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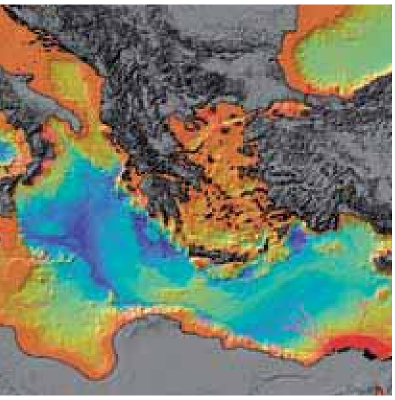
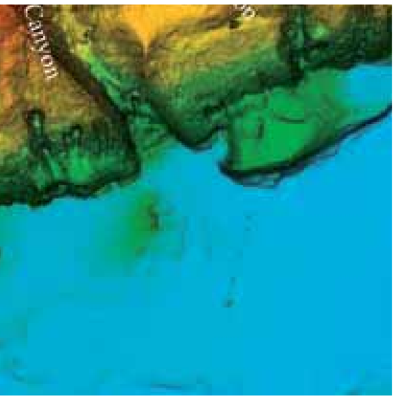
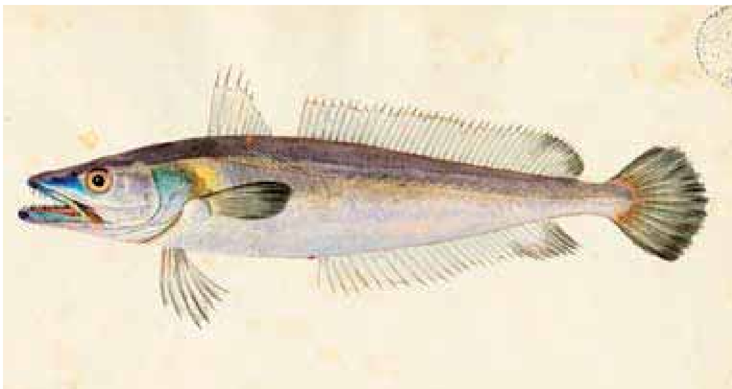
Mediterranean Submarine Canyons

Ecology and Governance

Maurizio Würtz, Editor







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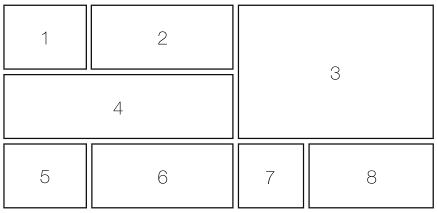

1 Cap de Creus.

2 Morpho-bathymetry of the Mediterranean Sea showing the main canyon and channel systems around the basin.

3 Sperm whale fluke. Maurizio Würtz – Artescienza s.a.s.

4 Shaded bathymetric map illustrating the morphology of the western Ligurian margin.

5 Sperm whale encounters near Ischia during the period 2000-2008.

6 Colonies of Madrepora oculata (left) and Lophelia pertusa observed at 500 m depth in the Lacaze-Duthiers canyon.

7 Bathymetric map of the north-western Mediterranean showing the pathway of the dense shelf water cascading mechanism extending from the Gulf of Lion to the Catalan continental slope and the open-sea convection region.

8 *Merluccius merluccius.* Vincent Fossat (1877 and 1878), Coll. Muséum d'Histoire naturelle de Nice.

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3.7. The benthic communities of the Cap de Creus canyon

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CAP DE CREUS CANYON: LOCATION AND ABIOTIC CHARACTERISTICS

The Cap de Creus canyon is located at the westernmost part of the Gulf of Lion continental margin, considered to be the last of a dense network of submarine canyons that characterize the area (Fig. 1). The head of the canyon is located about 5 km north-east from the Cap de Creus promontory and its end side meets with the end of the Sète Canyon at around 2150 m depth. The Cap de Creus canyon incises the shelf edge at depths of 110-130 m for more than 50 m and progressively widens to attain a maximum amplitude of 6 km, where it reaches depths ranging from 650 m to 2200 m. Both flanks of the canyon show characteristic morphological features due to differential depositional settings and hydrodynamic regimes. While the northern side displays a smooth morphology with rounded gullies and scars, showing a sedimentary depositional set of conditions, the southern flank has an erosive sedimentary nature, characterized by extensive rocky outcrops, vertical walls and terraces (Lastras *et al.*, 2007; DeGeest *et al.*, 2008; Puig *et al.*, 2008). Extensive linear erosive furrows occur at depths between 150 and 1400 m which appear to be associated with the dense-shelf water cascading phenomenon and represent the preferential routes for sediment transport along the southern flank of the canyon (Canals *et al.*, 2006; Lastras *et al.*, 2007; Puig *et al.*, 2008; Ulses *et al.*, 2008).

