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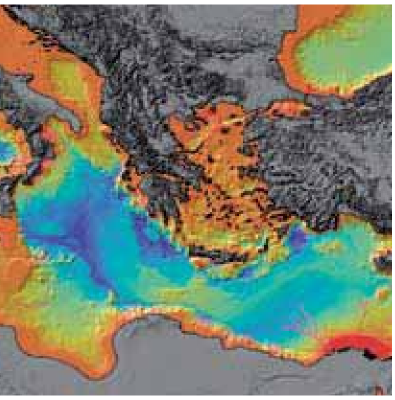
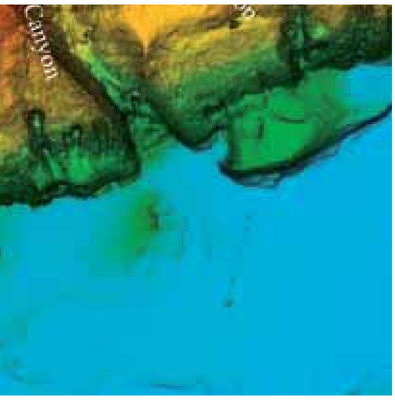
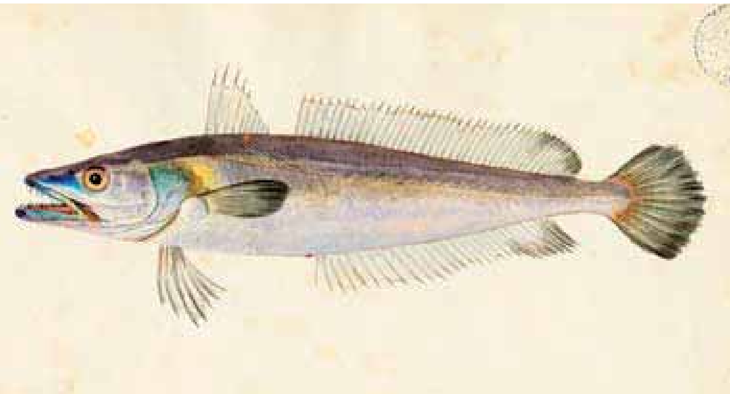
Mediterranean Submarine Canyons

Ecology and Governance

Maurizio Würtz, Editor







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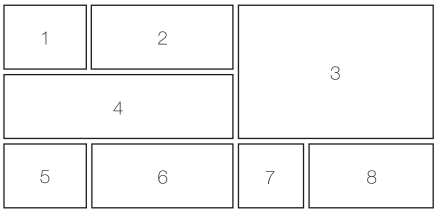

1 Cap de Creus.
2 Morpho-bathymetry of the Mediterranean Sea showing the main canyon and channel systems around the basin.
3 Sperm whale fluke. Maurizio Würtz – Artescienza s.a.s.
4 Shaded bathymetric map illustrating the morphology of the western Ligurian margin.
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8 *Merluccius merluccius.* Vincent Fossat (1877 and 1878), Coll. Muséum d'Histoire naturelle de Nice.

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FOREWORD

Workshops focusing on governance of the Mediterranean held in Tunis (2007), Rabat (2008), Nice (2009), Istanbul and Procida (2010) and Monaco (2011) have enabled the IUCN to formulate recommendations to Mediterranean countries whereby they apply a precautionary principle to canyons situated in waters under their jurisdiction, and incorporate the issues which are at stake and priorities for the protection and management of submarine canyons into national, regional and international strategies for marine protected areas.

These recommendations are based on the unique and vulnerable character of these canyons which play a specific role in the Mediterranean ecosystem. These Mediterranean canyons are, in fact, structural elements in the ecosystemic functioning of both the Western and Eastern basins, and in particular the three subensembles of the canyons in the Gulf of Lion, the Alboran Sea and Aegean-Levantine Sea.

Scientific data is in short supply, and we thus need to extend our knowledge of the ecological and biological roles of these ecosystems, their key role in trophic networks and the cycles of certain marine species, as well as their economic and ecological importance with regard to the services they render. It is equally essential to study the entire range of anthropogenic impacts to which they are subjected: various kinds of telluric pollution, waste disposal, sampling and extractions (extended to adjacent zones), over-exploitation of resources, as well as direct impacts caused by deep-bottom fishing gears on benthic communities, in order to introduce measures for integrated marine and coastal management, and ensure that they are both appropriate and effective. Priority must be given to scientific research in order to enhance our knowledge of Mediterranean canyons and thus protect them.

Enhancing our knowledge would make it possible to incorporate the protection strategy for canyons into a marine spatial planning project on the basis of CBD-EBSA criteria. In this respect, the IUCN must strengthen and structure this group of experts and develop regional cooperation, both technical and scientific, to support in particular the activities of the Regional Activity Centre for Specially Protected Areas (RAC/SPA). It should, in fact, especially by raising the awareness of the States concerned, support the work being carried out by the RAC/SPA in Tunis to develop projects for the creation of Specially Protected Areas of Mediterranean Importance (SPAMIs), taking canyons and their systemic role into account.

It is especially vital to support pilot projects for the protection of canyons proposed by the RAC/SPA within the region: cooperation between France and Spain for the creation of SPAMIs in the Gulf of Lion; cooperation between Morocco, Algeria and Spain for the creation of SPAMIs in the Alboran Sea.

