ELSEVIER INSIGHTS

SEAFLOOR GEOMORPHOLOGY AS BENTHIC HABITAT

GEOHAB ATLAS OF SEAFLOOR GEOMORPHIC FEATURES AND BENTHIC HABITATS

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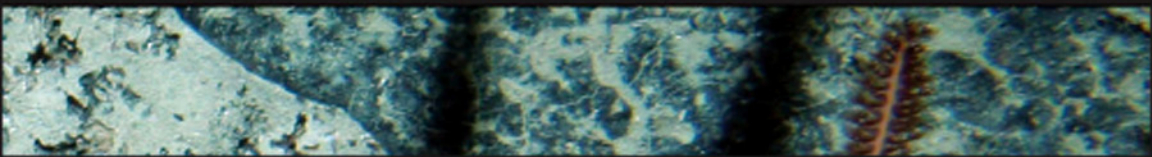

32 Habitats of the Cap de Creus Continental Shelf and Cap de Creus Canyon, Northwestern Mediterranean

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Abstract

The Cap de Creus continental shelf and Cap de Creus canyon are located in the southernmost sector of the Gulf of Lions, in the northwestern Mediterranean. The Cap de Creus continental shelf contains sandy and muddy sediments and an abrupt morphology, with rocky outcrops, relict bioherms, erosive features, and planar bedforms. The Cap de Creus canyon breaches the shelf at a depth of 110 m and denotes a marked difference in the morphology between the northern and the southern flank, reflecting a different depositional regime. The most common substrates correspond to coarse and medium sands (28%) and silty sediments (40%). The most common megabenthic assemblages of the shelf correspond to the communities of "offshore detritic" (31.95%) and "coastal terrigenous muds" (36.99%), mostly dominated by sea pens, alcyonaceans, and ceriantharians. The northern flank of the Cap de Creus canyon is predominantly depositional, whereas the southern flank is erosional. Rocky outcrops provide the substratum for cold-water coral (CWC) communities' development, in which the white coral *Madrepora oculata* is the most abundant species.

Key Words: Swath bathymetry, Continental Shelf, Submarine Canyon, Geomorphology, Habitat mapping, Northwestern Mediterranean

Introduction

Continental shelves and submarine canyons represent peculiar environments that are geologically heterogenous on a small spatial scale (form hundreds to tens of meters) and therefore play a central role in increasing the ecosystem biodiversity [1–4].

Seafloor Geomorphology as Benthic Habitat. DOI: 10.1016/B978-0-12-385140-6.00032-3

