the specific vulnerability of deep-sea ecosystem to change in environmental conditions and nutritive resources[195] challenge the capacity to efficiently anticipate impacts on a regional and ecosystem-type basis.

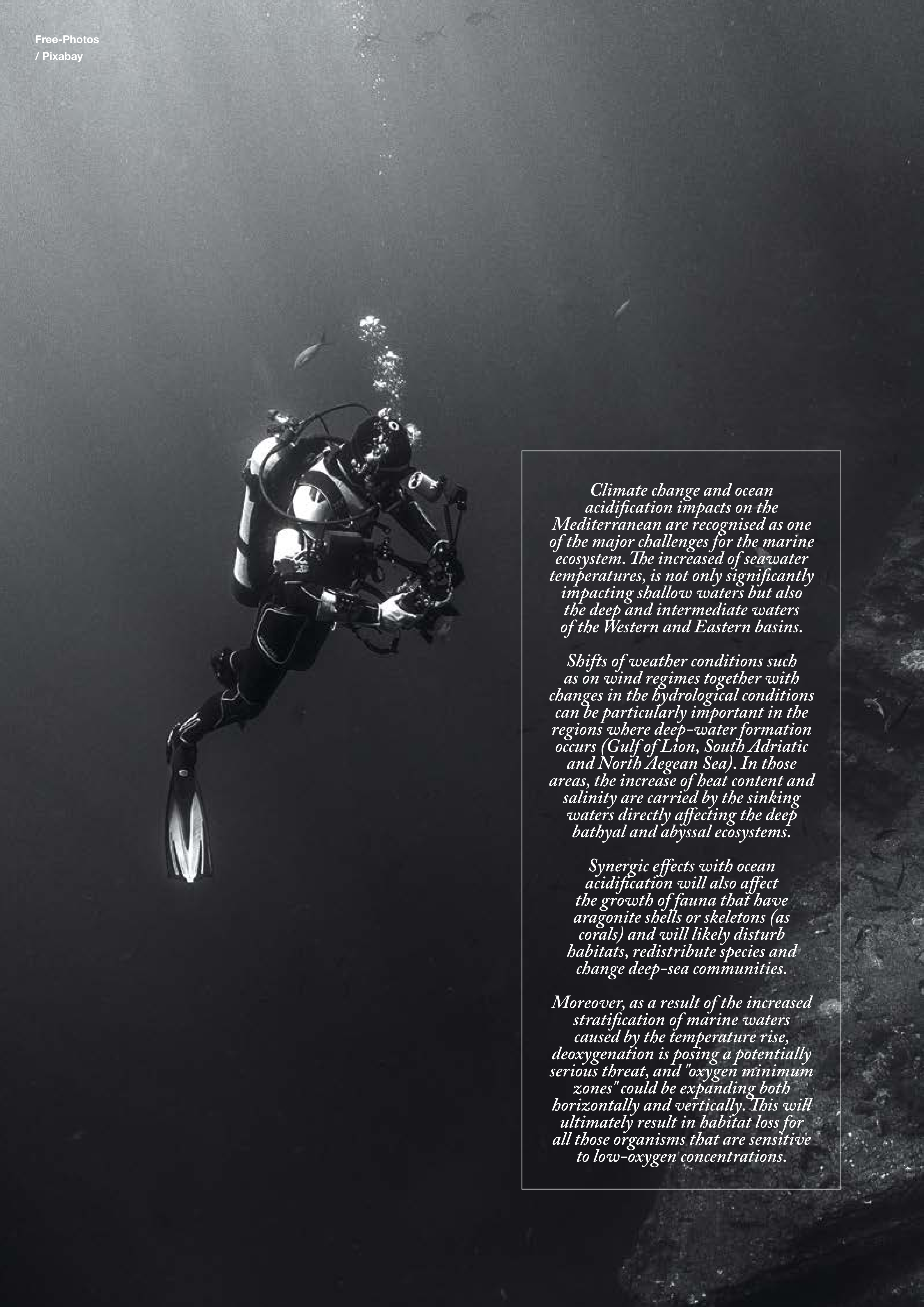
Cyclic episodic/catastrophic climate driven events have been described to have an impact on deep-sea fauna, benthic community diversity and structure, and related biodiversity and ecosystem functions on continental margins[197]. Direct links between meteorological wind regime and the hydrological conditions on the deep-sea floor at depths exceeding 2,000 m have been documented[195,214]. In the Mediterranean Sea, these links are particularly important in the regions where deep-water convection occurs (Gulf of Lion, South Adriatic and North Aegean Sea). In those areas, the sinking of cold and saline surface waters in winter, drives the ventilation of deep waters and make the bathyal and abyssal ecosystems under the direct influence of climate.

Recent analysis of long term observations (1993–2016) further reveal an increased heat content and salinity of the intermediate water masses from the Eastern to Western Mediterranean that contribute to the water mass formation[198]. These trends are much stronger than those observed at intermediate depths in the global ocean and will have (and already do have) significant consequences. Once transported to the dense water formation region in the Gulf of Lion, more salt and heat in the intermediate water masses will further enhance the tendency of this region to produce warmer and saltier deep waters.

For example, an important ecological effect on the maintenance of rose shrimp (*Aristeus antennatus*) populations in the north-Western Mediterranean has been linked to the climate-driven episodic events of dense shelf-water cascading (i.e. dense water forms over the continental shelf due to strong cold wind regime that fall down along the continental margin) in the Gulf of Lions[199]. Further impacts are also expected to result from changes in pelagic productivity and diversity. The increase of seawater temperature will affect the water column stratification and this might reduce the input of organic matter to the deep areas. Seasonal differences in the growth of cold-water corals in submarine canyons of this area have recently been revealed and have been hypothesized to reflect the sensitivity of coral growth to nutrient inputs[200]. Another example comes from the increase in gelatinous organisms (blooms of jellyfish and ctenophores) observed in recent years. When these organisms die and sink, a large mass of material is transported to the deep-sea, with possibly important implications for certain species, such as the Risso's smooth-head fish *Alepocephalus rostratus* that can feed on this material (> 60 % of the megafaunal biomass in the Western and central Mediterranean basins). Turbidity in currents as well as episodic deep warm water emissions related to

* **Deoxygenation:** oxygen minimum zone

Free-Photos
/ Pixabay



Climate change and ocean acidification impacts on the Mediterranean are recognised as one of the major challenges for the marine ecosystem. The increased of seawater temperatures, is not only significantly impacting shallow waters but also the deep and intermediate waters of the Western and Eastern basins.

Shifts of weather conditions such as on wind regimes together with changes in the hydrological conditions can be particularly important in the regions where deep-water formation occurs (Gulf of Lion, South Adriatic and North Aegean Sea). In those areas, the increase of heat content and salinity are carried by the sinking waters directly affecting the deep bathyal and abyssal ecosystems.

Synergic effects with ocean acidification will also affect the growth of fauna that have aragonite shells or skeletons (as corals) and will likely disturb habitats, redistribute species and change deep-sea communities.

Moreover, as a result of the increased stratification of marine waters caused by the temperature rise, deoxygenation is posing a potentially serious threat, and "oxygen minimum zones" could be expanding both horizontally and vertically. This will ultimately result in habitat loss for all those organisms that are sensitive to low-oxygen concentrations.

seismic activity have also been taken into consideration to explain some of the past deep coral mass mortalities[201].

Nonetheless, these impacts will depend on the different regions, marine habitats and ecosystems and their sensitivity to ocean biogeochemistry change[214]. Surface water warming under climate change has two potential consequences. The first is an increased stratification reducing the oxygenation of deep waters. The second is the progressive warming of deep waters, which may occur more rapidly than in large ocean basins due to faster thermohaline circulation across the basin (< 100 years). This feature appears particularly evident in the deep Mediterranean Sea where, given the very high deep-sea temperatures (more than 10 °C higher than Atlantic ecosystems at the same depths) many species (including deep-water corals such as *L. pertusa*) appear to be at their threshold of thermic tolerance[202].

The effects of ocean acidification, with an observed decreasing trend of a pH -0.0044 units per year in the Mediterranean Outflow Waters[214], will also impact coral growth rate although recent laboratory studies indicate significant resilience in cold-water corals[203, 219]. Organisms that have aragonite shells or skeletons[204,205] would be mostly excluded from seafloor areas below the aragonite carbonate compensation depth, which is expected to decrease as a consequence of global warming.

Vulnerability of deep-sea habitats and species

Research suggest that more diverse deep-sea systems are characterised by higher rates of ecosystem functioning than less diverse systems, as well as by an increased efficiency (e.g. biomass production).

One case study from the deep Eastern Mediterranean identified a clear link between ecosystem functioning and functional diversity[206]. After the extreme climate event known as the Eastern Mediterranean Transient (between 1987 and 1995), which caused a rapid change in water salinity and temperature (by ca. 0.4 °C), significant changes in species compositions were observed. In particular, ca. 50 % of the species that were present before this episodic event were replaced by others. These changes resulted in a decrease in the functional diversity (by ca. 35 %), which, in turn, was linked to a decrease in the benthic fauna biomass (ca. 40 % reduction) and a strong decrease in ecosystem functioning (e.g., nutrient regeneration rates). The most sensitive deep-sea ecosystems that could be affected by climate change are cold-water coral systems, canyons and deep-sea plains[221].

For deep-sea cold-water coral habitats, as the threshold is predicted to shoal progressively due to the increase of anthropogenic CO_2, the growth and survival of corals and other calcifying deep-sea species will be challenging. Locally, the adaptive capacity of communities and habitats still needs to be assessed and supported by reducing other stressors arising from direct impacts.

04
Policies and international agreements governing mediterranean deep-sea conservation

The following are the main international and regional regulatory frameworks and instruments governing fisheries, seabed mining, and Mediterranean deep-sea conservation.

UNCLOS

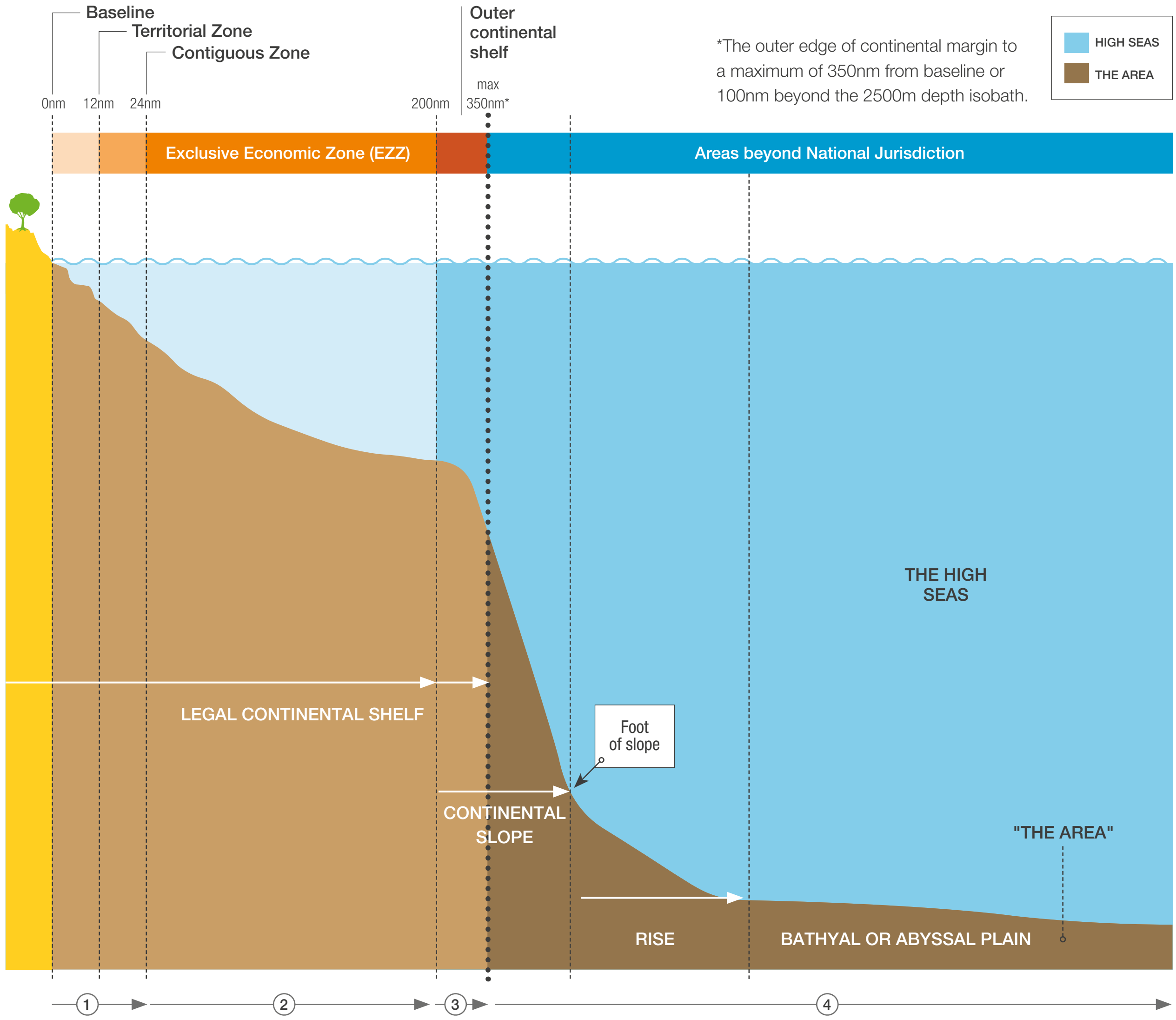
The **United Nations Convention on the Law of the Sea (UNCLOS)** provides an international framework for the protection and preservation of the marine environment. Part XII of the Convention contains general obligations to protect and preserve the marine environment, including obligations to address imminent pollution damage and contingency planning and to carry out environmental monitoring and environmental impact assessment. There is a general obligation for all signatory States to protect and preserve the marine environment and to take all measures necessary to prevent, reduce, and control impacts from any source.
The following sources are addressed more specifically:

a) Land-based activities.
b) Offshore seabed activities.
c) Activities of dumping from vessels.
d) Pollution from or through the atmosphere.
e) Pollution resulting from the use of technologies under national jurisdiction or control.