The proximity of the canyon to the coast, and therefore the reduced extension of the adjacent continental shelf, is another remarkable feature of this canyon. The continental shelf extends to about 130 m depth, displays a rough morphology and is very narrow near the Cap de Creus promontory and the canyon (2.7 km). The proximity to the coast added to the global configuration regarding the Gulf of Lion renders this canyon very particular. The Cap de Creus canyon appears to be a major export path of particulate matter (coming from river input and seasonal storms) from the shelf to the deep areas. The preferential direction of the coastal currents and the narrowing of the shelf towards the west result in the majority of off-shelf sediment transport on this margin running through the Cap de Creus canyon. Sediment fluxes observed in this canyon are much higher than in eastern and central Mediterranean submarine canyons (Palanques *et al.*, 2006). Dense-shelf water cascading, which occurs more frequently and with higher intensity in this canyon, also favors the supply of nutrients and oxygen to the deeper parts of the canyon (Durrieu de Madron *et al.*, 2005; Canals *et al.*, 2006). This process has important biological and ecological implications that contribute to make it a unique system. The large amounts of organic material transported along the Cap de Creus canyon probably play an essential role in the maintenance of high local biodiversity rates and its associated deep-sea ecosystems (Canals *et al.*, 2009; Orejas *et al.*, 2009).

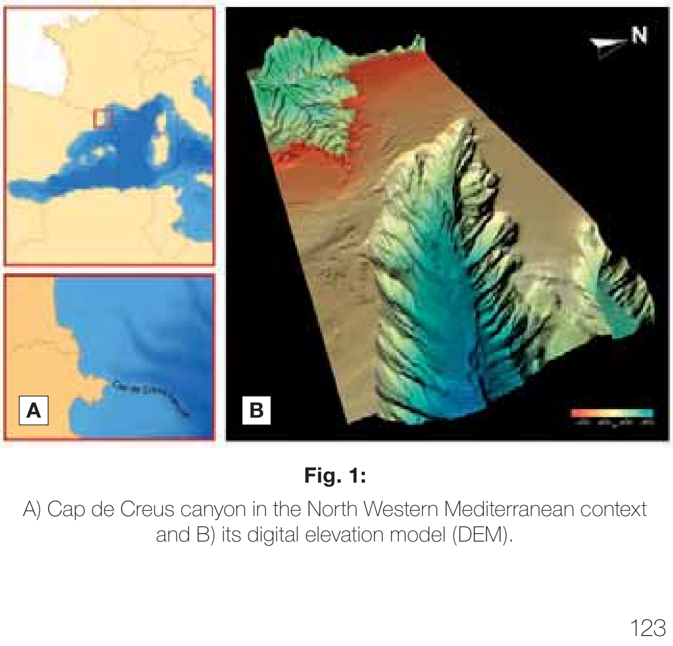

Fig. 1:
A) Cap de Creus canyon in the North Western Mediterranean context and B) its digital elevation model (DEM).

BENTHIC COMMUNITIES IN THE CANYON

The benthic communities found at the head of the canyon and its neighbouring area of the continental shelf have been studied for the last ten years and are still the subject of thorough research studies. The different types of megabenthic communities that dwell in this region are determined by the geological and environmental configuration of the continental shelf and canyon. Two main types of benthic communities have been identified in the southern flank of the canyon between 150 and 400 m depth: circalittoral communities also found on the continental shelf, and bathyal communities of cold-water corals (Gili *et al.*, 2011; Lo Iacono *et al.*, 2012). The description of the megabenthic communities is made after Pérès and Picard (1964), Desbruyères *et al.* (1972–1973) and Pérès (1985).

Circalittoral communities

The circalittoral communities identified are located on the shelf edge and break where sediments are very clean of silt and gravel predominates. There are two communities defined here:

1. The offshore detritic community of the shelf edge and break ("*biocoenose des fonds détritiques du large*") dominates in the outer shelf region (estimated surface area of 31.95%) (Lo Iacono *et al.*, 2012). It is characterized by sessile macrofauna, mainly the sea pens *Pteroeides spinosum, Pennatula rubra* and *Cavernularia pusilla*, together with the soft coral *Alcyonium palmatum* and sponges. Two different *facies* can be distinguished in the upper canyon rim and canyon head, those with shared dominance between sea pens and ceriantharians, and those dominated by sea pens and hydrozoans (Fig. 2 A, B).