It would also be helpful to mobilize all of the sectorial protection tools offered by the GFCM (FRA, Fisheries Restriction Area) and IMO (PSSA, Particularly Sensitive Sea Area), in order to incorporate canyons into a coherent network of marine protected areas in the Mediterranean and define the best management practices to be implemented, by combining the knowledge of all concerned in a single procedure of intersectorial expertise.

This publication on Mediterranean canyons would not have been possible without the mobilization of scientists, legal experts, technicians and experts from the IUCN and their significant contributions. I would like to express my special thanks to them.

Christophe Lefebvre

Delegate for International Affairs
for the Marine Protected Areas Agency
IUCN Oceans Councillor

ACKNOWLEDGMENTS

This publication is the result of work which has been achieved thanks to contributions on the part of several major institutions.

It has been pursued in close collaboration with the Regional Activity Centre for Specially Protected Areas within the Mediterranean Action Plan (RAC/SPA).

It was financed by the French Agency for Marine Protected Areas.

It was undertaken in follow-up to the conclusions drawn by the IUCN's Group of Experts on Governance of the Mediterranean, and is thus a result of the framework agreement between France and the IUCN. This group of experts has, in fact, benefitted from the constant support of the Ministry for Ecology, Sustainable Development, Transport and Housing and the Ministry of Foreign Affairs.

The TOTAL Foundation financed the ISHMAEL project on relationships between sperm whales and canyons, from which this publication has benefitted.

The MAVA Foundation is financing the PROMETEOS project on relationships between predators and seabeds, which will continue this work by proposing a complementary study on Mediterranean seamounts.

Finally, the Foundation Albert Ist, Prince of Monaco, hosted the meeting of experts in the conference room at the Oceanographic Museum on April 26th and 27th, 2011.

1. SUBMARINE CANYONS AND MEDITERRANEAN ECOSYSTEM

1.1. Submarine canyons and their role in the Mediterranean ecosystem

Maurizio Würtz
University of Genoa, Italy

INTRODUCTION

Almost 518 large submarine canyons have been identified in the Mediterranean Sea (Harris and Whiteway, 2011), and they can indeed be considered as key structures for its ecosystem functioning. As defined by Shepard (1973), submarine canyons are "*steep-walled, sinuous valleys, with V-shaped cross sections, and relief comparable even to the largest of land canyons; tributaries are found in most of the canyons and rock outcrops abound on their walls*". Because they play a fundamental role in "Deep Oceans-Shelf Exchanges", submarine canyons can be defined as "super highways", allowing the energy turnover to speed up by reducing the time and the distances covered by water masses, organic and inorganic sediments, benthonic and nektonic organisms during their active or passive movements from shallow to deeper waters and vice-versa (Paull *et al*., 2008).

Interest in submarine canyons and related bottom structures has been firstly driven by economic reasons, i.e. exploration for fossil energy resources and exploitation of ancient deposits. Detailed studies on canyons' geological evolution and morphology have been carried out in order to lay cables and pipelines across the seafloor and support naval submarine operations.

Recent interest has focussed on the role of submarine canyons in the exchanges between the deep ocean and continental shelf, as well as in the functioning of the benthic and pelagic ecosystem. Mixing rates inside canyons could be as much as 1000 times greater than rates measured in the open ocean, and upwelling associated with canyons enhances local primary productivity with the effects extending up the food chain to include birds and marine mammals. Consequently, commercially important pelagic and demersal fisheries (see also in this volume papers by Farrugio, Sacchi, Revenga de Pazos and Madurell *et al*.), as well as cetacean feeding grounds, are commonly located at the heads of submarine canyons (Hooker *et al*., 1999; see also paper in this volume by David and Di Meglio, Aissi *et al*. and Pace *et al*.), and unique benthic habitats are associated with submarine canyons, particularly the heads of shelf-incising canyons that are characterised by steep bedrock exposures upon which biologically diverse communities may occur. Submarine canyons that extend across the continental shelf and approach the coast are known to intercept organic-matter-rich sediments being transported along the inner shelf zone. This process causes organic-rich material to be supplied and transported down-slope, where it provides nourishment to feed a diverse and abundant macro fauna.

The report "The Mediterranean deep-sea: highly valuable ecosystems in need of protection" published in 2005 by the IUCN and WWF, led the Members of the General Fisheries Commission for the Mediterranean (GFCM) to prohibit the use of towed dredges and trawl net fisheries at depths beyond 1000 m and in areas called "Deep Sea Fisheries Restricted Areas", such as the *Lophelia* reef off Capo Santa Maria di Leuca, the Nile delta area cold hydrocarbon seeps, and the Eratosthenes Seamount (South of Cyprus). Based on the results of studies completed by the French Agency for Marine Protected Areas and the Spanish Superior Council for Scientific Research (CSIC), in 2009, the GFCM added the submarine canyons of the Gulf of Lion to the list of fisheries restriction zones (Toropova *et al*., 2010).

The IUCN, WWF, GFCM and UNEP Mediterranean Action Plan are currently working together to strengthen these conservation measures and improve the conservation status of Mediterranean deep-sea ecosystems. Although there is a common agreement on the importance of conservation of Mediterranean submarine canyons amongst international organizations, their governance is complex: the canyons' extension covers waters and seabeds under various types of jurisdictions (territorial waters, Fisheries Protection Zone, Ecological Protection Zone, including delimitation issues).