States are also obligated to address the intentional or accidental introduction of non-native (alien) species, which may cause significant or harmful changes to a particular part of the marine environment. There is also an obligation for States to cooperate in formulating and elaborating further rules and standards at global and regional levels, and there are also provisions regarding enforcement rights and obligations on the part of flag States, coastal States, and port States.

Regarding this Convention, it is important to note that a coastal State's sovereign right to exploit its natural resources must be carried out in accordance with duties to protect and preserve the marine environment (Art. 193 UNCLOS). States' measures to protect and preserve the marine environment under Part XII must include those necessary to protect and preserve rare or fragile ecosystems and habitats of depleted, threatened, and/or endangered species (Art. 194 UNCLOS). The exchange between shallow and deep-sea ecosystems is bi-directional as most of the contaminants and wastes reaching deep-sea ecosystems originate from the continental platform and from the coastal zones. Thus, the future of the deep oceans and coastal zones are intimately related. UNCLOS has classified the various maritime regions as follows *(Fig.19)*:

a) Internal Waters.
b) Territorial Sea.
c) Contiguous Zone.
d) Exclusive Economic Zone.
e) Continental Shelf.
f) The Area and High Seas.



Scale of rights

1. **Territorial waters:** Full sovereign on the sea and the seabed below.
2. **Exclusive Economic Zone:** Sovereign rights for exploring, exploiting, conserving and managing living and non-living resources of the water, seabed and sub-soil.
3. **Continental shelf:** Sovereign rights for exploring and exploiting non-living resources of seabed and subsoil, plus sedentary species.
4. **No National Rights:** Beyond any national jurisdiction. Seabed and subsoil non-living resources administered by International Seabed Authority.

Fig.19. Maritime zones under UNCLOS with zones measured from the baseline (1 nautical mile (nm)= 1852 m).

Note: The outer edge of continental margin is defined to a maximum of 350nm from baseline or 100nm beyond the 2500m depth isobath. Given that in the Mediterranean, the greatest distance between opposite States is no more than 400 nm, all parts of the seabed are within the continental shelves of its coastal States and may not extend the continental shelf beyond 200 nm from the baseline. The extension of the continental shelf has to be determined by agreement with neighbouring State(s) and the majority of this area has not been delimited because of overlapping boundaries.

The term 'deep-sea' (marine areas located at depths of more than 200 m) is subject to a legal "approach" which also depends on the interactions between current legislation related to the High Seas, continental shelves, Exclusive Economic Zone, etc. The application of one or another of the special regimes depends on a combination of geographical and legal criteria, which are set out in the UNCLOS in order to identify marine zones and who can manage and exploit their resources. Moreover, UNCLOS makes specific provisions on shipping, the protection of the marine environment (in particular for the prevention, reduction and control of contaminations), and scientific research carried out in the deep-sea.

Under UNCLOS, **the International Seabed Authority (ISA)** is the regulatory authority in charge of establishing regulations and procedures to ensure the protection of the marine environment. The ISA has adopted a sets of regulations (The Mining Code) for the exploration of different types of mineral deposits and recommendations for Environmental Impact Assessments defining also the set of environmental data, including both physical and chemical parameters on biological communities to be collected in areas where exploration for exploitation is conducted (ISA LTC, 2013). Such requirements can change with respect to the specific types of mineral deposits (e.g., polymetallic nodules, polymetallic sulphides and

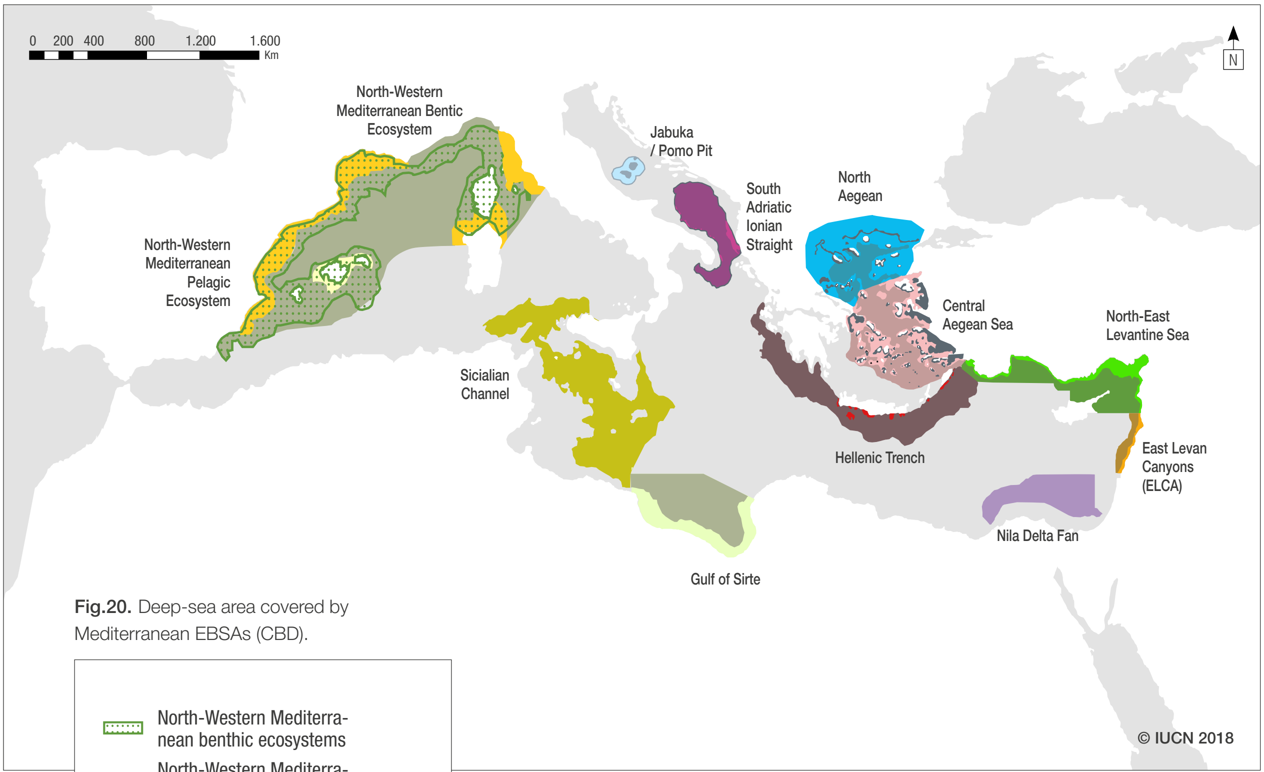


Fig.20. Deep-sea area covered by Mediterranean EBSAs (CBD).

cobalt-rich ferromanganese crusts) of industrial interest (ISA Assembly, 2012). At the present time, a consultation process is underway to further develop a Regulatory Framework for the management of the actual exploitation phase of deep-sea mining in the areas beyond National Jurisdiction (the 'Area')[3]. The ISA (outside EEZ areas) has defined **"reference areas"** that, to a certain extent, could be regarded as Marine Protected Areas (even though its effectiveness is widely debated) as these areas are excluded from the industrial activities of exploitation and are dedicated to monitoring. Spatial management measures can, therefore, be established through cooperation amongst States within the umbrella of regional bodies. However, it is important to highlight that the Mediterranean does not officially have **High Seas** (i.e. in areas beyond national jurisdiction). The majority of Mediterranean coastal States have enacted legislation for the establishment of an EEZ or **derivative zones***, and some of them have reached a formal agreement with neighbouring countries on the delimitation of their EEZ **boundaries****.

Convention on Biological Diversity

Under the mandate issued by the Convention of Biological Diversity (CBD) for marine environment protection, the Aichi Biodiversity Target 11 specifically gives particular emphasis to protect critical ecosystems (e.g. cold-water coral reefs and seamounts) by addressing protected areas as follows:

Target 11: *By 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape.*

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[3] International Seabed Authority. Decision of the Council of the International Seabed Authority relating to the summary report of the Chair of the Legal and Technical Commission, ISBA/22/C/28, Kingston, Jamaica, 2016. https://www.isa.org.jm/deep-seabed-minerals-contractors.

* **Derivate zones:** Derivative zones according to national laws can be established, e.g. ecological and fishery protection zones within the EEZ or the 200NM boundary. ** **Boundaries:** The entire seabed of the Mediterranean is subject to continental shelf claims.

To comply successfully with Target 11, effective management after designation of the Protected Areas is necessary.
Moreover, the Aichi Biodiversity Target 6 on Sustainable management of marine living resources, states that:

Target 6: *By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.*

Target 6 requires that fisheries must not have significant adverse impacts on either threatened species or vulnerable ecosystems, such as those of the deep-sea; similar commitments for deep-sea fisheries on the high seas are also therein mandated. The Aichi Biodiversity Target 10 also reflects the expected effects of several proposals to reduce the pressures on vulnerable ecosystems such as deep ocean coral reefs:

Target 10: *By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.*

Following the agreement reached at the ninth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP-9) in 2008 on the scientific criteria for identifying ecologically or biologically significant marine areas (EBSAs) in need of protection in open-ocean waters and deep-sea habitats, the COP-10 set up the process along with the scientific and technical exercises to identify such sites so as to enhance their conservation and management measures.

In 2014, the CBD also organised a regional workshop to facilitate the identification of EBSAs in the Mediterranean. Consequently, the 12th Conference of the Parties (COP-12) to the CBD in October 2014 adopted the decision to recognise several EBSAs including 17 Mediterranean areas[4] that have been registered in the CBD EBSAs Repository. Among these areas, several included deep-sea ecosystems (Jabuka/Pomo Pit, South Adriatic Ionian Straight, North-Western Mediterranean Benthic Ecosystems, East Levantine Canyons, Nile Delta Fan, North-East Levantine Sea, North Aegean, Sicilian Channel and Hellenic Trench) *(Fig.20)*.

It is expected that this process will support the institution of new protected sites (SPAMIS, MPAs, etc.) or aid in the application of new management measures to reduce pressures on these areas, thus enhancing their governance. Moreover, it will further support UN Sustainable Development Goals, specifically Target 14 "*to conserve and sustainably use the oceans, seas and marine resources for sustainable development*".

International Convention for the Prevention of Pollution from Ships (MARPOL)

The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) is the main international marine convention designed by the International Maritime Organization (IMO) to prevent pollution from ships, which may occur as a result of both operational and accidental causes. The Convention comprises six technical Annexes. In Annex I Prevention of pollution by oil, Annex II Control of pollution by noxious liquid substances, Annex IV Prevention of pollution by sewage from ships and Annex V Prevention of pollution by garbage from ships, MARPOL defines certain sea areas as **"special areas"** in which, for technical reasons relating to their oceanographical and ecological

[4] https://www.cbd.int/ebsa/ebsas

Dendrophyllia ramea.
Yiannis Issaris

condition and to their sea traffic, the adoption of special mandatory methods for the prevention of sea pollution is required. Under the Convention, these special areas are provided with a higher level of protection than other areas of the sea. The regulation of Annex I designates the Mediterranean Sea as a special area where discharge and garbage restrictions from ships apply.