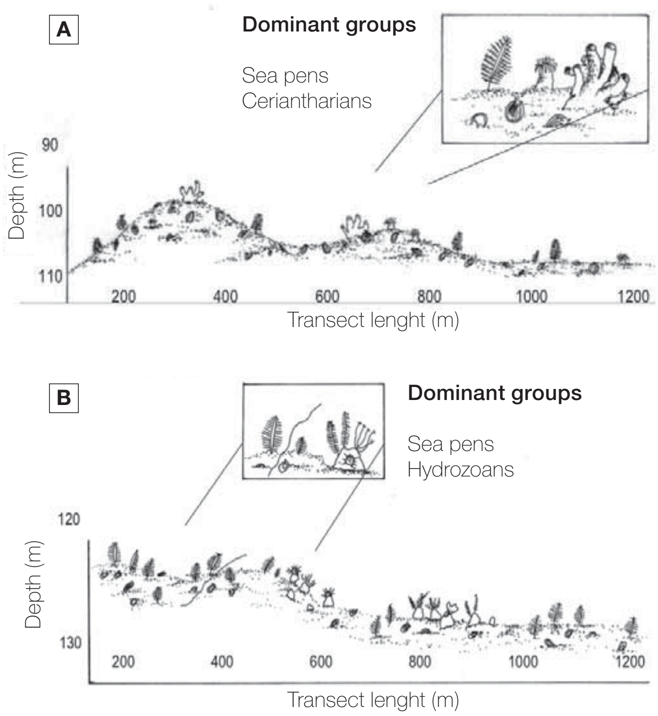

Fig. 2:

Schematic representation of the offshore detritic communities dominated by (A) sea pens and ceriantharians and (B) sea pens and hydrozoans.

2. The offshore rocky-bottom community at the end of the continental shelf (outer shelf) (Fig. 3), known as the "*biocoenose de la roche du large*", has an estimated surface area of 1.81% (Lo Iacono *et al.*, 2012). This community is characterized by the presence of relatively small superficial rocky outcrops that are colonized by a rich fauna of sessile organisms, dominated by sponges like *Phakellia ventilabrum* and *Poecillastra compressa*; colonies of the cnidarian *Eunicella sp,* and a variety of hydroids, bryozoans and ophiurids (genus *Ophiura*). Several species characteristic of both deep areas of the continental shelf as well as individuals from shallower coralligenous communities (e.g. *Parazoanthus axinellae* or *Dysidea tufa)* are also found in well-preserved rocky areas (Gili *et al.*, 2011). This community has been affected by trawl fishing and its presence in the Cap de Creus Canyon is remarkable.

Cold-water coral community

The cold-water coral community found on the southern wall of the Cap de Creus canyon is known as the "*biocoenose des coraux blancs*". This community develops on rocky substrates, dominated by boulders and vertical walls (Fig. 4). The most abundant cold-water coral species present in the Cap de Creus canyon are *Madrepora oculata*, *Lophelia pertusa*, *Dendrophyllia cornigera* and *Desmophyllum dianthus* (known in the Mediterranean as *D. cristagalli*) (Fig. 5), the dominant species being *M. oculata*. Quantitative analysis of occurrence and density of *M. oculata* shows a preferential presence of this species in rocky substrates and a spatial distribution pattern in patches of varying size reaching maximum densities of around 11 colonies/m^2 (Orejas *et al.*, 2009). *D. cornigera* has always been found either alone or in small groups, and *Lophelia pertusa* as isolated colonies.

Another feature of the cold-water coral community in the Cap de Creus submarine canyon is the high diversity of associated species, mainly of benthic suspension feeders such as brachiopods (especially *Gryphus vitreus* and *Mergelia truncata*), polychaetes (*Sabella pavonina*), sponges, bryozoans and other cnidarians including, for instance, octocorals like the red coral *Corallium rubrum.*

The cold-water coral occurrence in the rocky areas of the southern wall of the Cap de Creus canyon is probably related to the food supply through the energetic current flows that periodically carry nutritive suspended particles from shelf environments (Canals *et al.*, 2006) and through the resuspension of shelf organic matter by inertial internal waves (Ogston *et al.*, 2008; Orejas *et al.*, 2009; Tsounis *et al.*, 2010; Purser *et al.*, 2010). The presence of corals in available hard substrates is also related to the reduced sediment accumulation rates caused by cascading phenomena and in general by the strong currents found in the area (DeGeest *et al.*, 2008; Puig *et al.*, 2008). The canyon's northern flank is mainly characterized by soft sediments with high accumulation rates (DeGeest *et al.*, 2008). The lack of rocky substrates probably explains the scarce presence of cold-water corals on the northern wall. However, explorations carried out in this flank of the canyon have been punctual and consequently the communities have not been thoroughly studied yet. Further surveys in the Cap de Creus canyon will provide a comprehensive map of the habitats present in the whole study area.

Fig. 3:
Detail of the rocky-bottom community found at the deeper parts of the continental shelf and canyon head, dominated by sponges.

Fig. 4:
Colonies of *Madrepora oculata* found at depths of 250 m on the southern flank of the Cap de Creus canyon.