Conservation of deep-sea features, such as canyons, requires improving our understanding of the biological and ecological role of these ecosystems, threats and conservation issues, limits and chances of national and international jurisdictions. This report, published thanks to the joint efforts of the French Agency for Marine Protected Areas and the IUCN, has been written with the intention of meeting this need by reviewing interdisciplinary contributions of experts from various Mediterranean countries.

SUBMARINE CANYON MORPHOLOGY

Submarine canyons, as defined by Shepard (1973, 1981), are just one of the seven different types of sea floor valleys identified in his pioneering morphogenetic classification: *delta-front troughs* (located on the prograding slope of large deltas); *fan valleys* (the abyssal, seaward continuation of submarine canyons, some of which are remarkably long); *slope gullies* (incised into prograding slope sediments); *fault valleys* (structural-related, trough-shaped valleys, generally with broad floors); *shelf valleys* (incised into the shelf by rivers during sea level low stands, generally less than 120 m deep); and *glacial troughs* incised into the continental shelf by glacial erosion during sea level low stands, generally U-shaped in profile and having a raised sill at their seaward terminus.

Submarine canyons are features typical of continental slopes deeply incising the continental shelf (Fig. 1); their upper ends are termed "canyon heads" while fan valleys (see above) can also be called "turbidite channels", as canyon continuation seaward from the "canyon mouth" (or canyon end) across deep-sea fans and channel-levee complexes at the base of the continental slope and rise (Canals *et al*., 2004, Canals *et al*., 2009). These last are V-shaped or trough-shaped and are cut into unconsolidated fan sediments. Some authors tend to use the term "canyon-channel system" to refer to submarine canyons extended by turbidite channels. Typical examples of the most common type of turbidite system in the Mediterranean Sea are located along the western margin of Corsica and Sardinia (Fig. 2). Relatively low input volumes and steep gradients characterize these turbidite systems, which are fed through down-slope joining, tributary canyons connected directly to the subaerial drainage basin. Slightly elongated sandy canyon-mouth lobes are lens-shaped in profile and, extending from the mouth of each canyon, are several tens of kilometres wide (Kenyon *et al*., 2002).

The boundary between the continental shelf and submarine canyon is know as a "canyon rim"; where a shelf-slope transition generally displays a convex-shaped sea-floor, defined as "continental margin"; where the continental edge is characterized by markedly increased slope gradients toward the deep ocean bottom, it is referred to as a "shelf break".

The heads of some submarine canyons terminate on the slope, making so-called "blind" or "headless" canyons. The largest canyons, however, commonly incise into the continental shelf and may even continue as shelf valleys which have a direct connection to modern terrestrial fluvial systems (Harris and Whiteway, 2011).

Sediment supply has been associated with different canyon morphologies and depositional processes. Most submarine canyons are erosive conduits through which sediments are transported from areas of high coastal sediment supply onto large submarine fans. High sediment supply forms steep slopes and shelf-indenting, sand-rich canyons with erosive morphologies and downslope submarine fans. The low sediment supply creates shallower slopes and canyons characterized by smooth, aggradational morphologies, no shelf-edge indentation, mud-rich fill, and no downslope sediment accumulation (Jobe *et al*., 2011).