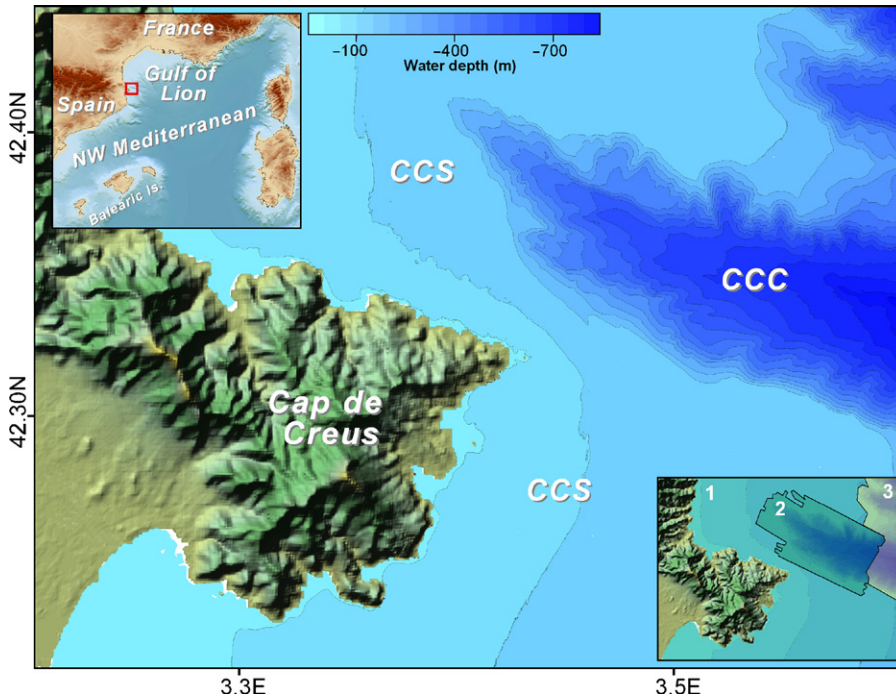

Figure 32.1 Bathymetric map of Cap de Creus continental shelf (CCS) and Cap de Creus canyon (CCC) based on a 10 m resolution grid. Top-left inset: location map showing the northwestern Mediterranean and the survey area, outlined in red. Bottom-right inset: coverage of the multibeam surveys on which this work is based (1, light green: Spanish Fishery General Secretary-ESPACE Project; 2, dark green: Fugro N.V., AOA Geophysics, University of Barcelona; 3, yellow: INDEMARES Project). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this book.)

The study area of this work includes the Cap de Creus continental shelf and the Cap de Creus canyon (depth range 40–800 m), located in the Gulf of Lions, where a complex network of submarine valleys cut the continental shelf and slope regions [5] (Figures 32.1 and 32.2). The total surface of the area is around 611 km^2, 74.7% of which is covered by the continental shelf and a small portion of the upper slope (456 km^2), whereas the remaining 25.3% is covered by the submarine canyon (155 km^2). The continental shelf in this region displays a rough morphology and its width is dramatically reduced between the Cap de Creus promontory and the canyon (Figure 32.1). Shelf sediments are mainly composed of muds and change to coarser fractions along the outer shelf, reflecting an intensification of bottom currents flowing from the North [6]. Numerous studies of sediment transport and accumulation processes have been recently conducted in the submarine canyons from the Gulf of Lions, providing a unique temporal and spatial perspective of their functioning [7,8]. These studies recognized the importance of major storms and dense shelf-water cascading

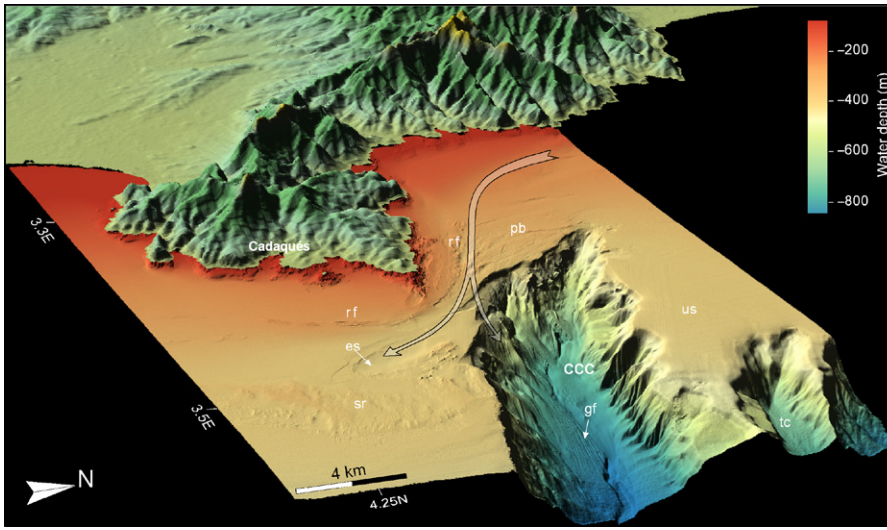

Figure 32.2 Three-dimensional perspective model of the study area: rf: relict features; pb: planar bedforms; es: erosional scour; sr: suboutcropping rocks; us: upper slope; CCC: Cap de Creus canyon; gf: giant furrows; tc: tributary channel. Forked arrows: bottom current paths of the area based on Ref. [6] and inferred from the orientation of the observed morphologic features.

events in exporting shelf waters and particles toward deep-sea regions [7,8]. The preferential direction of the coastal currents, the narrowing of the shelf and the coastal topographic constrains result in most of the sediment transport occurring through the Cap de Creus canyon, where observed sediment fluxes associated with a approximately 1 m/s near-bottom current, mainly flowing across the southern canyon flank, are two orders of magnitude higher than in the eastern and central submarine canyons [9].

In this study, we present a characterization of the main morphological and depositional features and related habitats of the Cap de Creus continental shelf and canyon head, in the northwestern Mediterranean (42.21°–42.44°N, 3.12°–3.50°E), integrating swath bathymetry, video images, and sediment samples. No statistical analyses have been carried out to analyze relationships between abiotic surrogates and benthos.