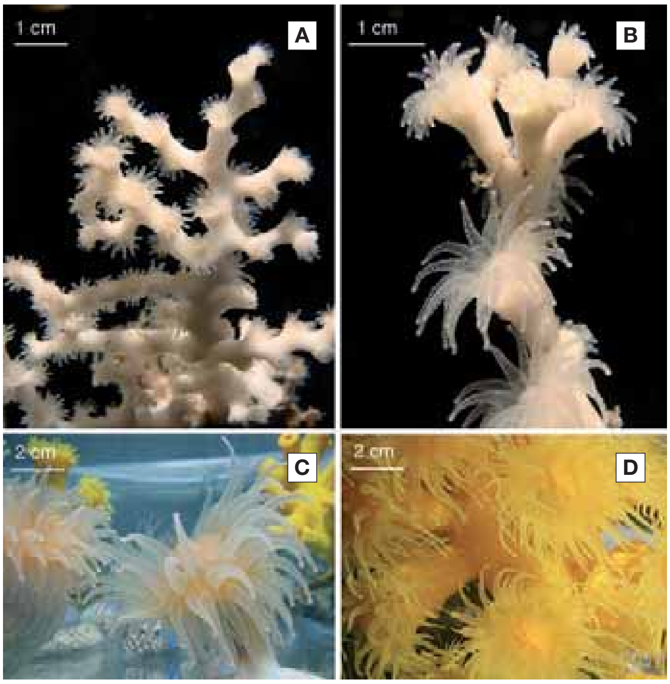

Fig. 5:
Detail of the four dominant cold-water corals found in the Cap de Creus canyon (A) *Madrepora oculata*, (B) *Lophelia pertusa*, (C) *Desmophyllum dianthus* and (D) *Dendrophyllia cornigera* (source Orejas *et al.*, 2011a).

EXPERIMENTAL WORK: FEEDING ECOLOGY AND GROWTH OF COLD-WATER CORALS

The experimental research developed during the last 5 years focusing on cold-water corals, mainly on feeding ecology and growth rates (Fig. 6), has given new insights into the ecology of these species. These kinds of ecophysiological studies are important to obtain a clearer understanding of suitable locations for their development, their population dynamics, as well as the recovery capacity of these species after disturbances of natural or anthropogenic origin.

Aquaria experiments on capture rates developed for some cold-water corals show how efficient these species are when preying on large zooplankton (Tsounis *et al.*, 2010; Purser *et al.*, 2010). The role of zooplankton as prey on key physiological processes of the cold-water coral species *Desmophyllum dianthus* has also been studied recently, showing that this food source is important in sustaining respiratory metabolism, growth and organic matter release (Nauman *et al.*, 2011). These studies emphasize the importance of zooplankton for these organisms. Furthermore, the role of the cold-water coral communities as a hot spot for carbon recycling has also been proven in some locations (van Oevelen, 2009). Experiments performed in aquaria to study the growth rates of cold-water corals showed that, in some cases, these rates are not as slow as it was previously supposed and documented (Roberts *et al.*, 2009). Recent findings show that, in some cases, their growth rates are even comparable to the growth of some of their tropical counterparts. This is the case for *M. oculata* specimens from the Mediterranean, which showed growth rates comparable to *Galaxea fascicularis* colonies, originally from the Red Sea (Orejas *et al.*, 2011b). Growth rates for the 4 dominant cold-water coral species found in the Cap de Creus canyon showed different values in terms of weight increase, which have been related to possible inter-specific physiological differences (Orejas *et al.*, 2011a). The relative high growth rates recorded for the cold-water coral *M. oculata* suggest a higher recovery potential for these communities after disturbances. Further studies would be important to predict future scenarios, where environmental threats such as ocean acidification could play an important role in cold-water coral growth, as it has already been documented for tropical corals (e.g. Marubini and Atkinson, 1999; Marubini *et al.*, 2008; Schneider and Erez, 2006) and for some cold-water corals (Maier *et al.*, 2009, 2011). Studies on the biology of cold-water coral species are therefore critical to enlarge our knowledge on the ecology of these organisms, providing the basis to develop effective conservation plans and guarantee sustainable management of this community.

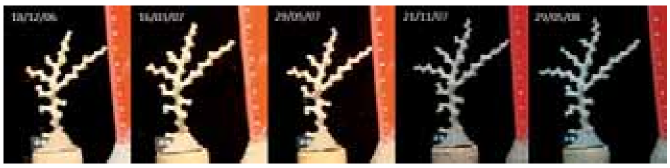

Fig. 6:
Growth of *Madrepora oculata* between December 2006 and May 2008, showing the lengthening of branches, new polyps and the covering of the artificial base by new tissue. Colour differences in the last photograph are due to different lighting during photography.