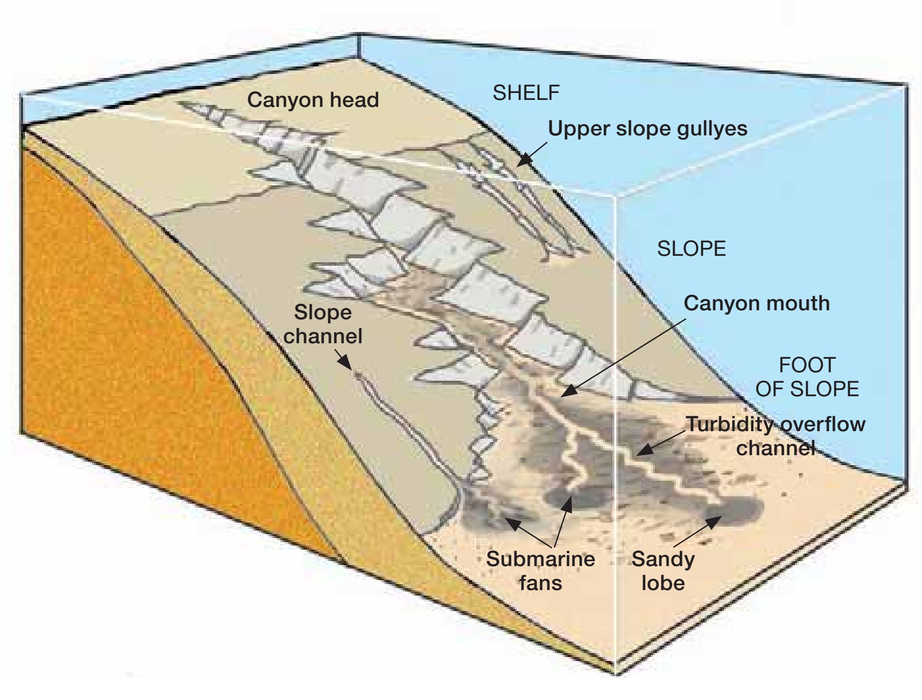
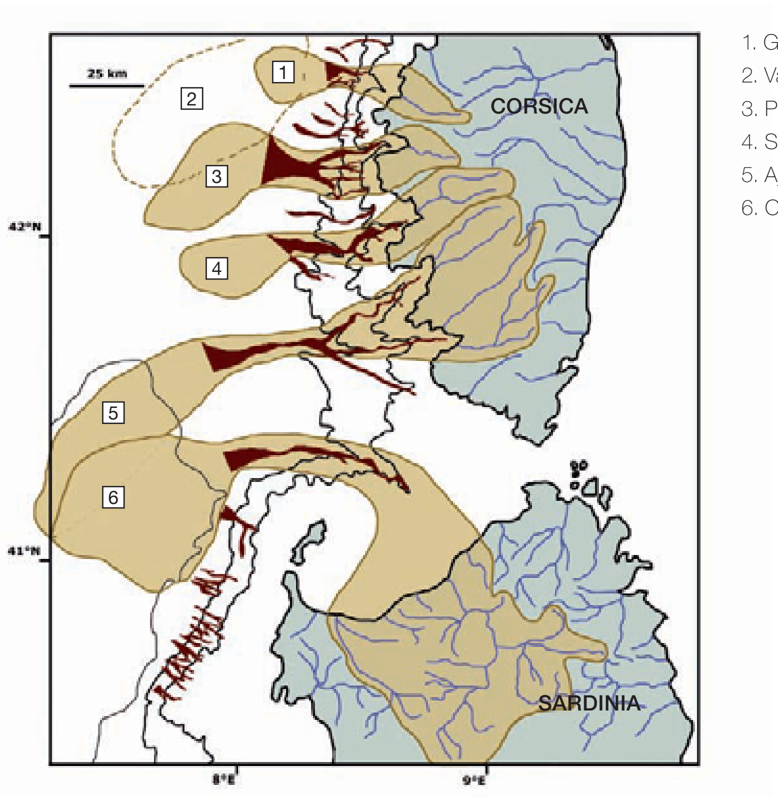


Fig. 1:
Schematic representation of a submarine canyon.



1. Galeria lobe
2. Var lobe
3. Porto lobe
4. Sagone lobe
5. Ajaccio lobe
6. Castelsardo lobe

Fig. 2:
Turbidite system of western Corsica and north-western Sardinia Islands. Dark-brown areas indicate the main canyons. (modified from Kenyon *et al.,* 2002).

Harris and Whiteway (2011) sub-divided large submarine canyons into three main types, in order to study their geomorphic differences between active and passive continental margins on a global scale: Type 1) shelf-incising canyons having heads with a clear bathymetric connection to a major river system; Type 2) shelf-incising canyons with no clear bathymetric connection to a major river system; and Type 3) blind canyons incised onto the continental slope. All three canyon types include at least one major canyon with possible tributary canyons forming dendritic canyon complexes (Fig. 3).