Geomorphic Features and Habitats

The Cap de Creus continental shelf has been mapped during a number of oceanographic cruises conducted since the 1990s by the Spanish National Research Council (CSIC) [10]. High-resolution swath-bathymetry data of the continental shelf presented in this work were kindly provided by the Spanish Fishery General Secretary ("Secretaria General de Pesca") and acquired in the frame of the ESPACE Project (Estudio de la Plataforma Continental Española) (Figure 32.1). Additional bathymetric data were

acquired in specific sectors of the shelf as a part of the projects DEEPCORAL and INDEMARES [11]. Multibeam data from the Cap de Creus Canyon has been acquired during two surveys conducted in 2004 by Fugro N.V., AOA Geophysics, and the University of Barcelona, and in 2010 by the Instituto de Ciencias del Mar (ICM-CSIC) in the frame of the INDEMARES Project (Figure 32.1). The combination of the different swath mapping data sets allowed the production of 10 m cell size high-resolution bathymetric images of the area for depths ranging from 20 to 850 m (Figures 32.1 and 32.2). Twenty-two video surveys were conducted from 2005 to 2007 using ROVs and the manned submersible JAGO (IFM—GEOMAR) in a depth range of 50–400 m. Megabenthic communities in the area were observed in video records, and in some cases, organisms were collected. Video analysis was performed with the Final Cut software (Apple Inc.). Three classes (soft sediment, rocky boulders, and massive hardrock outcrops) have been defined in order to characterize the different substrates in the video transects as well as the correspondence between organisms and substrate type [4].

Several sediment samples have been collected in the area since the 1970s [6,12]. Analysis of the main characteristics of sediments (composition and grain size) and of their associated benthic assemblages resulted in a high-resolution habitat mapping of the shelf and of the canyon [11]. The totality of data have been merged using Quantum-GIS software, an open source Geographic Information System (GIS), and ArcInfo mapping software, in order to produce maps and carry out spatial analysis operations.

The Cap de Creus continental shelf: The continental shelf mapped around the Cap de Creus promontory covers a surface of around 400 km^2, displaying a width ranging from a minimum of 2.7 km near the cape to a maximum of 12 km along the regions south and north of the cape. The average slope of the shelf is 1°, with maximum values of 2.5°, in correspondence with the easternmost sector of the cape. The inner shelf area shows reduced extensions and very steep rocky outcrops along the coastal belt for depths of up to 60 m. The shelf edge lies at an average depth of 120–130 m and is N–S oriented, except for sector where it is breached by the southern flank of the Cap de Creus canyon, showing a NW–SE trend (Figure 32.3A).

The shelf alternates between smooth areas, where sandy and muddy sediments prevail, to rough rocky areas (7.16%), mainly present along the coast and in the outer shelf for depths between 95 and 130 m (Figure 32.3A). Rocky outcrops, elevated by about 6 m above the general seafloor, trend parallel to the coastline at depths of 90–100 m (Figures 32.2 and 32.3A). These outcrops correspond to circular highs located north of the Cape and concentrated along a 17 km long and 500 m wide NW–SE trending area and to 4.5 km long linear ridges located south of the Cape along a 600 m wide NW–SW trending area ("rf" in Figure 32.2). These features correspond to relict coastal sedimentary features and/or relict bioherms whose formation is related to the last sea-level rise stage [10]. North of the Cap de Creus promontory, between the described circular highs and the southern flank of the canyon, juxtaposing planar sedimentary beds occur for a depth range of 100–120 m, giving rise to sinuous steps up to 3 m high ("pb" in Figure 32.2). The area, covering a surface of around 12 km^3, is characterized by very coarse sediments, which have been described as detritic communities in section "Macrobenthic Communities" (Figure 32.3B).