ASSOCIATED ZOOPLANKTON OBSERVATIONS

The video images recorded with the submersible JAGO at about 200 m depth (Fig. 7) show large clouds of Euphausiacea. There are few observations of large swarms of krill near the bottom as observed in the Cap de Creus canyon, which are mainly reported from Antarctic waters (Gutt and Siegel, 1994; Clarke and Tyler, 2008). In the Mediterranean, observations of the most abundant krill species *Meganyctiphanes norvegica* show maximum abundances (0.09 ind/m^3) in deep areas, around 120 m depth (Tarling *et al.* 2001). The abundance estimated from zooplankton samples in the Cap de Creus canyon for the most abundant species *Nyctiphanes couchii* shows maximum values of up to 0.24 ind/m^3 (Gili *et al.*, 2011). These observations are important because krill is the main food source for many marine organisms, especially cetaceans. Zooplankton is also an important prey in the diet of cold-water corals, as has been determined from biochemical analysis (Duineveld *et al.*, 2004; Kiriakoulakis *et al.*, 2005; Cartier *et al.*, 2009) and direct observations on-site (Mortensen, 2001; Freiwald, 2002).

Fig. 7:
Swarms of krill over a patch of *Madrepora oculata* on the southern flank of the Cap de Creus canyon at 200 m depth.

The presence of fish larvae among the zooplankton communities inside the canyon is also important. The species composition of samples obtained within the canyon includes the presence of larvae of some species of high commercial value, such as hake (*Merluccius merluccius*) (Gili *et al.*, 2011), as well as neritic and mesopelagic species (Fig. 8). The presence of fish larvae suggests how important this particular habitat is as a spawning and nursery area for fish. It is known that cold-water corals act as potential places of refuge, breeding and feeding for many deep-sea species in other regions, including commercially important fish (Husebø *et al.*, 2002; Fossa *et al.*, 2002; D'Onghia *et al.*, 2010). The Gulf of Lion is also a breeding ground for commercially important pelagic species like the anchovy *Engraulis encrasicolus* in spring-summer time and the sardine *Sardina pilchardus* in autumn-winter months (Sabatés *et al.*, 2007).

ANTHROPOGENIC IMPACT

The area of Cap de Creus is characterized as being subjected to considerable maritime traffic, being the connection between the populated and industrialized areas of southern France and Barcelona harbour. It is also regarded as a preferential area for intense fishing activities. Additionally, the anthropogenic impact on the coastal region is exacerbated by discharge from sewage collectors, nautical and recreational activities which intensify during the summer months, and fishing (spearfishing) from recreational boats (Lloret *et al.*, 2008a,b). All these activities, especially fishing, have an important impact on the marine ecosystems and require thorough evaluation.

FISHING IMPACT

Trawl fishery

The Vessel Monitoring System (VMS) provides information regarding vessel code, position, time, speed and direction of the boat to the fishing authorities. In the EU, from 2005 onwards, VMS applies to all large fishing vessels exceeding 15 m in length (EC Regulation No. 2244/2003). Since January 1st 2012, VMS has been extended

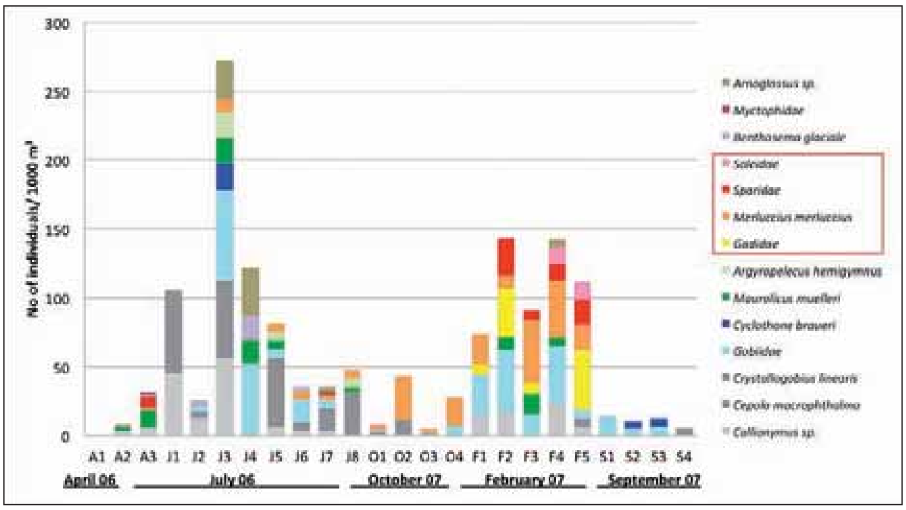

Fig. 8:
Fish larvae in zooplankton samples collected inside the Cap de Creus canyon. Commercial species are highlighted.

to all vessels longer than 12 m (EC Regulation No. 1224/2009). Although VMS purposes are primarily for fisheries enforcements, they are currently employed as a unique and independent tool to spatially and temporally allocate the distribution patterns of fishing activity (Gerritsen and Lordan, 2011; Mills *et al.*, 2007; Witt and Godley, 2007; Skaar *et al.*, 2011).