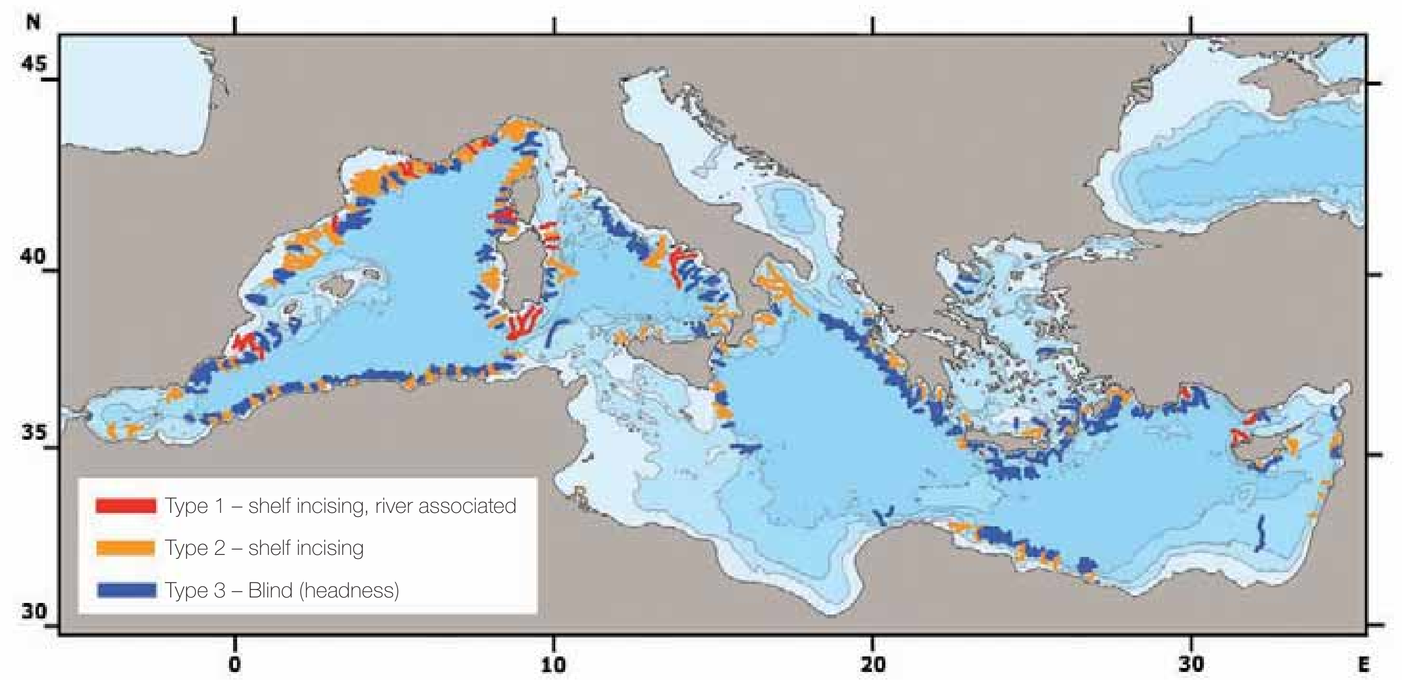
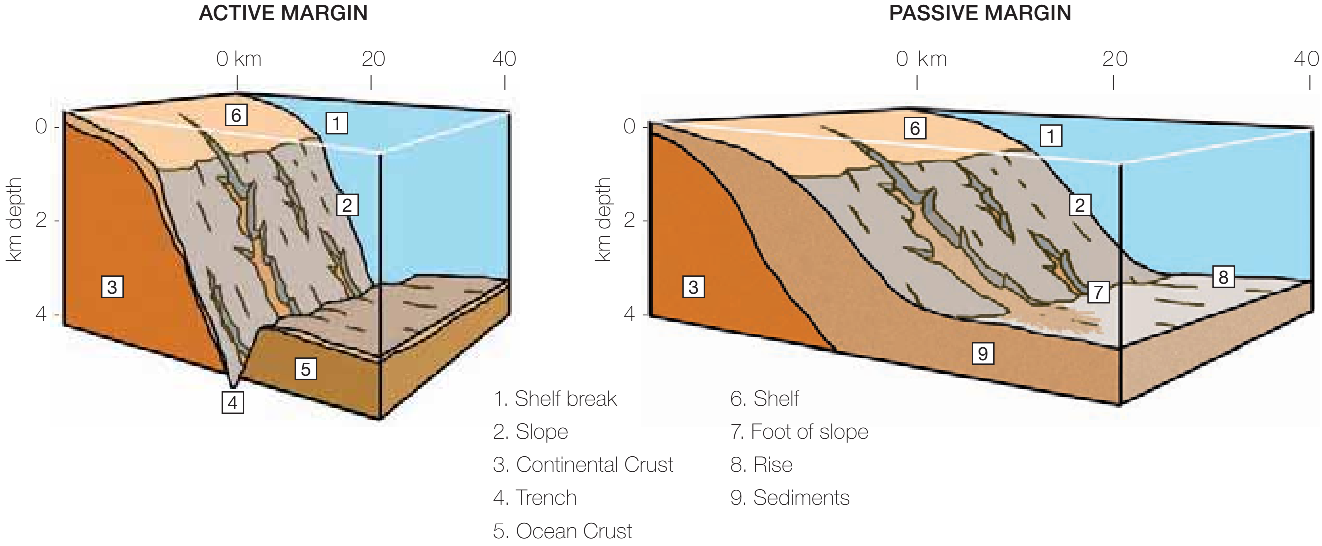


Fig. 3:
Types of submarine canyons and their distribution in the Mediterranean Sea (modified from Harris and Whiteway, 2011).



1. Shelf break
2. Slope
3. Continental Crust
4. Trench
5. Ocean Crust
6. Shelf
7. Foot of slope
8. Rise
9. Sediments

Fig. 4:
Schematic representation of active and passive continental margins.

In the Mediterranean, active margins are mostly located off the northern coast, while passive margins are located off its south-east shores (Libya and Egypt). Active (endogenetic) and passive (exogenetic) continental margin types exhibit differences in morphology that can be attributed to the processes governing their formation. Passive margin morphology is controlled by erosion and deposition processes, whereas tectonic/magmatic processes control active margin morphology; the continental slope ends in an oceanic trench, and beyond the trench, the topography is hilly, irregular and often dotted with rugged volcanic seamounts (Fig. 4).

Canyon morphology might also be expected to vary between active and passive margins and also amongst passive margins undergoing either net erosion or net deposition. Nevertheless, there has been no study that has demonstrated a statistically significant difference in canyon morphology between the two kinds of plate margins.

Results of the study carried out by Harris and Whiteway (2011) on worldwide occurrence and morphology of canyons indicate that the Mediterranean is a globally different region. Here, canyons are more closely spaced (14.9 km), more dendritic (12.9 limbs per 100,000 km^2), shorter (mean length of 26.5 km), amongst the most steep (mean slope of 6.5°), and have a smaller depth range (mean depth: 1613 m) than canyons occurring in other oceans. Within the Mediterranean sea, the Gulf of Lion is one of the areas of the world oceans with the higher canyon density per 100 km (Fig. 5).

For further details about submarine canyon morphology, see Migeon *et al.* (in this volume).