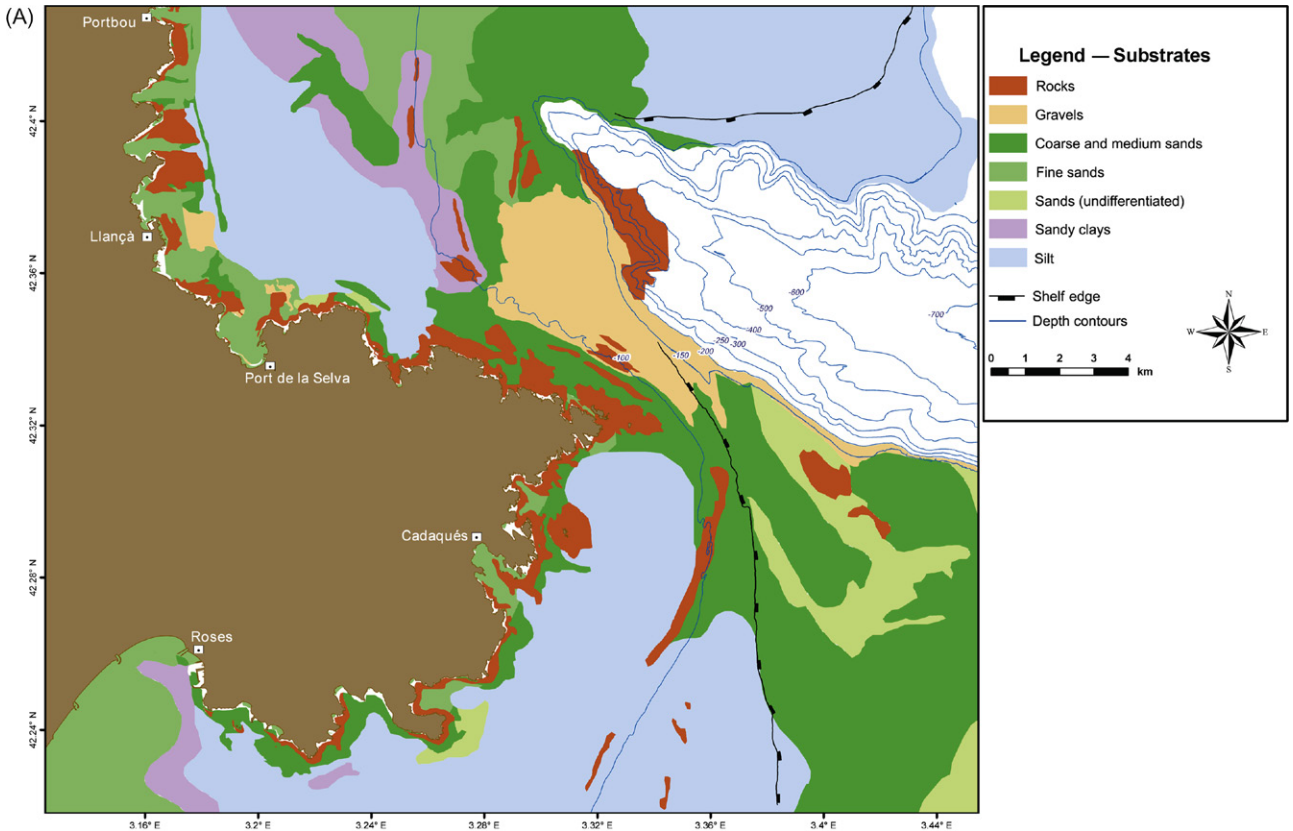

Figure 32.3 (A) Sedimentologic map of the Cap de Creus continental shelf and canyon; (B) map of the megabenthic communities of Cap de Creus continental shelf and canyon.