The data processed from the VMS has provided the opportunity to visualize the spatial behavior of the fishing industry and hence study its potential influence on benthic communities. The provisional analysis so far developed shows an apparently higher density of signals in spring, autumn and winter in the southern part of the Cap de Creus canyon, whereas such fishing activity moves towards a northern canyon during the summer (Fig. 9).

Artisanal fishing

Artisanal fisheries have a long tradition in the Cap de Creus area, and are defined by combining fishing arts, target species, fishing geographical zones and seasonality (Table 1). Despite alternating seasons for target species and closed fishing seasons, this activity takes place all year round, weather permitting (Table 1). Fishermen's local knowledge determines this seasonality by considering a species' behavior and its abundance throughout the year (Stelzenmüller *et al.*, 2007). Fishermen tend to state a lack of specificity in the choice of their fishing grounds, but in fact weather and the previous day's fishing experience determine their destination. Despite their activity, a decline in artisanal fisheries has been observed during the last decades to the benefit of progressive expansion of other practices such as semi-industrial fishing and tourism-related activities (Gómez *et al.*, 2006).

In order to define the degree of impact that fishing gears exert on benthic communities, an overlap value was established (Purroy *et al.*, 2010). The assigned values ranged from 0 to 4 depending on the physical coexistence of the main fishing gears (surface and bottom longlines, trammel nets and gillnets). The absence of fishing gears detected in a given area was attributed the value 0, for those areas where only one fishing gear was active the given value was 1, and so on. A value of 4 was not obtained, indicating that confluence of all 4 gears has not been recorded in the area. The coverage percentage of a particular gear attained values of 60%; the coincidence of two gears corresponded to a value of 29%, whereas interaction of 3 fishing gears being used simultaneously was only observed in 11% of cases. The resulting map reflected the limitations in the coexistence of particular fishing types, i.e. trammel nets and longlines hardly coincide, due to the incompatibility of their fishing techniques.

Comparing Fig. 11, which highlights the well-preserved communities in the study area, and Fig. 10 with the overlap value map, a relationship between the best-preserved communities and the degree of impact of fishing activities can be observed. Thus, areas of high ecological interest coincide with those with less overlap of fishing gears, with values ranging from 0 to 2.

In both cases, artisanal fishing and bottom trawling, the study of the fishing footprint revealed those areas where little fishing gear overlap occurred, coinciding with those areas of high ecological interest, and indicating the degree of impact that fishing gears have on benthic habitats (Gili *et al.*, 2011). The fishing footprint could be used to localize areas where low fishing impact has presumably helped towards the preservation of benthic communities, where potentially pristine areas with high diversity rates can be found. Thus, the fishing footprint appears as an appropriate tool for the assessment and management of areas of interest for conservation.

Fishing impact from ROV images

We investigated the level of the potential anthropogenic impact on cold-water coral species by quantifying the amount of benthic long-line fishing gear and other anthropogenic remnants observed within the canyon (Orejas *et al.*, 2009). Results showed an average of one fishing line every 10 m of video transect. The hard substrate areas snag the long-lines, where they can get entangled by the coral colonies and therefore represent a potential threat to the corals (Fig 12 A, B). Other fishing gears such as gillnets and plastic debris were occasionally observed. Although there is no bottom trawling in the canyon head, the influence of trawling was presumably noticed in the canyon rims where depositions of detritic communities and cold-water coral remains indicated trawling net activity.

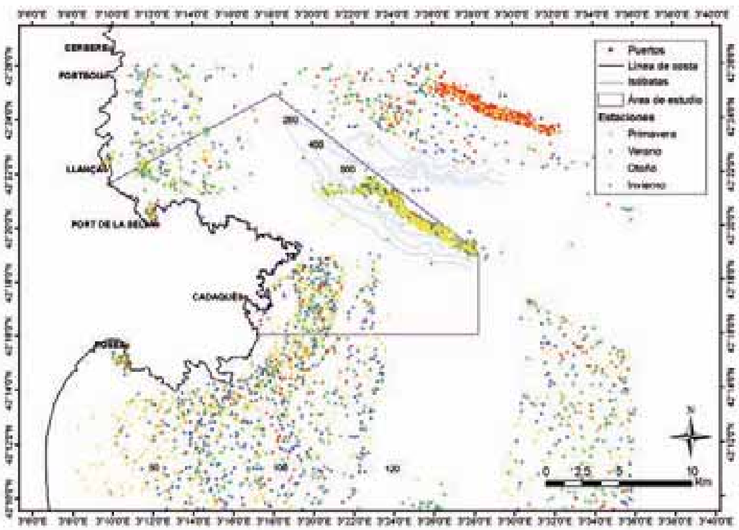

Fig. 9:

Distribution map of fishing vessel locations in the Cap de Creus area in different seasons.