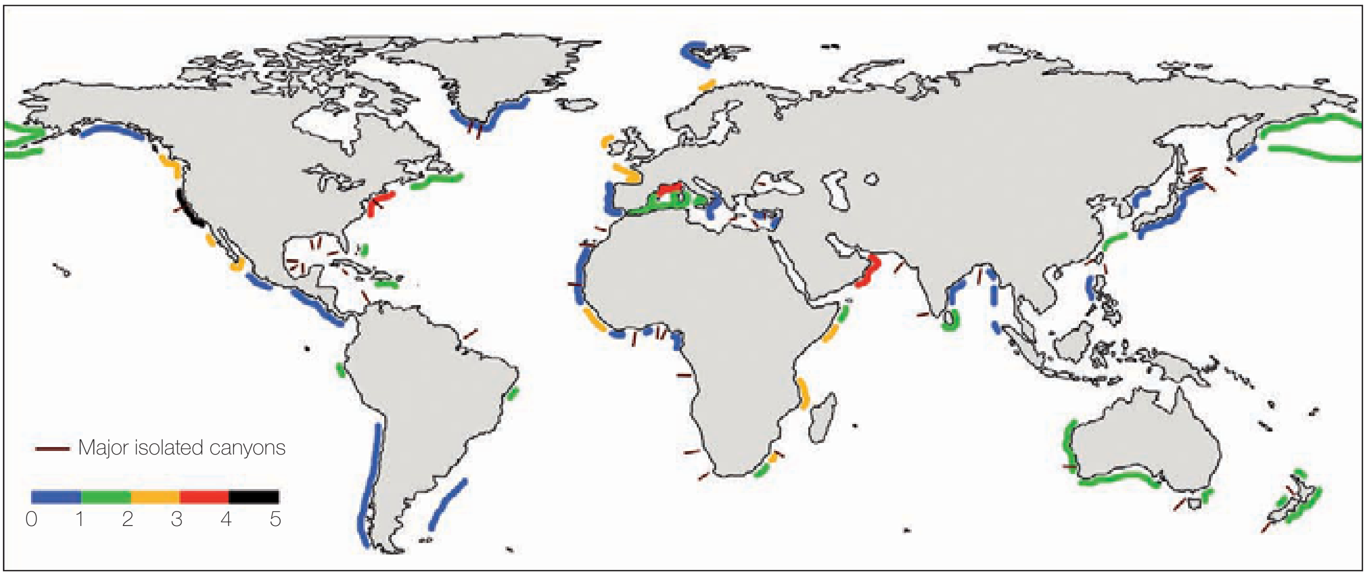


Fig. 5:
Canyon density per 100 km along the shelf break (modified from Allen and Durrieu de Madron, 2009).

ORIGIN

The origin of submarine canyons has intrigued marine geologists for a long time. What process or processes could erode such canyons and deep-sea valleys so deep below sea level? The data indicates that most of these structures do not evolve on a daily basis. The main processes involved in their origin include:

- Subaerial erosion of the upper canyon.
- Erosion by turbidity currents.
- Erosion by the slow mass movement of sediment down-canyon by creep, progressive slumps, sand falls, and later redistribution of sediment by deep-sea bottom currents.
- Erosion by bottom currents other than turbidity currents.
- Drowning by subsidence of valleys cut subaerially, and upbuilding of canyon walls.

Subaerial erosion may have taken place during the Pleistocene lowered sea levels. In many canyons, the upper parts show episodes of cut and fill, which are probably related to sea level changes. Furthermore, local subsidence, which would have submerged many upper canyon reaches, may have played a role in this process.

When sediments accumulating on the slope or shelf edge become unstable and slump, or are set in motion by an earthquake or storm, they form turbidity currents by developing a heavy, turbid mass capable of descending along the slope. Turbidity currents are generally credited with the excavation of submarine canyons and with transporting great quantities of sediment down the canyon to form the fans at the base of the continental slopes. If a canyon was already cut into the slope, the turbidity current is not necessarily the initial cause of its origin, but it may perpetuate the canyon itself by preventing it from being filled with sediments, or even excavate the canyon to a greater depth. Temperature and salinity gradients, along with internal waves and tides, as well as ordinary bottom water currents, can produce strong flows and also excavate sediments in submarine canyons, or at least build the submarine fans and keep the fan-valleys open. Turbidity currents might be expected to come to an end due to loss of sediment at the base of the steep gradient, but the ordinary currents, not dependent on a slope, could persist. Sediment deposition on the canyon rims can increase the total wall heights. Downcutting with upbuilding over a long period of time allows the formation of huge canyons. Creep erosion in the canyon is where turbidity currents could not play an important role; once initiated along a plane of weakness, very little energy is required to maintain a slow downslope creep by large sedimentary masses.