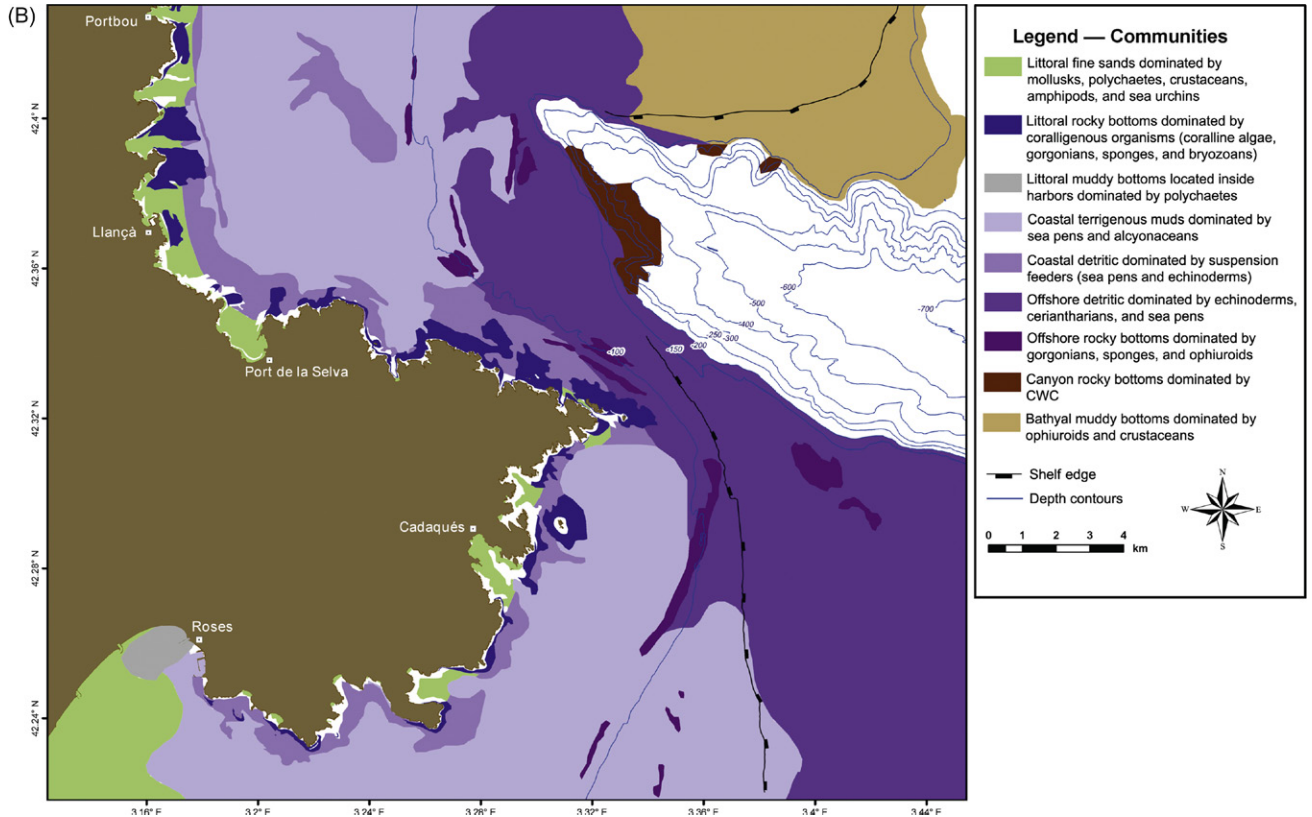

Figure 32.3 (Continued)

Table 32.1 Areal Extent (%, km^2) of Substrates and Communities of the Cap de Creus Continental Shelf and Canyon

Substrate	**Surface Area (%)**	**Surface Area (km^2)**
Rock	7.16	28.11
Gravels	4.79	18.82
Coarse and medium sands	27.72	108.66
Sands (undifferentiated)	4.96	19.45
Fine sands	10.33	40.49
Sandy clays	4.86	19.02
Silt	40.18	157.59
Total	100	392.14
Community	**Surface Area (%)**	**Surface Area (km^2)**
Coastal detritic	6.53	25.51
Coastal terrigenous muds	36.99	145.33
Coralligen	3.16	12.43
Fine sands	5.69	22.21
Offshore detritic	31.95	125.28
Offshore rocks	1.81	7.13
Cold-water corals	1.19	4.68
Bathyal muds	12.12	47.47
Port communities	0.56	2.10
Total	100	392.14

South of the Cap de Creus canyon, the shelf region is marked by a rough morphology for depths deeper than 120 m. A NW–SE-oriented 10 m deep elliptical hole (scour) with the major axis 5 km long and the minor axis 1 km long, occurs at a depth of 130 m and reflects a strongly erosive regime controlled by bottom current flowing from the north across the shelf ("es" in Figure 32.2). An outcropping and suboutcropping rocky area occurs between 120 and 135 m, rising from the general seafloor for 10 m on average and covering up to 34 km^2 ("sr" in Figure 32.2). North the Cap de Creus canyon, the shelf gently slopes to the upper slope region to depths of 160 m, with an average gradient of 2°. In this area, NE–SW-oriented linear bedforms occur for depths from 125 to 135 m. For deeper depths the seafloor is breached by a tributary channel of the Cap de Creus canyon ("tc" in Figure 32.2).