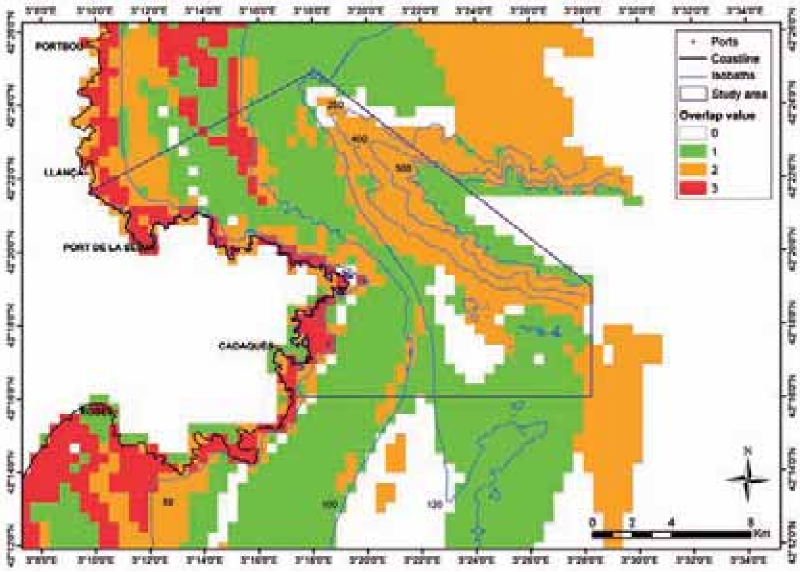

Fig. 10:

Overlap value in the study area of Cap de Creus. Minimum value of overlap is 0 when no fishing gear is present, and maximum value is 3 when 3 different gears coexist.

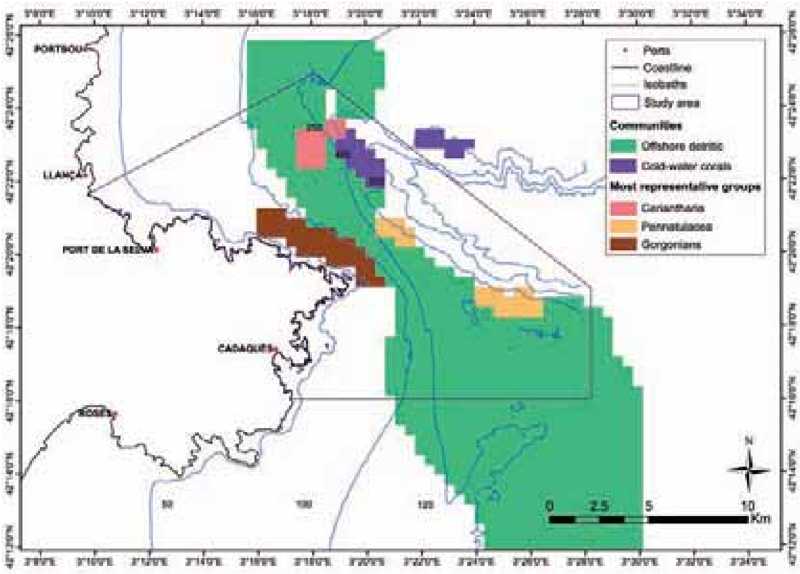

Fig. 11:

Delimitation of communities and the most representative groups in the study area.

MARINE PROTECTED AREA

The geomorphology and oceanography of the Cap de Creus region, as well as the high number of benthic communities hosted in this area, have a decisive influence in converting this region into a remarkable case for the Mediterranean. The relatively small Cap de Creus area holds high species (α) and habitat (γ) diversity, both representatives of most Mediterranean biocenoses. In this area, many coastal communities (i.e. *Posidonia oceani*ca beds, *Cymodocea nodosa* beds, and Maërl beds), and shelf-slope communities (i.e. shelf communities dominated by gorgonians, *Leptometra phalangium* beds) are found. At the same time, this region is one of the few known sites in the Mediterranean Sea to host cold-water coral communities. All of them have been identified as Sensitive Habitats by the European Commission. The shelf and slope region have been proposed as a marine Site of Community Importance (p-SCI) candidate under the Natura 2000 network. The information compiled on the characteristics of the area has been produced through the project LIFE+ INDEMARES "Inventory and designation of marine Natura 2000 areas in the Spanish seas".