IMO, through its Marine Environment Protection Committee (MEPC), is also responsible for assessing proposals for and designating **Particularly Sensitive Sea Areas** (PSSAs) and adopting associated protective measures (APMs) applicable to international shipping. PSSAs are defined as sea areas needing special protection through action by IMO because of their recognized ecological, socio-economic or scientific attributes which may be vulnerable to damage by international shipping activities. In the Mediterranean, the Strait of Bonifacio is designated as PSSA and has a series of recommendations on navigation, mandatory ship reporting system and routing measures (MEPC 62, July 2011 Resolution MEPC.226(64)).

Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean

The most important regulatory instrument to address key environmental pressures and risks affecting the Mediterranean Sea is the *Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (also referred to as Barcelona Convention).* The main aims of the **Barcelona Convention** are "to prevent, abate, combat and, to the fullest extent possible, eliminate pollution of the Mediterranean Sea Area" and "to protect and enhance the marine environment in that area so as to contribute towards its sustainable development." Protection of the marine environment is pursued "as an integral part of the development process, meeting the needs of present and future generations in an equitable manner." At present, 21 countries surrounding the Mediterranean Sea, as well as the European Union, are Contracting Parties to the Barcelona Convention.

The Convention is enhanced by the Protocol concerning **Specially Protected Areas and Biological Diversity (SPA/BD Protocol)** adopted in Barcelona in 1995. This Protocol aims at promoting the conservation and the sustainable management of areas having a particular natural or cultural value and at the conservation of the animal and plant species endangered or threatened. It provides mechanisms for the creation, protection, and management of **Specially Protected Areas** (SPAs) as well as the establishment of **Specially Protected Areas of Mediterranean Importance** (SPAMIs) with the general goal of protecting and conserving species and their habitats. SPAMIs can be established both in marine and coastal areas under sovereignty or the jurisdiction of the Parties involved. Among the existing declared SPAMI sites, very few include deep-sea ecosystems (e.g. The Pelagos Santuary or Calanques National Park).

A list of prospective SPAMI sites, including areas with deep-sea ecosystems were reported in "Overview of scientific findings and criteria relevant to identifying SPAMIs in the Mediterranean open seas, including the deep-sea", compiled in 2010. Among all the sites listed, potential areas such as *Eratosthenes Seamount*, *Northern Aegean*, *Southern Ionian, Northern Strait of Sicily*, and *Gulf of Lion Shelf* and slope are of interest to this report on account of the presence of deep-sea species, deep-sea coral habitats and canyons. Further efforts are thus specifically needed to include these and other deep-sea sites in the Barcelona Convention and augment the list of SPAMI sites with deep-sea areas in order to promote cooperation in the management and conservation of habitats and the protection of vulnerable and threatened species.

All the cetacean species and several endangered deep-sea shark and ray species are included in Annex II (List of threatened and endangered species) of the SPA/BD Protocol. The latest Decision adopted at the last Contracting Parties meeting (December 2017) included in this Annex, new deep anthozoans species (*Isidella elongata*, *Desmophyllum dianthus*, *Dendrophyllia cornigera*) listed on threatened status under Red List criteria together with the relatively shallow-water species and also endangered, *Dendrophyllia ramea*. Other cnidarians species such as the cold-water corals *M. oculata* and *L. pertusa* and black corals (e.g. Leiopathes glaberrima), considered under endangered status on the IUCN Mediterranean Red list[158] as well as the bryozoan *Hornera lichenoides* and few deep-sea sponge species (the endemic *Axinella cannabina*, *A. polypoides*, *Tethya spp.*) that can form sponge gardens, are also included in this Annex of the SPA/BD Protocol.

Within the SPA/BD Protocol, the Strategic Action Programme for the Conservation of Biological Diversity in the Mediterranean (SAP/BIO) provides a logical framework for interesting parties (Contracting Parties, International Organizations, NGOs, private sector, etc.) undertaking activities for the protection and management of the marine and coastal environment in the Mediterranean. The SAP/BIO proposes a list of specific priority actions for Contracting Parties to undertake, such as inventorying, mapping, and monitoring the Mediterranean coastal and marine biodiversity, conserving sensitive sites, species and habitats, assessing and mitigating the impact of threats to biodiversity, developing research to improve knowledge, and fill in gaps regarding biodiversity. The Initial Gap Analysis on existing measures under the Barcelona Convention for achieving or maintaining good environmental status (UNEP(DEPI)/MED WG.408/, 2015) reported that:

> *"The SAP/BIO Analysis also notes that, despite the scientific programmes which have been implemented to gain better knowledge of Mediterranean biodiversity, several areas in the Mediterranean are still little studied, with the main gaps concerning the southern and Eastern Mediterranean, the sizes of the populations of certain species and their distribution (for example cetaceans) and the biodiversity of the deep-sea areas."*

Under the SPA/BD protocol, the **Action Plan for the conservation of habitats and species associated with seamounts, underwater caves and canyons, aphotic hard beds and chemo-synthetic phenomena in the Mediterranean Sea** (Dark Habitats Action Plan) adopted during the Eighteenth Ordinary Meeting of the Contracting Parties to the Barcelona Convention (Istanbul- Turkey, 2013) **proposes a series of initial measures to conserve deep habitats**. The objectives of the Action Plan are to:

Conserve the habitats integrity, functionality (favourable state of conservation) by maintaining the main ecosystem services and their interest in terms of biodiversity through the establishment firstly of legislative measures, setting up MPAs in secondly and foremost the application and development of regulatory procedures to restrict or prohibit some human activities if they exist.

Encourage the natural restoration of degraded habitats via reduction of human origin impacts.

Improve knowledge about dark populations (e.g. location, specific richness, functioning, and typology) through national and regional data and scientific work in accordance with the objective of establishing a summary of knowledge of dark populations and their distribution around the Mediterranean in the form of a geo-referenced information system.

As part of this plan and other related programme measures, in December 2017 a **Reference List of Marine and Coastal Habitat Types** was proposed by the COP Contracting Parties as a first basis for identifying reference habitats to be monitored at the national level under the Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and Related Assessment Criteria (Draft Decision IG.23/8). This list includes descriptive common list of deep-sea habitats for the inventorying and monitoring of dark assemblages at the basin. The final adoption of this list will be discussed by the COP 2019.

Further works under this Action plan aim to support countries by increasing their knowledge of deep-sea areas under their national jurisdiction and to facilitate their conservation as well as revise the classification of benthic marine habitat types, taking into account dark assemblages, with the view to submitting said revised classifications to the Contracting Parties at their next meeting.

Another important **Protocol under the Barcelona Convention is the Protocol for the Protection of the Mediterranean Sea against pollution resulting from exploration and exploitation of the continental shelf and the seabed and its subsoil** (Offshore Protocol). Activities such as exploration and development drilling, installation of structure for recovering resources and seismological activities and surveys fall within its scope. The Protocol provides mechanisms for the activities to be conducted in the Protocol Area and the national rules and protocols, including contingency planning, to obtain prior authorisation.

Additional measures are also included for Mediterranean Specially Protected Areas. Currently, common standards and method guidelines to harmonise regional practices for the disposal of oil and oily mixtures, the use and disposal of drilling fluids and cuttings and associated analytical measurements as well as seabed sampling programmes are being discussed.

The 19th Meeting of Contracting Parties (COP-19), held in February 2016, adopted the **Integrated Monitoring and Assessment Programme (IMAP)** of the Mediterranean Sea and Coast and Related Assessment Criteria. In its Decision IG. 22/7, a specific list of common indicators and targets as well as the principles of an integrated Mediterranean Monitoring and Assessment Programme was elaborated and the draft guidance on the monitoring of common indicators and their targets to deliver the achievement of Good Environmental Status (GES) were further discussed and agreed upon during the COP-20 in late 2017. Several of these indicators also relate to the deep-sea environment.

In compliance with the objectives and principles of the Mediterranean Regional Plan on Marine Litter Management (Decision IG.21/7) to prevent, reduce and control marine litter generation and its impact on the coastal and marine environment, the implementation plan (Decision IG.22/10) has also recently been adopted. This includes the fishing for litter guidelines, marine litter baseline values, a basin-wide marine litter reduction target of 20% of beach litter by 2024, and a significant and measurable decrease of other marine litter items.

Sperm whales (*Physeter macrocephalus*) prefer the deep continental slope waters of the Mediterranean Sea. **Izanbar / Dreamstime.com**

ACCOBAMS

The ACCOBAMS (**Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area**) is an intergovernmental agreement to reduce threats to cetaceans in the Mediterranean and Black Seas. Among its different activities, ACCOBAMS aims to study the distribution, abundance and status of target species, causes of cetacean mortality events, interactions between cetaceans and fisheries, and to identify areas of special importance (e.g., MPA) for the protection and conservation of cetaceans.

The aim of the ACCOBAMS strategy (2014-2025) is to improve the current conservation status of cetaceans and their habitats in the ACCOBAMS area by 2025. More specifically, it aims at having the status of all the regularly present species currently listed as "Endangered" (EN) on the IUCN Red List downgraded to at least "Vulnerable" (VU). Moreover, it seeks to guarantee Good Environmental Status (GES), as defined in the EU Marine Strategy Framework Directive and in accordance with the Ecosystem approach process as implemented by the Mediterranean Action Plan, in areas which represent critical habitats. The specific objectives are grouped in two chapters: "Management of the Agreement" and "Cetacean Conservation Efforts". Conservation efforts are focused on:

a) Improving knowledge about the current state of cetaceans.
b) Reducing human pressures, particularly those related to the interaction with fisheries and habitat loss and degradation.
c) Raising public awareness.
d) Improving national capacities.
e) Enacting effective conservation of cetacean critical habitats, including those in deep-sea environments.

General Fisheries Commission for the Mediterranean (GFCM-FAO)

The General Fisheries Commission for the Mediterranean (GFCM) is a Regional Fisheries Management Organization (RFMO) established under the provisions of Article XIV of the FAO Constitution. The main objective of the GFCM is to promote the development, conservation, rational management and best utilization of living marine

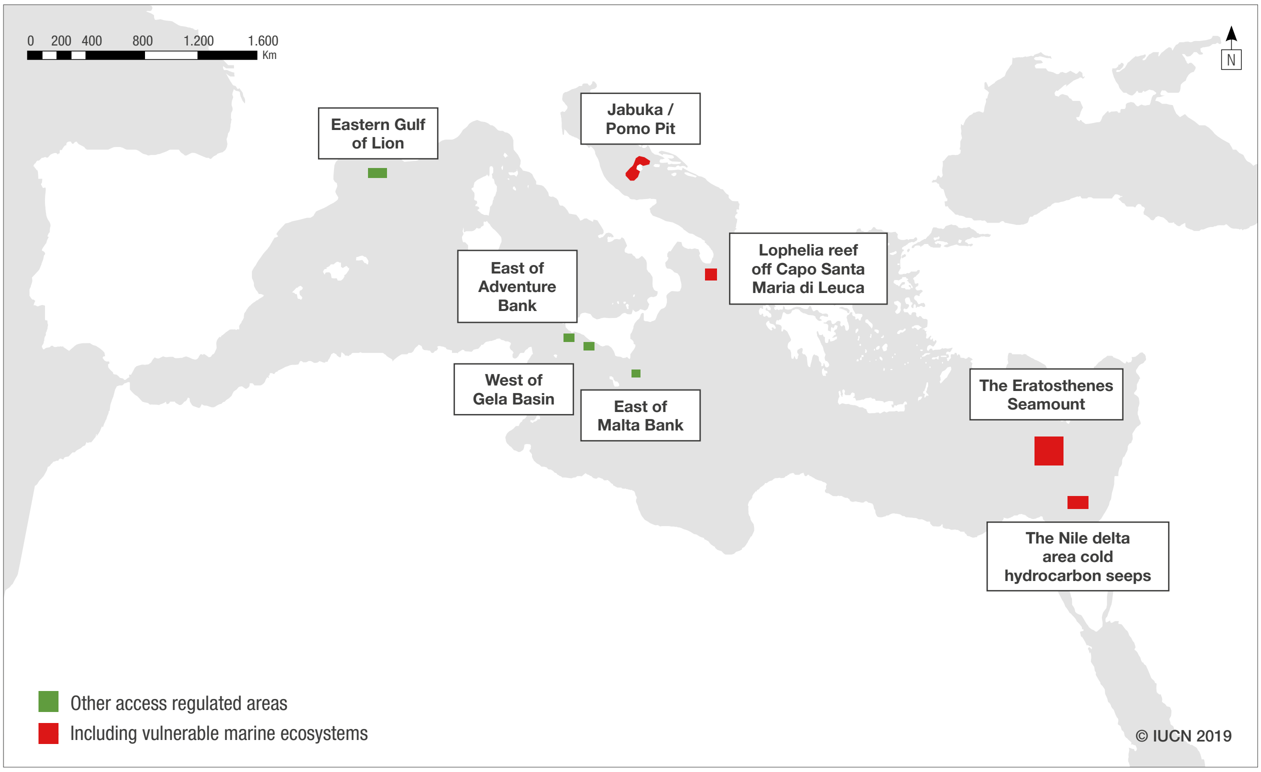


Fig.21. Current Fisheries Restricted Areas in the Mediterranean (GFCM), 2019.