Silty sediments constitute the dominant sediment fraction on the Cap de Creus shelf (40.18%) (Table 32.1). Fine sediments accumulated in the Cap de Creus shelf close to the coast, as well as in deeper areas [13] (Figure 32.3A). From the inner shelf to a depth of up to 90 m, sediments are mainly composed of silt, mud, and fine sands (60.3%) (Table 32.1; Figure 32.3A). From the depth of 100 m, along the canyon head and along the outer shelf south the Cap de Creus canyon, sediments are composed by coarse and medium sands (27.7%) or detritic bioclastic gravels (4.79%) (Table 32.1; Figure 32.3A). The occurrence of such coarse sediments at these depths is related to the bottom current acceleration documented along the outer shelf regions of the area

[14] (Figure 32.2). Finally, silty sediments characterize the northern portion of the shelf from depths from 100 m to the upper slope region, partially sinking to the Cap de Creus canyon through its northern flank [14,15] (Figure 32.3A).

The Cap de Creus canyon: The Cap de Creus canyon is the southwesternmost submarine canyon of the Gulf of Lions, before the constriction of the Cap de Creus promontory (Figure 32.1). The canyon incises the shelf edge at depths of 110 m for more than 50 m and progressively widens for maximum amplitude of up to 6 km and depths of more than 650 m (Figure 32.2). The thalweg displays a deeply incised V-shaped morphology, 2.5º steep on average, descending to a depth of 615 m. From this depth, the thalweg amplitude increases, widening from 2 to 3.5 km. The flanks of the canyon present a different morphological configuration, indicating different depositional settings and hydrodynamic regimes. The southern flank is mainly characterized by broad areas with rocky outcrops, steep and overhanging walls, and terraces indicating an ongoing, predominantly erosive regime [16] (Figure 32.2). Giant furrows, tens of kilometers long, occur for depths between 150 and 1,400 m (out of the limits of the area investigated in this work) ("gf" in Figure 32.2) [15]. These erosive morphological features are generated by dense-water cascading and represent the preferential routes for sediment transport along the southern canyon flank [8,16,17]. The northern flank displays a smooth morphology, with rounded gullies and scars, suggesting a depositional regime for this sector (Figure 32.2). The observed contrast in flank aspect is mainly ascribed to the strong bottom currents and associated high suspended sediment loads flowing down the canyon preferentially along the southern flank [17] (Figure 32.2).

Sediments on the canyon head are composed of coarse sands and shell debris until a depth of 400 m. At deeper depths, the canyon axis is composed of soft consolidated muds mixed to interlayered shell debris [14]. Along the southern flank, where sediment accumulation rates are very low [6], thin layers of gravels and very coarse sands mixed to fine fractions occur along the upper canyon rim until a distance of 15 km from the canyon head. The northern flank of the canyon is mainly composed of clays, with sediment accumulation rates of up to 1.5 mm/year, probably due to advection via nepheloid layer transport controlled by regional southward currents [6].

Megabenthic Communities

The geological configuration of the continental shelf and of the canyon of Cap de Creus (Figure 32.3A) gives rise to different kinds of megabenthic communities (Figure 32.3B). Considering the shelf and the canyon together, more than 1,200 species have been recorded to date (Table 32.2). Benthic suspension feeders are the dominant functional group. Description of the megabenthic communities is based on Pérès and Picard (1964) [18] and Desbruyères et al. (1972–1973) [12]. Original French names after Pérès and Picard (1964) are in cursive within brackets.

The Cap de Creus continental shelf: The coastal rocky bottoms of the Cap de Creus continental shelf are dominated by the community of coralligenous

Table 32.2 Number of Benthic Species Recorded in the Cap de Creus Continental Shelf and Canyon

Phylum	Class	Order	Species Number
Porifera			21
Cnidaria	Scyphozoa		6
	Hydrozoa		101
	Anthozoa (Hexacorallia)		40
	Anthozoa (Octocorallia)		25
Ctenophora			1
Entoprocta			1
Mollusca	Bivalvia		38
	Cephalopoda		16
	Gasteropoda		78
	Polyplacophora		4
	Scaphopoda		2
Annelida			173
Echiura			1
Sipuncula			1
Arthropoda (Crustacea)	Malacostraca	Amphipoda	100
		Decapoda	128
		Isopoda	4
		Mysidacea	12
		Euphausiacea	11
		Cumacea	10
		Tanaidacea	3
		Stomatopoda	2
	Copepoda		133
	Cirripedia		5
	Ostracoda		4
Bryozoa			87
Brachiopoda			2
Chaetognatha			5
Echinodermata	Crinoidea		2
	Holothuridea		1
	Echinoidea		9
	Asteroidea		6
	Ofiuroidea		9
Chordata (Cephalochordata)			1
Chordata (Tunicata)	Ascidiacea		31
Chordata (Vertebrata)	Chondrichthyes		15
	Osteichthyes		159
	Reptilia		3
	Aves		15
	Mammalia		6
Total			1,271

Source: References [11,18]; this work.