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Trammel nets												
Scorpaena spp.			■	■	■	■	■	■				
Mullidae			■	■	■	■	■	■	■	■		
Palinurus elephas			■	■	■	■	■	■	■	■		
Soleidae	■	■	■			■	■	■	■			■
Sepia officinalis	■	■	■	■	■	■						
Gillnets												
Sarda sarda				■	■	■	■	■	■	■	■	■
Diplodus sargus									■	■	■	■
Mullidae	■	■	■	■	■	■	■	■	■	■	■	■
Merluccius merluccius	■	■	■	■	■	■	■	■	■	■	■	■
Pagellus acarne	■	■	■	■	■	■	■	■	■	■	■	■
Atherina boyeri	■	■	■	■	■	■	■	■	■	■	■	■
Pagellus erythrinus									■	■	■	■
Gillnets-Trammel nets												
Sarda sarda				■	■	■				■	■	■
Pots												
Octopus vulgaris	■	■	■	■	■	■	■			■	■	■
Sepia officinalis			■	■	■	■	■					
Longlines												
Sparus aurata	■	■										■
Diplodus sargus	■	■	■	■	■	■	■	■	■	■	■	■
Conger conger	■	■		■	■	■	■	■			■	■
Pagellus erythrinus	■	■	■	■	■			■	■	■	■	■
Phycis blennoides			■	■	■	■	■	■				
Merluccius merluccius	■	■	■	■	■	■	■	■	■	■	■	■
Dicentrarchus labrax				■	■	■	■	■	■			
Bottom longlines												
Merluccius merluccius	■	■	■	■	■	■	■	■	■	■	■	■
Pagellus bogaraveo	■	■									■	■
Miscellaneous gears												
Paracentrotus lividus	■	■	■							■	■	■
Mytilus galloprovincialis						■	■	■	■			
Corallium rubrum	■	■	■	■	■	■	■	■	■	■	■	■
Nereis spp.	■	■	■	■	■	■	■	■	■	■	■	■
Handlines and pole-lines												
Loligo vulgaris	■					■	■	■	■	■	■	■
Boat or vessel seines+A14												
Gymnammodytes cicerelus	■	■	■	■	■					■	■	■
Donax trunculus	■	■	■	■			■	■	■	■	■	■
Acanthocardia tuberculata	■	■	■	■	■	■	■	■	■	■	■	■

Tab. 1:

Monthly specificity of *métiers* for each fishing gear (http://www.faocopemed.org).
The concept of *métier* corresponds to a combination of gear, target species and fishing geographic zone, and is applied in order to define the real effort invested in a resource.

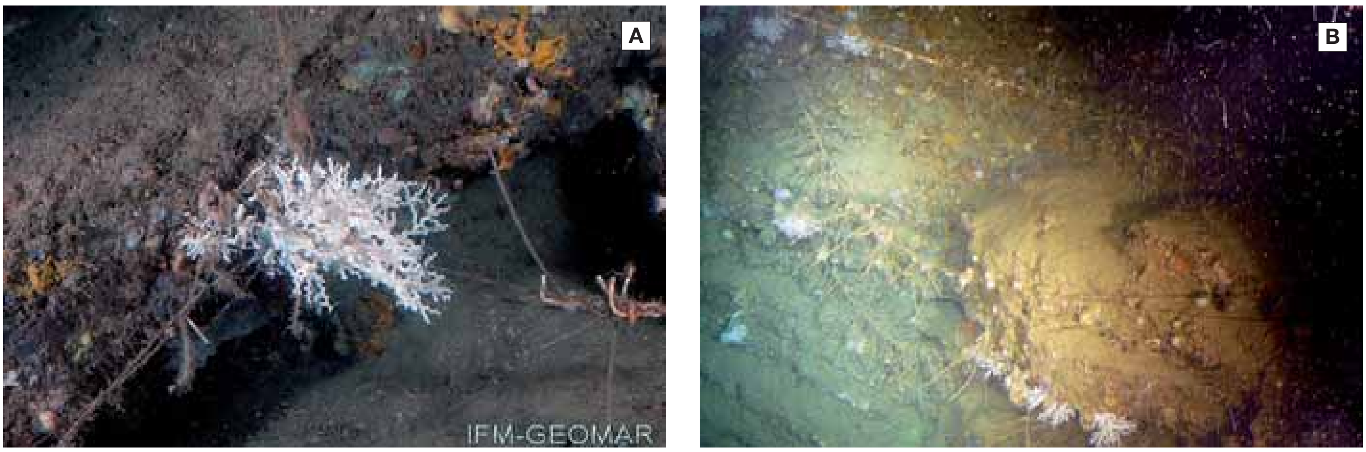

Fig. 12:

A) Colonies of *Madrepora oculata* entangled in a long line.

B) Long lines on the vertical walls of the Cap de Creus canyon.

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