Adapted by IUCN, 2019.

resources as well as the sustainable development of aquaculture in the Mediterranean, the Black Sea and connecting waters. The GFCM is currently composed of 24 members (23 countries and the European Union).

The deep-sea species targeted for fishing in the Mediterranean includes hake (*Merluccius merluccius*) and deep-sea shrimps (*Aristeus antennatus*, *Aristeomorpha foliacea*). However, deep sea fisheries are multispecies and other species captured include blue whiting (*Micromesistius poutassou*), greater forkbeard (*Phycis blennoides*), angler fish (*Lophius sp.*), conger eel, blackspot seabream (*Pagellus bogaraveo*), megrims (*Lepidorhombus spp.*), bluemouth, other shrimps (*Parapenaeus longirostris*, *Pasiphaea spp.*, *Plesionika spp.*), norway lobster (*Nephrops norvegicus*) and crabs (*Geryon longipes*, *Paramola cuvieri*)[217]. Bycatch of endangered deep-water sharks (*e.g. Squatina spp.*, *Etmopterus spinax*, *Hexanchus griseus*), rays and chimaeras (*e.g. Chimaera monstrosa*) occur in these fisheries[151,152].

Under GFCM, a spatial based management measure named Fisheries Restricted Areas (FRA) has been developed in order to protect shallow and deep-sea Sensitive Habitats and Essential Fish Habitats (Recommendation GFCM/30/2006/3). During the last decade, only eight areas have been declared as Fisheries Restricted Areas *(Fig.21)*, which also cover management towards deep vulnerable marine ecosystems (Recommendation GFCM/30/2006/3; GFCM/40/2016/4; GFCM/2017/41th Session of Commission):

1. Fisheries Restricted Area "Lophelia reef off Capo Santa Maria di Leuca". This area was protected to guarantee the conservation of a unique ecosystem of cold-water corals.

2. Fisheries Restricted Area "The Nile delta area cold hydrocarbon seeps". This area hosts an exceptionally high concentration of cold hydrocarbon seeps.

3. Fisheries Restricted Area "Eratosthenes Seamount". This unique area contains scleractinian corals, rare deep water sponges, dense populations of deep-water actinarian Kadophellia bathyalis and unidentified zoantharians and antipatharians.

4. Fisheries Restricted Areas of "East of Adventure Bank", "West of Gela Basin" and "East of Malta Bank" in the Strait of Sicily. These new areas protect 1,493 km^2 between Italy, Malta and Tunisia from bottom trawling with the aim of preserving Essential Fish Habitats (EFH) –nursery grounds– for hake and deep-sea rose shrimp.

5. Fisheries Restricted Area in the "Jabuka/Pomo Pit" in the Adriatic Sea. From 140 to 217m depth, this area aims to contribute to the protection of Vulnerable marine ecosystems and important Essential fish habitats for demersal stocks such as European hake and Norway lobster.

In addition to those closures, in 2009 a Control of Fishing Effort was established in the Gulf of Lions (Recommendation GFCM/33/2009/1) in order to specifically protect spawning grounds of hake. At present, the Mediterranean FRAs cover more than 20,000 km^2 under 200m depth (excl. Gulf of Lion), about 0,9% of the Mediterranean deep-sea *(Fig.11)*.

In the designated areas, closure is permanent to towed dredges and trawl nets in the core zone. Nonetheless, the actual enforcement of the fisheries restrictions on some of these areas is weak, and preliminary evidence indicates that permanent damage to some of these delicate biocenoses might have already occurred[179]. The operation of distant fisheries present significant problems in monitoring, controlling, and surveilling them so as to ensure compliance with fisheries regulations such as closed areas.

The **Vulnerable Marine Ecosystem (VME)** concept, described as "groups of species, communities or habitats that may be vulnerable to impacts from fishing activities", was elaborated by the United Nations General Assembly (UNGA) in Resolutions 59/25, 61/105 and 64/72. These resolutions require States and regional fisheries management organisations (including GFCM) to take specific measures for VME protection. Criteria for their implementation were developed under *FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas* (FAO DSF) to assist States and RFMOs in defining VMEs and managing them. To reduce impacts on these sites, FAO DSF Guidelines[5] also recommend specific conservation and management measures. The UNGA Resolutions and Deep-sea Guidelines provide an opportunity to propose further areas for a proper management of deep-sea Mediterranean fisheries. However, despite the fact that GFCM is one of the oldest RFMOs, it has yet a work ahead to protect VMEs, and current GFCM measures related to VME protection are very limited. At the 40th session of the GFCM in 2016, it was agreed that GFCM would begin to take steps towards implementing the UNGA resolutions, with the aim of adopting measures for the protection of VMEs by 2018. As a result, several meetings of the group working on VMEs have been held since, with the Commission approval of the first technical elements for the implementation of management measures.

In September 2005, the GFCM adopted a ban of bottom trawling and towed dredges at depths below 1,000 meters. However, this prohibition has not conferred protection to many VMEs because most of them occur in shallower waters; plus, the majority of the Mediterranean fishing fleet cannot operate beyond that depth limit. The process to improve protection of VMEs from deep-sea fishing impacts at the GFCM level is still ongoing and is included in the objectives of the **Mid-term Strategy (2017-2020)**[6] toward the sustainability of Mediterranean and Black Sea fisheries. As part of this strategy, GFCM Members have also adopted several measures to commonly assess the status of stocks, bycatch, establish fishing quotes and control illegal unreported and unregulated (IUU) fishing, including, for example, the General Guidelines for a GFCM Control and Enforcement Scheme.

Moreover, all these measures stipulate that technical work be scaled up so as to improve the advice given on stock assessment methods for demersal species, including those associated with deep-sea ecosystems, and that support be given for the establishment of new management plans (e.g. deep-water shrimp management plan in the central-eastern Mediterranean). The mapping of the fishing footprint of deep sea fisheries will help also to achieve the above and address sustainable fisheries at these depths.

5 International Guidelines for the Management of Deep-sea Fisheries in the High Seas. Rome, Italy.

6 http://www.fao.org/fileadmin/user_upload/faoweb/GFCM/News/Mid-term_strategy-e.pdf

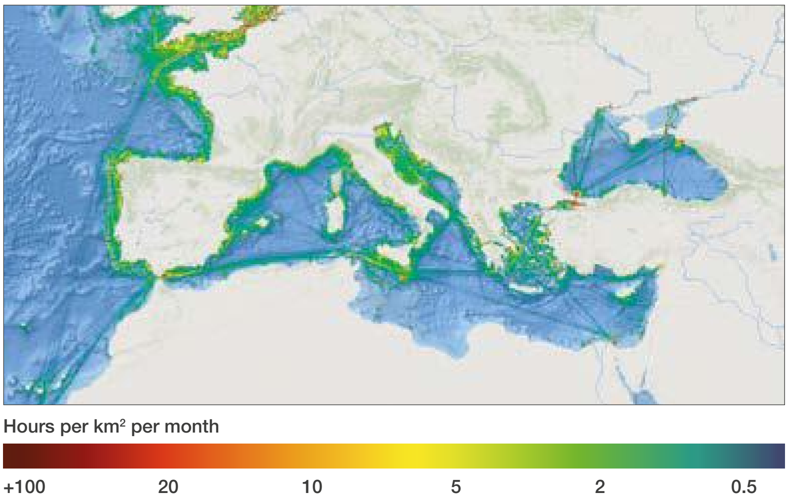


Fig.22. Density map of ship traffic in the Mediterranean Sea, 2017. European Atlas of the Seas, https://ec.europa. eu/ maritimeaffairs/atlas/maritime_atlas/ © European Union, 1995-2019.

European Union Policies

The Marine Strategy Framework Directive (MSFD 2008/56/EC) is the tool of the EU's instrument for Integrated Maritime Policy to achieve Good Environmental Status of marine waters by 2020. The Directive defines Good Environmental Status (GES) as:

"The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive, … within their intrinsic condition, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for users and activities by current and future generations".

The MSFD applies to the area of marine waters over which a Member State exercises jurisdictional rights in accordance with the UNCLOS. This includes a substantial component of deep-sea waters within European EEZs and includes, as defined by the MSFD, the seabed and subsoil under the water column. Member states are required to implement the MSFD by developing a Marine strategy with assessment, monitoring programmes, and programmes of measures for achieving the GES of the marine environment.
The MSFD sets out 11 qualitative descriptors of the marine environment, all of them are relevant to the deep-sea (e.g., biodiversity, non-indigenous species, fish, health of food webs, contaminants, litter, underwater noise, with the partial exception of the Descriptor 5 (eutrophication)). The first EU Mediterranean Member States' Submissions for the Marine Strategy Framework Directive on the determination of good environmental status in 2012 and MSFD 2014 reporting on monitoring programmes highlighted the uncertainties among countries about the use and derivation of quality standards for offshore and deep waters.

Specific examples of data-poor descriptors from the Mediterranean deep-sea included:

Descriptor 3: Deep-water fish stocks and information on causes of declines, e.g., highly migratory fish, such as oceanic sharks, is very limited.

Descriptor 7: Regarding hydrographical conditions, most of the reports by Member States focus only on the coastal zones.

Descriptors 8 and 9: Only a few Member States partly defined baselines on Contaminants and thresholds are unknown. Data on deep and offshore waters are overall very scarce.

Descriptor 10: Change in the nature, presence or abundance of anthropogenic debris on the deep-sea floor, even though it is known to be more abundant, is much less widely investigated than it is on continental shelves.

Barcelona port. **Jason Goh / Pixabay**

The application of these descriptors to the deep-sea for the next reporting phase is particularly challenging because of the lack of knowledge and the systematic need for long-term monitoring data. To assist in this, more specific criteria, methodological standards, specifications, and standardised methods have recently been established to assess the good environmental status of marine waters and the methods for monitoring and assessing them (Commission Decision (EU) 2017/848). Nonetheless, further work will still need to be elaborated to assess offshore waters.

Following the MSFD programme, programmes and measures to preserve deep habitats have already been defined in some Mediterranean States. In France[7], for example, specific measures have been identified to maintain the GES of deep-sea canyon habitats, preserve fishing resources of the Gulf of Lion continental shelf, and other general management measures for the marine environment.

Within the Joint Management Action of the European Union and UNEP-MAP-RAC/SPA, the EU GES indicators have been recently reviewed and simplified in order to be made applicable for other non-EU Mediterranean countries in coordination with the Barcelona Convention.

To address different management strategies for the coastal and marine environment and the threats they face, different EU Directives have also been developed:

a) The European Habitats Directive (1992).
b) The Strategic Environmental Assessment Directive (2001).
c) The Common Fisheries Policy (CFP).
d) The Maritime spatial planning Directive (2014).
e) The Environmental Impact Assessment Directive (2011).

The Habitats Directive[8] is aimed at halting biodiversity loss through the conservation of habitats and species in European territory. The Directive's objective is to set up a coherent network of Special Areas of Conservation (SACs), which are comprised of the habitats and species found on the conservation priority list (forming part of the Natura 2000 network). Article 6 of the Habitats Directive specifically deals with the protection of SACs from disturbance and outlines the procedures for the assessment of whether or not plans or projects would have a significantly negative impact on SACs. Such plans / projects should only take place where there is overriding public interest, otherwise alternatives should be adopted or the activity prevented from going ahead. However, the use of the Habitats Directive for the deeper environment has been limited so far.