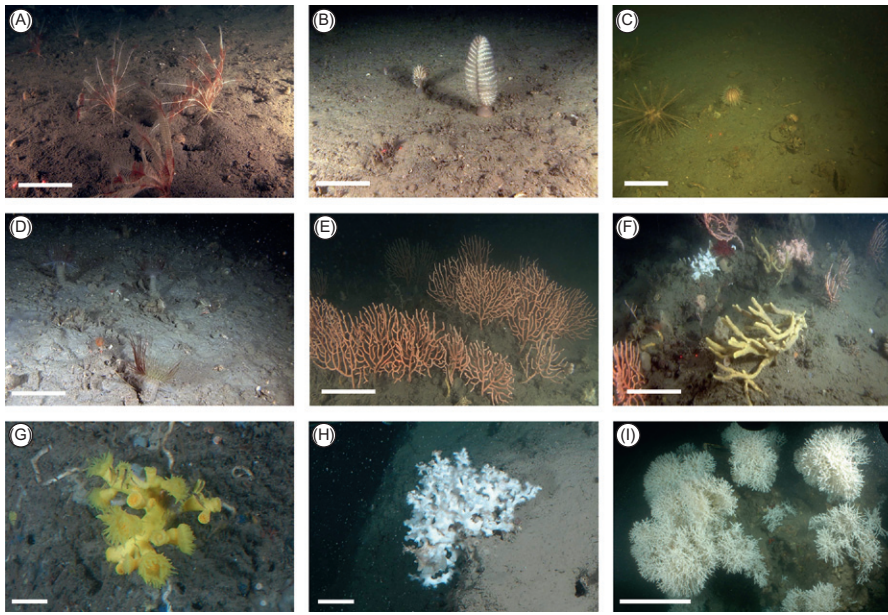

Figure 32.4 Megabenthic organisms of some of the biocenoses inhabiting the continental shelf and canyon of Cap de Creus. (A) Crinoids field of the genus *Leptometra*, which are characteristic of the community of coastal and offshore detritics; (B) community of coastal terrigenous muds, dominated by sea pens; (C, D) community of offshore detritic with exemplars of *Echinus melo* and *Cidaris* (C) characteristic in areas with presence of boulders, and of *Cerianthus membranaceus* (D), a frequent species in those communities in the soft-bottom patches; (E, F) offshore rocky community, mainly composed by gorgonias from the genus *Eunicella* (E), and sponges from genus *Axinella* (F); (G–I) community of white corals, two of the CWC species present in the canyon with low densities: *Dendrophyllia cornigera* (G) and *Lophelia pertusa* (H); the most abundant species is *Madrepora oculata* (I), forming, as in the picture, dense aggregations in rocky boulders. Bar scales: A–F: 10 cm, G and H: 5 cm, I: 20 cm.
Source: Images: A–F: Gavin Newman; G–I: JAGO team, IFM-GEOMAR. Communities have been named after Pérès and Picard (1964).

(*biocoenose coralligène*) (3.16%) (Table 32.1; Figure 32.3B), which is mainly characterized by coralline algae and suspension feeders species (gorgonians, sponges, and bryozoans). Sediments of the coastal belt and of the inner shelf are dominated by the community of fine sands (*biocoenose des sables fins et bien calibres*) (5.69%) and the community of costal detritic (*biocoenose des fonds détritiques côtières*) (6.53%) (Table 32.1; Figure 32.3B). The community of fine sands is dominated by the mollusk *Nucula sulcata*, polychaetes such as *Lumbrinereis gracilis* and *L. latreilli*, crustaceans such as the amphipod *Ampelisca diadema*, and sea urchins such as *Echinus melo*. The community of costal detritic is characterized by the presence of filter feeders as crinoids (Figure 32.4A), taking advantage of the strong

hydrodynamic conditions of this area. The muddy areas of the continental shelf (36.99%) are dominated by the community of coastal terrigenous muds (*biocoenose des vases terrigenes côtières*) (Figure 32.3B). This biocenosis is characterized by high densities of sea pens from the genus *Pteroides* and *Pennatula* (Figure 32.4B), and of the alcyonarian *Alcyonium palmatum*.