As Mediterranean submarine canyons show striking differences from similar structures in the world oceans, their particular features could be due to their different origin. River sediment discharge does not explain this difference, because the input from fluvial sediment is less than that occurring in other areas of the world (Walsh and Nittrouer, 2009). The tectonic setting of the northern Mediterranean could be compared with other active plate margins, but the geomorphic attributes of its canyons are quite different from the other regions. Late Miocene sea level lowering and desiccation of the Mediterranean basin (Messinian Salinity Crisis) may have exposed the continental margins to subaerial erosion resulting in canyon development at regional scale (Rouchy and Caruso, 2006). This phase of subaerial erosion is a unique feature of Mediterranean geological history. During this period, rivers would have incised incipient canyons which were further developed by submarine processes following re-filling of the Mediterranean basin. Tectonic uplift could have significantly modified or masked many canyons formed during the late Miocene, particularly along the northern active margin of the Mediterranean (Bertoni and Cartwright, 2005; Ridente *et al*., 2007). A large percentage of shelf-incising canyons could be expected if subaerial erosion had played a major role in canyon development: however, the Mediterranean does not in fact have a large percentage of Type 1 or 2 canyons (Harris and Whiteway, 2011) compared with other regions of the world (see chapter on Morphology).

Erosive density currents formed in winter by the cooling of shelf water masses which form cascades down submarine canyons (DSWC) may be another important factor in the origin of canyons, as shown by Canals *et al*. (2006) for the Gulf of Lion canyon system. For further details, see also Migeon *et al.,* this volume.

EFFECTS ON CIRCULATION AND ECOSYSTEM FUNCTIONING

Submarine canyons can affect general and local scale circulation patterns by deflecting the in-coming and out-coming flows (Flexas *et al*., 2008). Several key factors play a role by enhancing or reducing the canyon effect, i.e. the canyon's relative position (distance) from the coast, its size and morphology, general circulation and local currents, the in-coming flow direction (Klinck, 1996), the presence, intensity and amount of river outputs and wind stress strength, water mass stratification, etc. The result is a great variety of situations and effects which can occur for each single canyon (or each canyon system) set along the continental margin of the Mediterranean, and which are, in some cases, very different from what could be expected through oceanographic process modelling.

The tendency of geostrophic circulation to follow bathymetric contours limits the cross shelf-break exchanges. Canyons cutting the bottom topography can reduce the rotational effects of the current (geostrofic effect such as Coriolis force) and significantly force the flow to cross isobaths, leading to enhanced mixing through upwelling and downwelling (Allen and Durrieu de Madron, 2009).

Mediterranean circulation is mainly characterized by a large cyclonic gyre of in-coming Atlantic waters, which can generate anticyclonic eddies on the coastward right side of the flow, strongly affecting current patterns within the continental shelf. On the left side of the gyre flow cyclonic eddies are generated, which can affect circulation in the pelagic domain from the continental margin to far offshore. Bottom morphology (seamounts, submarine canyons, gullies, trenches, valleys, steep slopes, etc.) as well as wind forcing and increasing density processes can alter and deeply modify the above patterns, thus a high time-volume variability is the main feature of Mediterranean circulation.

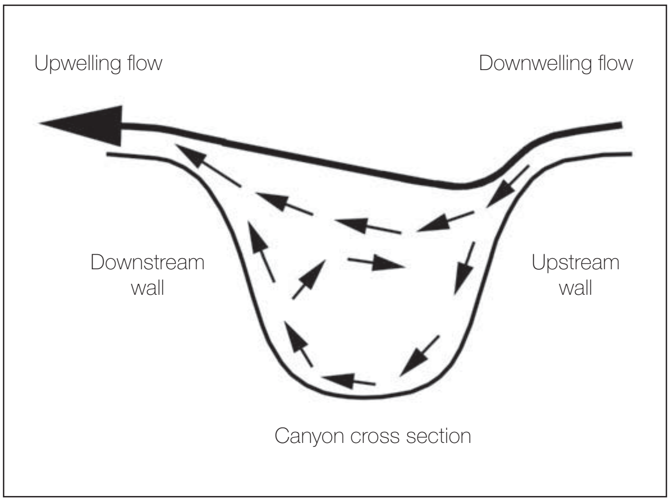


Fig. 6:

Schematic representation of a right-bounded flow (when the flow has the coast on its right): current-canyon interaction causes asymmetry in the vertical velocity field; downwelling is forced over the upstream wall, whereas upwelling is forced over the downstream wall. Modified from Allen and Durrieu de Madron (2009).

Nevertheless, in spite of this high variability, we can try to recognize some general features (processes) generated by circulation-canyon interaction:

— Near-bottom currents are constrained to the topography and closed circulations are observed in the canyons, while near-surface flow is unaffected by the underlying topography under real stratifications (Palanques *et al*., 2005). Flow across the canyon leads to localized upwelling and downwelling (Flexas *et al*., 2008).

— When the flow has the coast on its right (a right-bounded flow), the current-canyon interaction causes asymmetry in the vertical velocity field; downwelling is forced over the upstream wall, whereas upwelling is forced over the downstream wall (Fig. 6). In the northern hemisphere, flow propagating along the shelf/slope direction with the shoreline on the right is called "positive along-slope flow" (Fig. 7). Positive flows are associated with net downwelling (downward flow and flow toward the ocean) (Klinck, 1996; Flexas *et al*., 2008; Allen and Durrieu de Madron, 2009).

— When the in-coming current has the coast on its left (a left-bounded current), the current-canyon interaction causes local upwelling over the entire canyon. In the northern hemisphere, flow that travels along the slope with the shoreline on its left is referred to as "negative along-slope flow". Generally, negative flows are associated with net upwelling (upward flow and flow toward the coast) (Flexas *et al*., 2008; Allen and Durrieu de Madron, 2009).