In order to construct a coherent and representative Natura 2000 network, the participating European countries are obliged to designate sites that may host several distinct

[7] http://www.dirm.mediterranee.developpement-durable.gouv.fr/IMG/pdf/PDM_MO.pdf

[8] European Habitats Directive (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Union 206:7-50.

deep-sea habitats, as defined by the Interpretation Manual of the European Union, as well as maintain their good conservation status. According to this Manual, vents and seeps that contain substantial carbonate structures may classify as "Submarine structures made by leaking gases" (habitat type EU 1180) under Annex I of the Habitats Directive[160]. Following these guidelines, "Reefs", (habitat type EU 1170), could also be considered to contain several deep communities: facies and forests of gorgonians and black corals; *Isidella elongata* and *Callogorgia verticillata* gardens; red corals (*Corallium rubrum*); banks of D*endrophyllia ramea* communities, *Dendrophyllia cornigera*, and white corals banks of *Madrepora oculata* and *Lophelia pertusa*. Moreover, it also includes other Biogenic concretions formed by deep-sea biota such as hydroids, bryozoans, giant oysters, ascidians, and sponges (Interpretation Manual of European Union Habitats – EUR28). However, not all important deep-sea habitats and species found in the Mediterranean are considered under these habitats types.

Within the EEZs of the countries, the management of marine mining activities will fall under the same regulations as other industrial activities. **The Strategic Environmental Assessment Directive (SEA)** and the **Environmental Impact Assessment Directive (EIA)** in Europe involve the assessment of plans (overlapping with the Habitats Directive), including plans involving the deep-sea areas under the national jurisdiction of Member States. The SEAs tend to be undertaken by Member States with a view to examining the environmental effects of large-scale plans, projects or policy. EIAs tend to apply to specific projects undertaken by the public or private sector. In either case,

TeeFarm / Pixabay

Dealing with the multiple demands and the increasing pressure placed on the deep-sea requires adequate governance and management. International treaties, Conventions, Directives and Environmental Agreements relating to activities and resources in the Mediterranean Sea (including its deep/offshore environment) are addressing different aspects of marine governance but large challenges remain, particularly for offshore waters.

where significant environmental impacts are identified in these assessments then alternatives to the project must be assessed and appropriate measures taken to avoid, reduce, or offset environmental damage.

With respect to fisheries, the Common Fisheries Policy (CFP) sets the rules for managing European fishing fleets and for conserving fish stocks. Recently, the Council of EU Fisheries Ministers' working group has adopted a new **EU Deep-sea Fishing Regulation in the north-east Atlantic** (Regulation (EU) 2016/2336) which establishes specific conditions for fishing for deep-sea stocks and provides provisions for fishing in these international waters. This agreement has established the prohibition of bottom trawling below 800 metres in EU waters in the northeast Atlantic and seabed areas below 400 metres where Vulnerable Marine Ecosystems (VME) are known to or are likely to occur. To further protect VMEs, fisheries are only allowed in areas where they have fished in the past and vessels must report the sighting of any vulnerable species such as sponges or corals, indicate the catch and move to other fishing grounds in those case where a maximum amount of vulnerable species has been reached.

Overall, as a cross-sectoral tool with the **ICZM Protocol from the Barcelona Convention** on coastal activities that may affect the deep-seas, the **Marine Spatial Planning Framework Directive** should also aid in promoting cooperation among Member States for sustainable development and in identifying the proper utilization of maritime space in order to better manage ongoing activities as well as guide future development of spatial uses and conflicts, including those in the deep-seas.

05
A need for a common transnational strategy

This overview summarizes the present knowledge of the deep-sea environment and how relatively little is known about the way the Mediterranean may respond to the growing threats and increasing pressures. Even with the international commitments and present policy framework in place, the ongoing activities together with the development of future activities in the deep-sea require the expansive application of spatial and adaptive management tools, research programmes, and coherent assessment of actions to help protect and improve the Mediterranean deep-sea ecosystem. With the purpose of bringing this future strategy for the Mediterranean Sea into clearer focus, an analysis of the challenges we presently face and a few potentially key action areas are highlighted below.

Scientific knowledge challenges

All the implemented EU Directives and International regional tools employed by Mediterranean Member States have led to significant improvements in the assessment of the impact of human activities on the environment, including the deep-seas. That notwithstanding, major scientific knowledge gaps still remain.

The European Marine Board (formed by 36 Member Organisations comprised of National Funding Organisations and Research Performing Organisations across Europe) has reviewed the deep-sea research programmes and identified the potential of deep-sea research in the EU as well as the gaps in current knowledge which are needed to ensure the future of deep-sea ecosystems[207].

Further consultation with Mediterranean experts, emphasised that the lack of data on bathymetry, habitat maps and information on species distributions, ecological features, and response to impacts are significant barriers to establishing management measures that ensure conservation of deep-sea ecosystems in the basin. Moreover, the lack of information on deep-sea ecosystems becomes particularly problematic in relation to the increasing interest in the exploitation of deep-sea biotic and abiotic resources[9].

Existing problems also include the fact that most regulations imposed on fisheries within Mediterranean countries are not subject to any quotas or catch limits which follow scientific recommendations. Instead, restrictions are placed on the number and size of the fishing vessels (fishing capacity controls), the amount of time such vessels are allowed to fish (vessel usage controls), and the product of capacity and usage (fishing effort controls)[208].

There is also an imbalance between the geological and biological information that has been acquired over time. Most investigations in unknown areas start with the analysis of the geological and topographic features and in several cases limited or no information is gathered on the species inhabiting these systems or the waters and seafloors surrounding them. Studies on

[9] https://www.cbd.int/ebsa/ebsas

pelagic and/or benthic assemblages on Mediterranean seamounts, canyons, cold seeps, and hydrothermal vents are still extremely scarce, scattered or lacking a systematic approach. That being said, Spain and France have recently carried out extensive investigations on some Western Mediterranean canyons. Spain has also been working rigorously on shelf and canyons within the Catalan coast and around the Balearic Archipelago. Likewise, in the Alboran Sea. Italy is engaged in intensive research in the Ligurian, Gela, Sardinian and Bari canyons as well as on the Ligurian and Tyrrhenian seamounts. In 2006, the CIESM launched the programme SUB (Sur Un Bateau), devoted to the study of the biology and ecology of Tyrrhenian seamounts with the aim to reduce the sizable knowledge gaps pertaining to these key systems. A relatively small number of other scientific programmes and groups have been further investigating similar systems along the Mediterranean[209].

A preliminary census of key topographic features, such as seamounts and submarine canyons, has already documented more than 348 canyons and 242 seamount-like structures; yet, the related biological information is still scarce[96,105]. As such, there is a wide consensus that our understanding of the drivers of canyon systems and their biology (e.g. sediment transport, seabed composition, near-bed current flow, fluxes of particles, etc.) is still limited. This requires more investigations together with the ability to integrate physical and biological data (i.e., multi-beam and oceanographic data with biological data). The lack of knowledge on these geomorphological features and how they relate to ecosystem functioning and dynamics is particularly concerning if we are to anticipate the adverse effect of cumulative stresses due to climate related changes and other direct anthropogenic impacts. Moreover, indirect anthropogenic impacts need further investigation. How changes related to global warming such as changes in currents, higher temperature, acidification, etc. might affect deep ecosystems is still largely unknown.

In general, the current census of deep-sea Mediterranean habitats is far from complete. Consequently, any and all strategy and management actions will require feedback adaptation on the basis of future analyses and results.

Even less attention still is paid to the temporal dimension (including seasonality); this is due, in large part, to the limited capacity to repeatedly observe and investigate ecological processes over extended periods of time. Snapshot studies result in a very fragmented understanding of the vulnerability of ecosystems and their biodiversity. Furthermore, it is more and more evident, especially for Vulnerable Marine Ecosystems (VMEs), that the acquisition of fundamental biological data on distribution patterns, species densities, population structure, species co-occurrence, etc. ought to be acquired mostly via means of visual methods, namely: Underwater cameras, ROVs and/or manned submersibles which are non-destructive and offer valuable and fully quantitative information. Such methods will also provide a better understanding of deep-sea life found in specific structures (such as seamounts, seeps and canyons) and previously unknown behavioural patterns. In fact, some information coming out the the Alboran Sea in the Western Mediterranean, the south Adriatic Canyons, the Tyrrhenian Seamounts, the Lebanon sea canyons, and the Strait of Sicily has already been made available.

Peter Leahy /
Shutterstock

Nonetheless, little information exists concerning the importance of seamounts and canyons to the distribution of deep-sea pelagic organisms[210], which are potentially the main source of food for both benthic and pelagic predators. Their biomass, for example, has never been estimated, nor has their seasonal abundance, migrations, distribution, or life cycles, despite the fact that these species constitute key elements in the Mediterranean food webs (both benthic and pelagic). To date, the surveys conducted during the IUCN-MAVA Prometeos project in the Tyrrhenian Sea constitute the only systematic studies on the role of seamounts and canyons in relation to the aggregation of deep-diving predators.

Another relevant gap to be addressed is related to species connectivity and how populations are connected along canyons and seamounts.

In conclusion, **the main gaps in knowledge** for the Mediterranean deep-sea can be summarized as:

1. Limited availability of data for all deep-sea biological components, in particular over the temporal (both long-term and extreme events) changes in the sea environment and the process and functions of the ecosystems.

2. Little knowledge on the deepest areas and some key ecosystems such as chemosynthetic environments, brine lakes, or cold seeps as well as hydrothermal vents, especially from the North African and Eastern Mediterranean. A "map" compiling current knowledge and including a short description of each area could help to develop future scientific and conservation programmes.

3. Insufficient or not existent baselines. The scale and detail of the data needed to defined the baselines has not been identified yet.

4. Insufficient environmental characterization to support the analysis of the ecological status of deep-sea ecosystems, including rising temperatures, ocean acidification, toxic waste from fleets, impacts from military activities, etc.

5. Need to complete a census of habitats and deep-sea biodiversity in general together with the need for the spatial mapping of hotspots as well as the monitoring of their temporal changes, especially in the region of North Africa.

6. Need to complete the mapping of deep-sea habitats (e.g. cold-water coral reefs and other structuring habitats) as well as of the biotic components of the seamounts, canyons and adjacent slopes, cold seeps, hydrothermal vents and DHABs.

7. Need to complete information about deep-sea species which are considered threatened and compile more information about other deep-sea species to conduct future conservation assessments with special attention to data related to life history, which is virtually non-existent for most of deep-sea species.

8. Need to understand the resilience of key habitats and the biodiversity components and their connectivity in the deep-sea.

9. The lack of data for areas where deep-sea mineral resources may reside (primarily seamounts and bathyal/abyssal plains in the Mediterranean) hampers the development of appropriate management measures related to deep-sea mining.

10. Need to understand how the deep-sea recover from impacts.

Key management challenges

A solid methodological approach based on good knowledge of Mediterranean deep-sea ecosystems is needed to ensure their future. However, the gaps in *knowledge* summarized above have created an inevitable cascading effect, bringing about the following, seemingly insurmountable **gaps in methodology**:

1. Lack of standardized criteria, protocols and instruments for data collection (often data are collected with appropriate equipment and analysed correctly, but with insufficient replication or an inadequate sampling strategy); a need to develop baselines for a deep-sea approach to the analysis for the Descriptors of the MSFD as well as for Ecosystem Approach processes under the Barcelona Convention.

2. Lack of standard approaches/variables to assess the sustainability of the exploitation of deep Mediterranean resources (predicting the significance of environmental impacts, even where these have been identified).

3. Lack of monitoring programmes to identify unforeseen effects (post hoc) and to identify effective mitigation measures or alternatives.

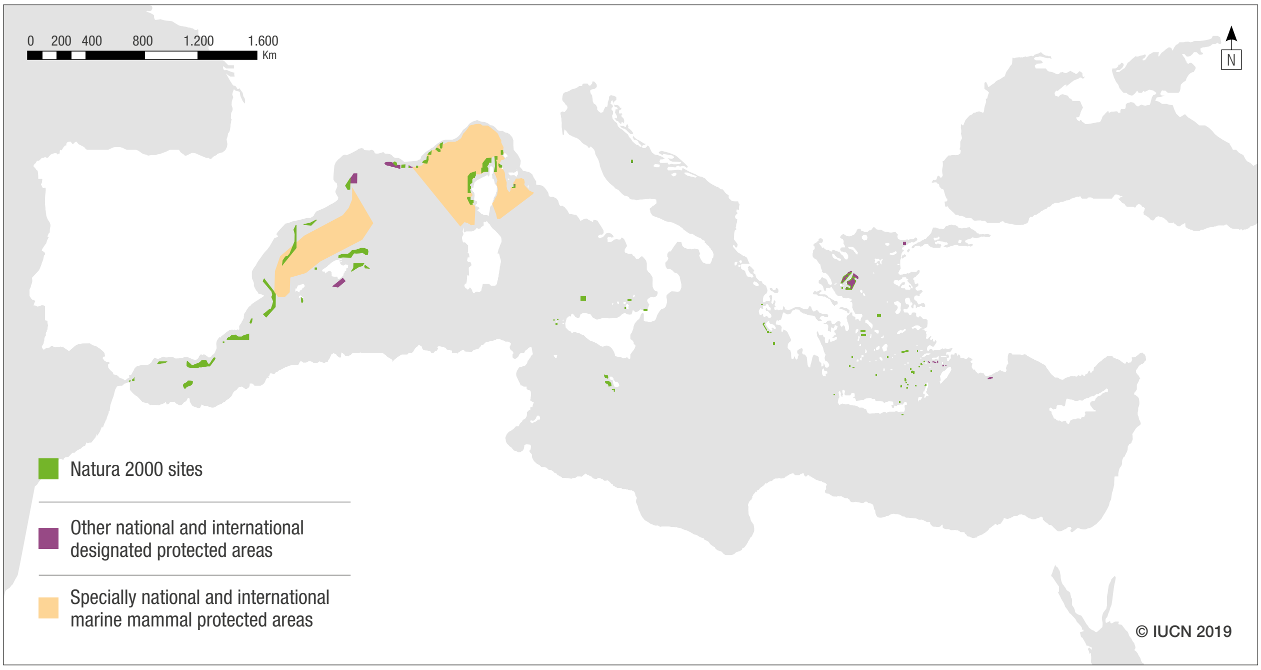


Fig.23. Area below 200m depth covered by different types of Protected Areas. **Adapted by** IUCN, 2019.