Along the outer shelf, species diversity as well as organism abundance decrease compared to the coastal areas. The community of the offshore detritic (*biocoenose des fonds détritiques du large*) dominates the outer shelf (31.95%) (Table 32.1; Figure 32.3B) and is characterized by patchily distributed dominant taxa: echinoderms (mainly sea urchins such as *Echinus melo* and *Cidaris cidaris*), ceriantharians (*Cerianthus membranaceus*), and isolated sea pens (Figure 32.4B–D); crinoids (from the genus *Leptometra*) have been found in this community (Figure 32.4A). The rocks outcropping along the outer shelf are colonized by the offshore rocky community (*biocoenose de la roche du large*) (1.81%), which is mainly composed by cnidarian species (mainly gorgonians from the genus *Eunicella*), sponges (genus *Axinella*), and ophiurids (genus *Ophioderma*) (Figure 32.4E–F).

The Cap de Creus canyon: The communities of the Cap de Creus canyon described in this chapter are located from 100 to 400 m depth, which to date correspond to the surveyed depth range. Sediments present on the southern flank of the canyon are patchily distributed and correspond to gravels mixed to fine sediments, with the dominant benthic communities corresponding to the offshore detritic (*biocoenose des fonds détritiques du large*), characterized by sea pens, alcyonaceans, or ceriantharians. The northern flank of the canyon is mainly characterized by soft sediments, and the corresponding communities have not yet been described. The most characteristic and studied community in the Cap de Creus canyon is the one growing on the rocky substrates (Figure 32.3B). The rocky areas of the canyon (different-sized boulders and vertical walls) shelter the highly diverse benthic community of white corals (*biocoenose des coraux blancs*). Four cold-water coral (CWC) species are the most conspicuous in the Cap de Creus canyon: *Madrepora oculata, Lophelia pertusa*, *Dendrophyllia cornigera*, and *Desmophyllum cristagalli* (Figure 32.4G–I). *M. oculata* (Figure 32.4I), always associated with hard substrate, is the most abundant species and is the coral framework maker of the Cap de Creus canyon. The populations of this species have been quantitatively analyzed and densities of around 11 colonies/m^{-2} have been documented in some locations [4]. The populations of *M. oculata* are present in different scenarios, occurring in some cases in large patches with different size colonies. This indicates that populations are healthy, as new recruits are present simultaneously with old individuals. *M. oculata* is also the dominant species in other Mediterranean CWC communities [19,20]; this dominance differs from the east Atlantic Ocean, where *L. pertusa* is the most abundant species [21]. The reason for this difference is still not clear. However, it is likely that *M. oculata* has a wider temperature tolerance than other CWC and is able to survive in the relatively warm Mediterranean deep waters (around 13ºC at 200–300 m depth in the Cap de Creus canyon) [8,17]. *L. pertusa*, *D. cornigera*, and *D. cristagalli* do not form real populations in the canyon and appeared mostly as isolated colonies. The CWC community presents a high diversity of associated species, mainly dominated

by crinoids, brachiopods, sponges, bivalves, polychaetes, hydroids, and bryozoans, among others.

Further surveys in the Cap de Creus canyon will accomplish a complete and exhaustive mapping of the habitats present in the area.

Acknowledgments

This research was supported by the European projects INDEMARES (Life + NAT/E/000732), HERMES (Goce-CT-2005-511234-I), HERMIONE (Contract number: 226354), INTERREG ("Pirineus Mediterrànis: La muntanya que uneix"), and the Spanish national projects DEEPCORAL (CTM2005-07756-C02-02/MAR) from the Spanish Ministry of Science and Technology and SHAKE (CGL2011-30005-C02-02) of the Spanish Ministry of Science and Innovation. Some bathymetric data has been kindly provided by the Spanish Fishery General Secretary ("Secretaria General de Pesca"). We are grateful to Dan Orange (AOA Geophysics Inc.) for having provided the bathymetric data set of the Cap de Creus canyon. We thank the captain and the crew of the R/V *Garcia del Cid* for their kind assistance during the surveys, and the UTM technician staff. We are grateful to Carlos Dominguez (ICM-CSIC) for his assistance in photo editing.

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