Source: MAPAMED database on Sites of interest for the conservation of marine environment in the Mediterranean Sea. MedPAN, UNEP/MAP/RAC-SPA. 2018. Note that only boundaries of Protected Areas below 200m depth are indicated and overlap between designations are not shown.

4. Insufficient number of deep-sea observatories to cover the 3 main sectors (Western, Central, Eastern) of the Mediterranean basin (**KM3NeT**[10] infrastructure: EMSO-Antares in the West Ligurian sea and the **EMSO**[11]-Catania in the Western Ionian Sea Node), with special reference to the ability to integrate the environmental information, biological components, connectivity among deep-sea population and habitats, continuing integrated ecological studies in relation to conservation measures and long-term monitoring networks in the deep-sea.

Challenges assessing pressures and impacts

Additionally, **the foremost gaps identified in relation to multiple stressors and impacts** in the deep Mediterranean are:

1. Lack of knowledge on changes in pH (limited information especially at bathyal depths, limited spatial coverage and scattered data over time), temperature shifts in Mediterranean deep waters (data available from few sites in the Western Mediterranean) and long-term changes in oxygen concentrations in deep-water masses.

2. Limited knowledge on the impacts and extent of episodic climate driven events (e.g., dense shelf water cascading events) and on altered deep-water circulation;

3. Limited information on the location and extent of deep-sea trawling and other fishing practices (artisanal and recreational) that damage habitat integrity.

4. Scant information on the contamination of deep-sea habitats and organisms, and lack of information on their biological response.

5. Limited information on the impact of noise in the deep-sea.

6. Very limited information on the occurrence of alien species in deep-sea regions and their potential impacts.

7. Lack of understanding of the synergetic impacts of multiple stressors.

8. Scarce knowledge regarding the effects of microplastics on demersal species (including commercial species) nor any knowledge concerning the effects of abandoned fishing gear strewn over fragile deep-sea habitats (e.g. entangled coral).

[10] **EMSO:** European Multidisciplinary Seafloor and water-column Observatory.
[11] **KM3NeT:** Kilometre-Cube Underwater Neutrino Telescope, European research infra-structure devoted to fundamental astrophysics research.

Caloforte coast, Sardinia. **Kolibri999**

Governance and biodiversity protection challenges

During the last decade, the number of MPAs has increased in the Mediterranean. A recent analysis done in 2016 by **MedPAN**[12] and **RAC/SPA**[13] showed that since 2008, 23 new MPAs have been created in 10 Mediterranean countries, and 55 others are currently being processed. To date, there are 1,231 MPAs and OECMs (Other Effective area-based Conservation Measures) in the Mediterranean Sea, covering 179,798 km^2 which places a surface of 7.14% under a legal designation[211].

However the existing set of MPAs lacks coherence, connectivity, and representativeness; and too little progress has been made so far in giving the deserved attention to the need of MPAs designation in the Mediterranean open seas and deep-seas *(Fig.23)*. Even the protection afforded by the region's offshore MPA –the Pelagos Sanctuary–, the Intercontinental Biosphere Reserve of the Mediterranean, the new cetacean Santuary (Cetaceans Migration Corridor in the Mediterranean) located in Levantine-Balearic region of Spain and deep-sea Natura 2000 sites remains almost nominal[14]. Thus, the current deep-sea Mediterranean MPAs are still far from becoming an ecologically coherent, well-managed network with adequately representation of deep-sea habitats.

Therefore, in relation to the management of deep-sea ecosystems these are the foremost gaps identified for the Mediterranean:

1. Need to complete the identification of vulnerable marine ecosystems (VMEs) and the development of related conservation and management measures.

2. Assess the spatial distribution and levels of pressure and resultant impact to establish environmental targets and associated indicators to monitor the progress towards achieving good environmental status (GES) in the deep-sea (offshore circalittoral, upper and lower bathyal and abyssal habitats).

3. Develop an adequate governance framework for Mediterranean countries, with an effective and shared policy for the assessment of future exploitation of the deep-sea (offshore circalittoral, upper and lower bathyal and abyssal habitats).

4. Need for the designation of new MPAs and other conservation measures which cover deep-sea areas in order to ensure connectivity between important biodiversity hotspots (including VME) in the Mediterranean MPA network.

[12] **MedPAN:** Mediterranean Network of Marine Protected Areas managers.

[13] **RAC/SPA:** Regional Activity Centre for Specially Protected Areas (RAC/SPA) of UNEP-MAP.

[14] Finike seamounts (Aneximender seamounts) located between the Hellenic and Cyprus arcs was declared by Turkey (Official Gazette no: 28737) in 2013. As offshore area, there are claims by neighboring countries on the maritime jurisdiction of this area.

Caloforte coast, Sardinia. **Luigi Asuni**

06 Potential management measures: strategic actions and targets

Establishment of well-managed Deep-Sea protected areas

MPAs can be an important tool for restoring damaged seascapes and for enhancing the recovery of over-fished stocks. In recent years, more vigorous efforts have been undertaken to establish MPAs both expressly for the purpose of biodiversity protection and additionally as tools for the management of fisheries to rebuild depleted stocks[212]. MPAs are viewed as an important vehicle for implementing the "shared obligations of all countries to protect against the decline of marine species and ecosystems, and the collapse of shared fisheries" and contribute to the protection of at least 10 % of the Deep Mediterranean Seafloor (AICHI TARGET 11, CBD).

Future research is essential to increase our understanding of the biodiversity and ecosystem functionings of the deep and to provide sound scientific data that enable policy makers and stakeholders to develop management options (including sustainable use of resources and conservation), for any future exploitation and preservation of deep-sea resources. In France for example, recent studies on submarine canyons along the Mediterranean French coastline (MedSeaCan and CorSeaCan campains), conducted by the French Marine Protected Areas Agency (now French Biodiversity Agency) in collaboration with different research institutions, have painted an initial background of the biological information on all of the canyons heads in terms of habitats, species and human pressures. These campaigns led to designation of the Lacaze-Duthiers submarine canyon as an MPA, the creation of the National marine Park in the Gulf of Lyon as well as the consolidation of the perimeter and extension of the MPAs of Scandola, Calanques, Cape Corse and a number of Natura 2000 sites.

A similar effort was conducted by the Deep-sea project in Lebanon, a partnership between Oceana, IUCN and UNEP/MAP-RAC/SPA, on behalf of the Lebanese Ministry of Environment and with the support of CNRS-L to explore the sea canyons of Lebanon (Cheka & Batroun, Bay of Jounieh, Northern St. George, Beirut Escarpment and Gulf of Beirut and Saida) and facilitate the creation of the first deep-sea Marine Protected Areas in Lebanon.

PROPOSED KEY ACTION TO: Establish well-managed deep-sea protected areas contributing to the protection of at least 10 % of the Mediterranean Sea

1. Identify and describe Vulnerable Biodiversity Hotspots in the deep-sea and formulate clear proposals for management measures to protect these sites from principal threats and pressures.

2. Identify active submarine canyons, i.e., those where there phenomena of upwellings is known to occur (possibly at a maximum distance of 100 nautical miles from each other), and the most important seamounts for biodiversity (e.g. the Anaximander, Eratosthenes, Palinuro, Vercelli Seamounts) to be proposed as MPAs and/or FRAs, and evaluate them as potential future SPAMI sites.

3. Propose protecting little known ecosystems such as fluid escape features and pockmarks as key habitats for ecosystem functioning.

4. Extend existing protection measures to offshore and deep-sea habitats including biogenic reefs and cnidarian gardens including both living and dead corals (frameworks and coral rubble) to facilitate the possible recovery of damaged habitats and associated species (e.g. commercial fish assemblages).

5. Propose the protection of areas containing several Vulnerable Biodiversity Hotspots (e.g. continental shelf and slopes, submarine canyons with deep-water corals on seamounts, hydrothermal vents) and a surrounding buffer zone.

6. Increase current research efforts to obtain a more complete map of key deep-sea ecosystems (seamounts, canyons, cold seeps, hydrothermal vents, DHABs, coral reefs and cnidarian gardens, sponge grounds) that could also enhance our understanding of the genetic connectivity among populations and species dispersal pathways.

PROPOSED KEY ACTION TO: Establish well-managed deep-sea protected areas contributing to the protection of at least 10 % of the Mediterranean Sea

7. Outline, the important role deep-sea habitats play in maintaining the "goods and services" the Mediterranean provides.

8. Following the agreements achieved under GFCM (2017), compile the existing data on VMEs (Vulnerable Marine Ecosystems) within a coordinated programme of research to identify areas where VMEs and fishing footprint occur for further evaluation and management measures.

Extending restricted fishery areas to protect against overfishing and habitat destruction

Previous joint efforts by the WWF and IUCN have led to the recommendations and thereafter GFCM's decision to exclude trawling beyond 1000 metres depth (54,5% of the basin) in the Mediterranean, making this deep benthic ecosystem the largest protected area from this type of fishing activity in the world. Despite the recommendations and assessments of scientific result analysis, the exploitation of deep-sea species above 1000 metres has, in many cases, exceeded scientific recommendations. This, together with commonly used, unselective and negatively impacting fishing methods (e.g. bottom trawling) in the Mediterranean, has produced rapid and substantial declines in most deep-sea stocks and on the ecosystem. The corollary damage is manifest in the diminishment of biodiversity as well as the decrease in cover and abundance of species. As a consequence, certain species and habitats have become highly vulnerable to fishing impacts. The further need for the implementation of UNGA Resolutions[10] related to VME protection is also a major issue for the sustainable use of deep-sea resources.

As part of a compilation exercise, a list of criteria for the selection of **Vulnerable Deep-Sea Biodiversity Hotspots** was elaborated. Keeping in mind that data is scarce for some sites and that the biodiversity aspects of the deep-sea environment have not been widely explored in some regions, the information available allows for a preliminary selection on known Vulnerable Mediterranean Deep-sea Ecosystems.

Based on the existing information gathered and examined by experts **on a set criteria** *(Table1)*, 20 sites have been initially proposed *(Fig.24)* for management measures given the fragility of their ecosystems, the threats facing them, and their slow recovery. The proposed sites provide examples of areas that could be selected as Fisheries Restricted or Protected areas including cold-water corals and hydrozoa formations (e.g. Stylasteridae), sponge dominated communities, milennial coral gardens, rich sea pen fields, and other fragile agregations of soft bottom communities along canyons and trenches, seamounts, plains, hydrothermal vents, and cold seeps (e.g. mud volcanoes for microbes and associated fauna). As further data becomes available, the updating of this information will allow the selection of additional sites for building of a coherent and representative network of MPAs or the application of other spatial management measures to ensure their conservation in the Mediterranean.

[10] UNGA Resolutions 59/25, 61/105 and 64/72

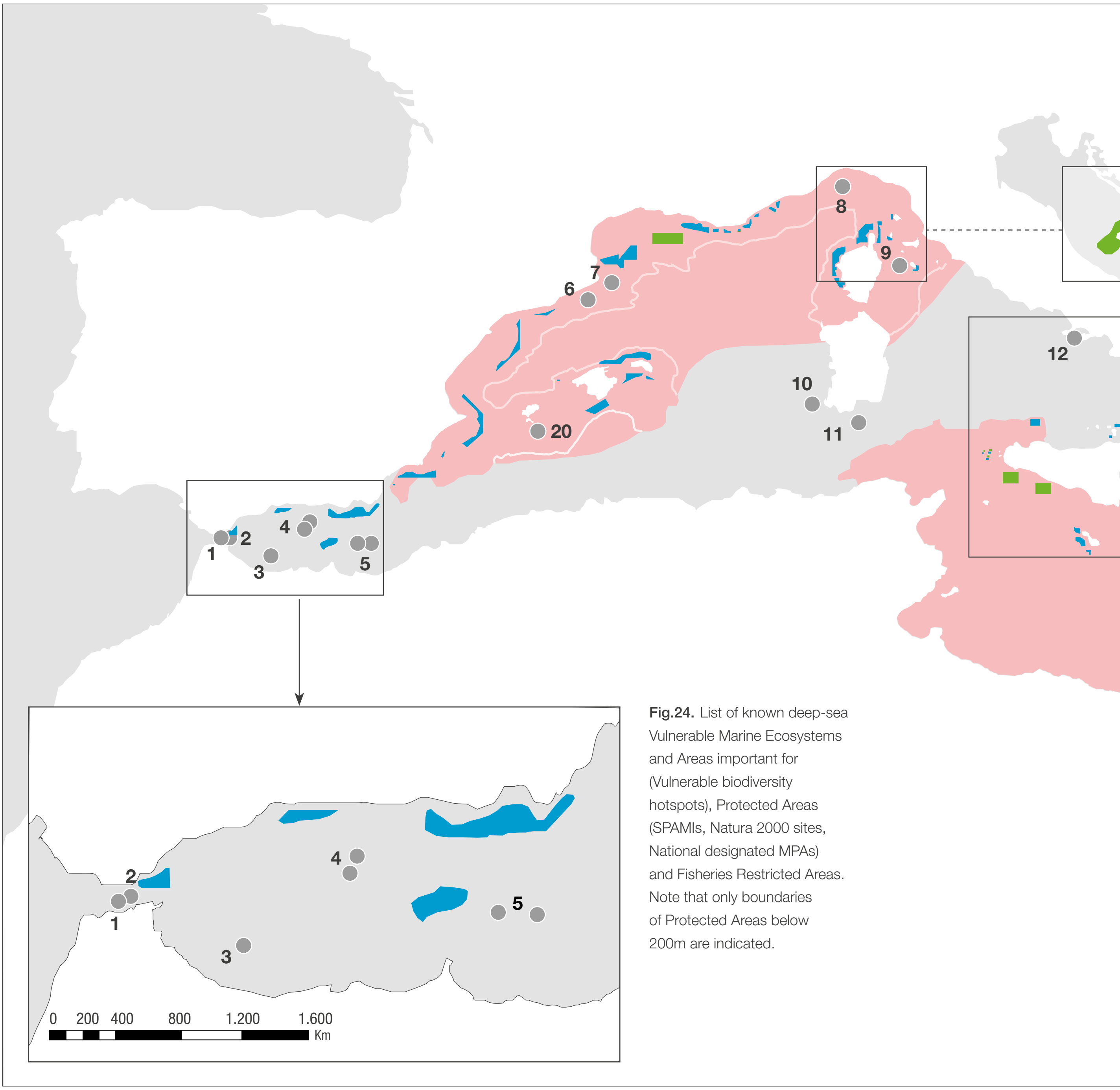
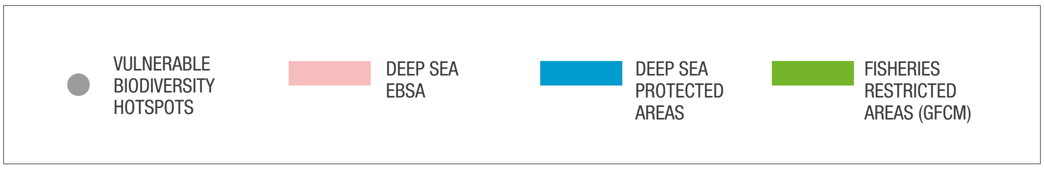
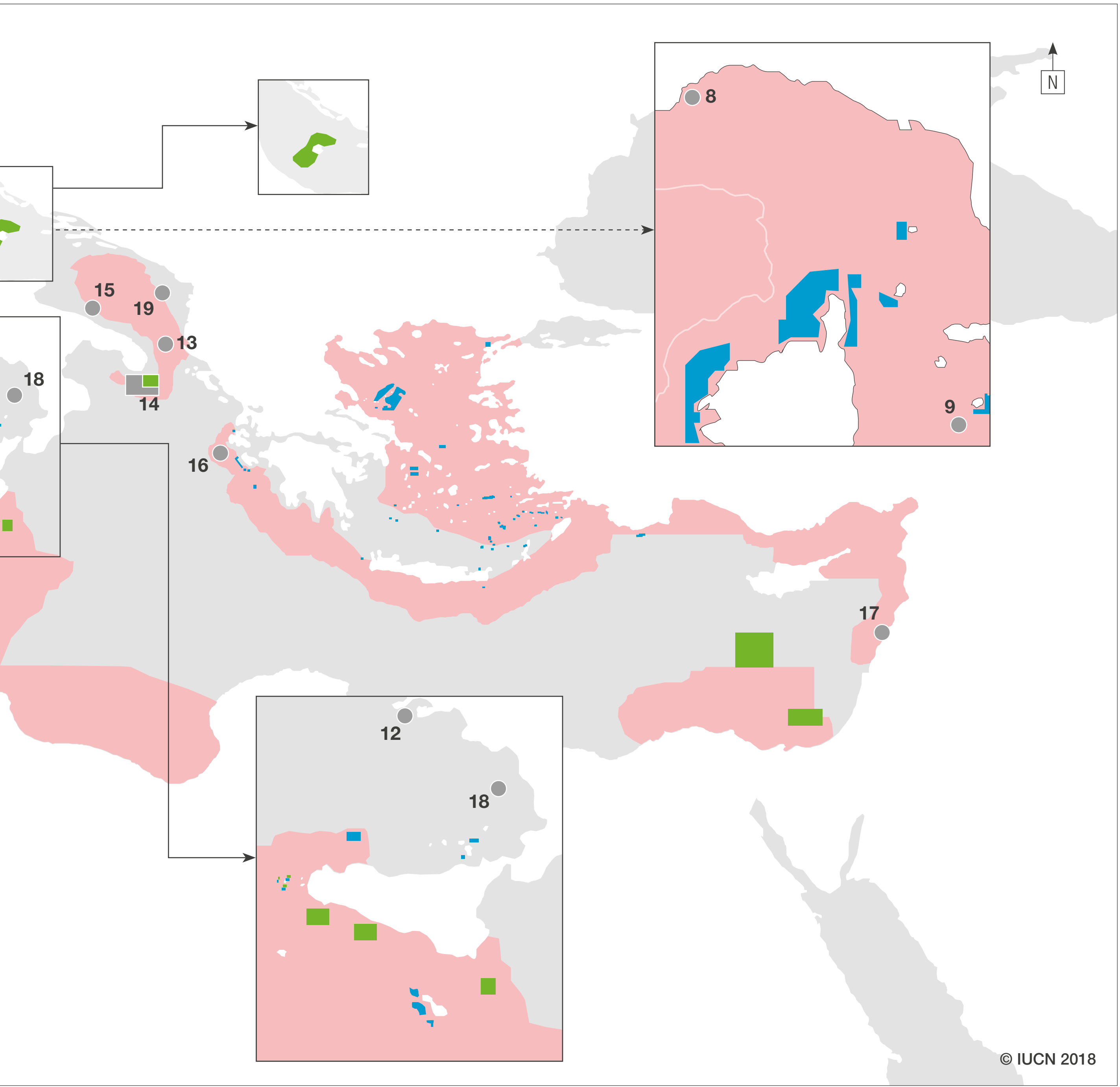


Fig.24. List of known deep-sea Vulnerable Marine Ecosystems and Areas important for (Vulnerable biodiversity hotspots), Protected Areas (SPAMIs, Natura 2000 sites, National designated MPAs) and Fisheries Restricted Areas. Note that only boundaries of Protected Areas below 200m are indicated.



Known Vulnerable Biodiversity Hotspots and existing deep-sea areas with protection



1. Hesperides seamount
2. Hercules seamount
3. Alboran seamount and cold seeps
4. Djibuti spur and bank (Herradura bank)
5. Cabliers and Catifas Banks
6. Blanes Canyon
7. Fonera Canyon (Palamos)
8. Mantice Shoal and Ligurian Canyons
9. Montecristo Shoal
10. Carloforte Shoal
11. South Sardinia Canyon
12. Dohrn Canyon
13. Otranto Strait
14. Extension of Santa Maria di Leuca cold-water coral province
15. Bari Canyon
16. South Cephalonia Island
17. Lebanon canyons
18. Palinuro seamounts
19. Montenegro Canyon & Cold seeps Carbonates
20. South Balearic Seamount (Ses Olives-Ausias March)

Table 1. Initial criteria for the selection of **Vulnerable Deep-sea Biodiversity Hotspots**.

VALUES
Habitat types present
Biological diversity
Structural role
Functional role
Special importance for life history stages of species
Present of relict species
Vulnerability, fragility, sensitivity, or slow recovery
Uniqueness or rarity
Biological productivity
Importance for threatened, endangered or declining species and/or habitats (according to IUCN Red List, Barcelona Convention Annex II, National Red List, EU Habitat Directive or others)
Economical values
USES
THREATS
PROTECTION FIGURES (IF ANY)
OTHER SPATIAL MANAGEMENT MEASURES IN THE AREA (EJ. FRA SITE, PSSAS*, ETC)
RELEVANT REFERENCES (SCI PUBLICATIONS, GREY LITERATURE)
KNOWN RESEARCH CAMPAIGNS

* **PSSAs:** Particularly Sensitive Sea Areas.

Fishermen at Mola di Bari, Italy. **Viktoriia Fokina Fokina / Dreamstime**

Cephalonia Island, Greece. **Nina Evensen / Dreamstime**

Box. Case Site 1. Bari Canyon Cold-Water Coral.

The Bari Canyon, located in the South Western Adriatic Sea is characterized by the presence of cold-water corals with extended facies of *M. oculata*. Other species, both colonial (*L. pertusa*, *D. cornigera*) and solitary cnidarians (*D. dianthus*, *Stenocyathus vermiformis*), sponges, serpulids, boring clams, and colonies of bryozoans are also abundant. Sponge fields, among which *Pachastrella monilifera*, mixed with living colonies of the white coral *M. oculata* dominate the deep assemblage in the Bari Canyon at depths between 380 and 500 m.

More than 70% of these species are of fishery interest, although of variable commercial value. This canyon also acts as a spawning ground for some commercially important species, thus representing an "essential fish habitat" for the renewal of their populations. The main threats are represented by fishing activities, mostly long lining, trawling, and discarded/lost fishing gear, as well as by plastic debris.

Box. Case Site 2. Cephalonia Island, Eastern Ionian Sea.

Between depths of 300 to 800 m, the northern side of Cephalonia Island consists of a muddy seabed with the rare presence of rich assemblages of deep water corals, specifically, Antipatharia, Plexauridae, Pennatulacea and Isididae.

This site is mostly composed of endangered black corals (*Antipathes dichotoma*) and the critical endangered bamboo coral *(Isidella elongate*), in close association with a fish assemblage that includes some unique species (blackmouth catshark *Galeus melastomus*, blackbelly rosefish *Helicolenus dactylopterus*). Other species that occur here are *Desmophyllum dianthus*, *Swiftia pallida* and *Pennatula phosphorea*, *Leiopathes glaberrima*, *Aristaeomorpha foliacea*, *Polyprion americanus*, *Schedophilus ovalis*, *Sudis hyalina Rafinesque*, *Brama brama* and *Trachipterus trachypterus*. The area is currently used for longline fisheries (blackspot seabream) and trawling on the adjacent shelf.

Caloforte coast (Sardinia, Italy). **Simon Steinberger / Dreamstime**

Box. Case site 3. Carloforte Shoal (Sardinia, Italy)

Carloforte Shoal is located 11 nautical miles off the Southwestern coasts of Sardinia (Western Mediterranean Sea). It has a complex topography with numerous rocky elevations that emerge from a flat muddy bottom at 210 m of depth. Here, a pristine and dense black coral population of *Leiopathes glaberrima* form important facies on these deep-sea rocky bottoms with individual colonies reaching up to 2 m-tall. Radiocarbon dating has demonstrated that these colonies could be approximately 2000 years old. The area is also a nursery site for dogfish *Scyliorinus canicula* and is considered a shallow refuge for the soft bottom gorgonian *Isidella elongata*.

This region is surrounded by an area subjected to intense trawling and long-line activities in pursuit of several deep-sea fishery resources (e.g. the rosefish *Helicolenus dactylopterus*, the blackspot seabream *Pagellus bogaraveo*).

Box. Case Site 4. Nora Canyon, Southern Tyrrhenian Sea

This recently discovered site, part of the Sardinia cold-water coral province, is characterized in the Nora canyon (down to 1000m) by a spectacular coral growth dominated by the branching scleractinian *Madrepora oculata* at a depth of 380–460 m. The area is also a hotspot of megafaunal diversity hosting, among others, live specimens of the deep-sea oyster *Neopycnodonte zibrowii* and the coral *Desmophyllum dianthus*, with several other co-occurring species such as *Lophelia pertusa*, *Dendrophyllia cornigera*, together with several deep-sea sponges (*Pachastrella monilifera* and *Poecillastra compressa*). Even though it is still being explored, the richness of fauna and the uncommon presence of some species (e.g. the sponge *Clathria* (*Paresperia*) *anchorata*) suggest that this site is indeed a hotspot with a rich biodiversity.

Strait of Gibraltar. **Vlad Man**

Box. Case Site 5. Carmen Mud Volcano, Alboran Sea

The Carmen mud volcano, discovered in 2005, is the most active volcano known within the entire Alboran region. It has an intense discharge of hydrocarbon fluids and gas bubbles, particularly methane, and a rich abundance of chemosynthic fauna, still to be described in detail. Cold-water corals have also been found growing in the top part of mud volcanoes of this western region.

As previously mentioned, trawling and dredging gears are banned in the entire Mediterranean basin for areas deeper than 1,000 m. However, there is a need to enter a new phase of identification, zoning, and management for the deep-sea, including the transition zone, which hosts a wide range of species that are impacted in the same way as deeper areas. Significant problems remain in the conservation of deep-sea communities as some of the existing protected measures specifically address the benthic ecosystem and do not have effective mechanisms to protect pelagic or demersal species.

As many of the Mediterranean deep-sea fisheries are multi-specific, incidental bycatch and impacts on vulnerable species and habitats occurs. There is an urgent need for implementing new elements in the fisheries regulations for the entire Mediterranean basin to have a proper management of the environment. In addition, recent evidence on the impact of trawling at depths >600 m and the related effects of desertification of the deep-sea point to a need to revise need to revise the "optimal" depth-limit of bottom-trawling and other such fishing practises[177,178].

Fishing Mediterranean trawler. **Shutterstock.com**

PROPOSED KEY ACTIONS to extend fisheries restricted areas and enhance management

1. Implementation of UNGA Resolutions related to vulnerable marine ecosystem (VME), protection including: 1) Identification of areas where VME occur or are likely to occur and closure of these areas to bottom fishing; 2) The requirement for impact assessments prior to fishing activities; 3) The requirement for vessels to cease bottom fishing in areas where they encounter VMEs.

2. Assess the enforcement of the ban on trawling below 1,000 m in the Mediterranean and evaluate the implications for the extension of enforcement to shallower depths (> 600m).

3. Define guidelines and restrictions that are flexible and able to adapt progressively to new scientific discoveries.

PROPOSED SIDE ACTIONS to extend fisheries restricted areas and enhance management

4. Outline, the important role deep-sea habitats play in maintaining the "goods and services" the Mediterranean provides.

5. Compile the existing data on VMEs within a coordinated programme of research to identify areas where VMEs occur for further evaluate implementation of management measures.

Applying the precautionary principle for oil drilling and mining

Management of Deep-Sea Drilling for Mining, Oil and Gas Exploitation

Although marine mineral mining is still in its infancy, by 2050 it is expected that 2-4 % of the world's minerals located on the sea-bed (e.g. cobalt, copper, zinc and rare earth minerals) will be mined from the sea floor, particularly deep-sea deposits of nodules and crusts[167]. Uncertainties and concerns remain in terms of the largely unknown environmental consequences of deep-sea mining extraction and the outcomes of the first projects that are currently being conducted elsewhere (e.g., the ongoing exploitation in Papua New Guinea). In the Mediterranean, deep-sea mining, if develop, could include the exploitation of mineral deposits such as nodules or manganese crust, as well as massive sulphides.

In other seas, all mineral exploration and exploitation activities beyond national boundaries must be sponsored by a State party to UNCLOS and approved by the International Seabed Authority (ISA). Nonetheless, in the Mediterranean, due of its status regarding offshore waters, these types of activities on the continental shelf are under the Barcelona Convention and its Protocol against pollution from exploration and exploitation, making national authorities in charge of ensuring effective protection for the marine environment from the harmful effects which may arise from mining-related activities in areas beyond national jurisdiction. Within national jurisdiction, that new regulations for pollution control from seabed oil and gas are being developed in compliance with international rules and recommendations.

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At present, the proposed areas for exploitation of deep-sea metal deposits do not yet include the Mediterranean deep-sea. Yet, the presence of wide volcanic areas, the large number of seamounts, the discovery of hydrothermal vents, and other recent evidence—along with the already ongoing exploration and exploitation of oil from the Mediterranean deep-sea floor—suggest that there is indeed a potential interest in the future use of these resources. Nonetheless, availability of sufficient resources, extraction methods, processing technology, costs, and knowledge on possible environmental impacts are challenges that first need to be addressed.

Manganese nodules, cobalt-rich crusts and massive sulphides grow very slowly, and their recovery might take thousands of years. Ongoing efforts to examine how is the formation of these deposits in ecosystems such as the hydrothermal vents of the Palinuro volcanic complex (south-Eastern Tyrrhenian Sea, Aeolian Island Arc, Italy), will allow to understand the ecosystems where they form and their resilience.

Offshore oil and gas production and increasing exploration plans are foreseen for the Mediterranean region. Oil and gas exploration or production takes place mainly in the Italian continental shelf, but also in Greece, Spain and Croatia, off the coasts of Algeria, Egypt, Israel, Libya, Tunisia and Turkey. Increasing exploration plans are also foreseen in the Cypriot, Greek and Maltese continental shelves.

The accident which occurred on the offshore oil drilling rig, Deepwater Horizon, in U.S. waters revealed how massive these impacts can be as well as highlighted the lack of sufficiently adequate technological tools to mitigate such risks.

Understanding the impact of accidental spills by the oil industry constitutes a key challenge that remains to be resolved. With the exclusion of the one developed for the Antarctic region, to date there are no international conventions or international strategies to prevent deep-sea drilling for oil and gas exploitation.

PROPOSED KEY ACTIONS FOR THE DEEP MEDITERRANEAN for applying the precautionary principle for oil drilling and mining

1. Apply the precautionary principle for deep-sea mining to avoid the destructive impact of mining activities on marine biodiversity and the release of potentially toxic substances in the deep Mediterranean waters and sediments. For this, there is an urgent need to implement bans on future mining activities within deep-sea areas beyond national jurisdictions on the basis of a precautionary approach and to ensure adequate regulations at national levels.

PROPOSED SIDE ACTIONS for applying the precautionary principle for oil oil exploration, exploitation and mining.

2. Develop a governance framework adequate for the assessment of future exploration and exploitation for oil and gas of the Mediterranean deep-seas.

07

Monitoring management effectiveness of conservation actions and communication

Spatial conservation measures and other forms of sustainable management need monitoring, control, surveillance (MCS), and enforcement of regulations. Improvements in satellite remote sensing and other technologies (use of remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) are providing solutions for the MCS issue. However, such technologies are not available to all countries, with the risk of a highly unbalanced monitoring capacity among regions. This problem is already evident with respect to the scientific knowledge acquired on deep-sea ecosystems, which is far more advanced in the northern regions of the Mediterranean than it is in southern regions. Difficulties finding specialists (taxonomists) for the identification of certain species groups is also a reality.

Although deep-sea scientific expeditions are costly, field work and multidisciplinary approaches are urgently necessary to implement the monitoring strategy of the deep Mediterranean Sea. The identification of "deep-water sentinel sites" for long-term monitoring of the ecological status, including sites with different types of habitats would be a step forward. Furthermore, long-term seabed and water column observatories could be implemented with the new technology of fixed cabled and docked mobile platforms and the tools to monitor biological and ecological components over extended periods of time. To date, the European Multidisciplinary Seafloor and Water Column Observation (EMSO[11]) represents the best infrastructural implantation scenario for monitoring and surveillance of deep Mediterranean ecosystems. This network is presently linking it to the installation of fixed cabled video-observatories in La Spezia canyon (500 m depth) for the Eastern EMSO branch in the Ligurian Sea[213], and in the seismically active Strait of Sicily off Capo Passero, at the harbour of Catania (Ionian Sea, 500 m depth). The latter is installed close to the NEutrino Mediterranean Observatory-Submarine Network (NEMO-SN1), which has two cabled branches. At both sites time-lapse imaging will collect observations at frequency of minutes together with multi-parametric oceanographic data[50, 220].

These types of network sites equipped with fixed cabled video and semi-mobile stations (e.g. Internet Operated Vehicles as crawlers) can already be found in the Hellenic Arc, Western Ionian, and Ligurian Sea and offer high-frequency, continuous and remote monitoring of a few deep-sea Mediterranean ecosystems[214] that could, in future, be used on other ecosystems such as cold seeps and hydrothermal vents fields.

Long-term deep-sea observatories may efficiently assist the implementation of the Integrated Monitoring and Assessment Programme of the Mediterranean Sea in terms of ecological and hydrological information and a range of ecosystem indicators can be obtained[220]. The Marine Strategy Framework Directive (MFSD) is paving the way in this regard, pushing EU countries to provide baselines and tools to assess the good environmental status (GES) of marine ecosystems, and to extend the monitoring to the deep-sea. Although the Directive involves only EU countries, the monitoring approach, tools, and descriptors, could represent a basis for exploring such monitoring approaches for the whole deep-sea basin as the MSFD has the unprecedented advantage of focusing on biodiversity and ecosystem functioning, along with the chemical characteristics of the ecosystem. Moreover, employing this approach would include the further advantage of already having allocated the necessary financial resources and trained the national institutions in charge of the monitoring activities in the specific deep-sea sites where these observatories are found.

The present knowledge of anthropogenic pressures and their effects on the Mediterranean deep-seas is indeed limited, but it is sufficient to start a monitoring program. Environmental impacts could be localized in relation to existing

[11] EMSO; www. http://www.emso-eu.org/

oil and gas exploration and deep litter disposal (including weapons, industrial wastes, persistent organic pollutants, and heavy metals). Equally, current and future threats related to fisheries or other activities on seamounts or seafloors with massive sulphides ("black smokers areas") as well as the potential use of deep-sea areas for sequestering carbon dioxide or the impact of mining (e.g., manganese nodules) will also need to be monitored. Fine scale side scan sonar (SSS), for example, could easily be used to detect the presence of trawling in banned areas or in SPAMI sites.

The effects of climate change and related stressors including acidification, oxygen decrease, and changes in surface productivity and its effects at greater depths will be particularly intense in the Mediterranean (and more rapid than in most ocean deep basins)[221]. Accordingly, these effects must be properly addressed in future monitoring strategies. Another related challenge is that the deep-sea ecosystems of the Western and Eastern basins are expected to respond differently to these effects.

In light of these considerations, the following key actions are herein proposed so as to implement a working strategy for deep-sea monitoring in the Mediterranean basin.

KEY ACTIONS for developing a monitoring strategy and communication

1. Develop guidelines for the exploration of deep-sea vulnerable ecosystems and the impacts of different human activities on them.

2. Apply the use of the deep-sea monitoring approaches and protocols (based on regionally approved descriptors and indicators, including the assessment of potential climate related changes) for the Mediterranean Sea.

3. Create a platform to link the available information from different databases on the deep Mediterranean (data from past and ongoing field activities, description of existing sensitive and biodiversity hotspots, sources to obtain deep-sea bathymetric maps, etc.). Unify the data repositories to make all of the available data produced by all Mediterranean countries carrying on monitoring in the deep-sea both useful and functional.

4. Develop a communication and awareness program on deep-sea Mediterranean environments.

5. Improve social awareness of the importance of goods and services provided by the deep-sea ecosystems, with special emphasis placed to the deep-seas of the Mediterranean.

PROPOSED SIDE ACTIONS for developing a monitoring strategy

6. Standardize the different approaches and research methodologies on deep-sea ecosystems.

7. Implement monitoring programs for deep-sea sites.

8. Create a network of deep-sea experts and interested stakeholders, identify common work objectives, broaden our knowledge on the southern part of the deep Mediterranean, and select "sentinel sites" for long term monitoring.


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