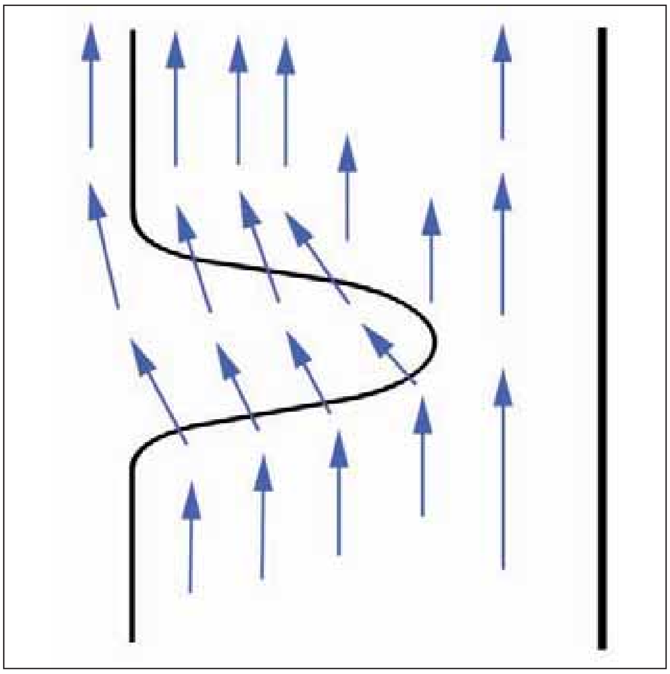


Fig. 7:

Positive flow in the Northern Hemisphere. Plan view sketch showing net flux through a canyon onto the shelf, accommodated by an increasing along-shelf flux. The black line is the shelf-break isobath, straight hatching on the right indicates the coast, and the blue arrows represent the flow. Modified from Allen and Durrieu de Madron (2009).

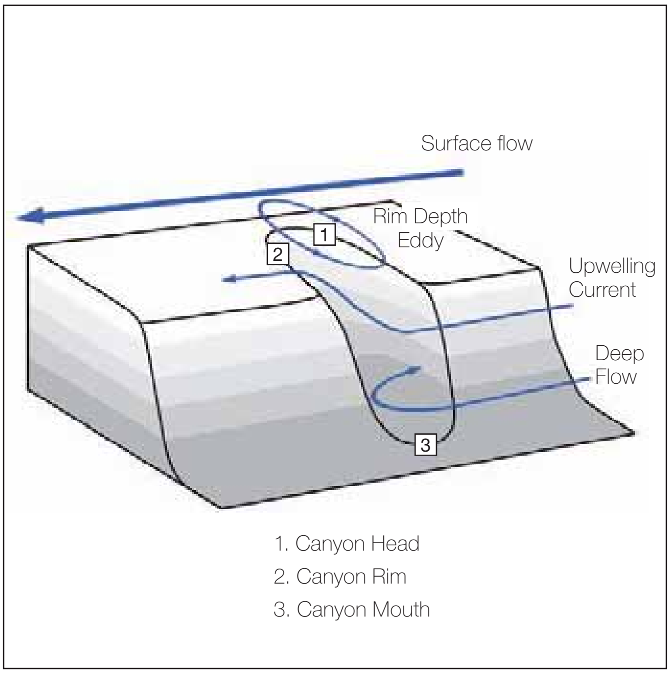


Fig. 8:

Wind-driven shelf-break or slope currents lead to upwelling or downwelling flows within the canyon, with the strongest effects at the canyon rim especially at shelf-break depth (modified from Allen and Hickey, 2010).

- Canyons in the Mediterranean are generally under the influence of positive flows (Allen and Durrieu de Madron, 2009).
- Narrow canyons have a strong effect on circulation and are characterized by a general cyclonic circulation within the canyon rims (Fig. 8).
- Wide canyons only modify the circulation along the topography (Klinck, 1996; Klinck, 1988; Flexas *et al.*, 2008).

Allen and Durrieu de Madron (2009) separate canyon conduit flow into two types:

- Wind-driven shelf-break or slope currents lead to upwelling or downwelling flows within the canyon, with the strongest effects at the canyon rim especially at shelf-break depth (Fig. 9).
- Deep water formation on the shelf similarly leads to strong cross-slope pressure gradients. However, these flows cascade down the canyon, are focused deep, near the canyon axis, and are, in many ways, independent of the wind-driven flows above.

Net fluxes to or from the ocean can be accommodated by changes in the along-shelf current. Waterhouse *et al.* (2009) described possible mechanisms driving upwelling due to different flow dynamics between the long and short canyons: isobath convergence, when long canyons,which closely approach the coast, have strongly converging isobaths (Fig. 9 A); advection, short canyon flow show this upwelling regime in the case of low Coriolis force effect (Fig. 9 B), and time dependence upwelling occurs with the lowest incident flow velocity in the short canyon (Fig. 9 C).

Allen and Durrieu de Madron (2009) distinguished three phases during the upwelling or downwelling scenario due to oscillatory coastal wind effects:

- An initial time-dependent response, as the shelf-break flow increases. It is generally strong and occurs quickly. If the along-shore current continues to increase (i.e. because of steady winds), density advection within the canyon reduces time-dependent upwelling after about 5 days (She and Klinck, 2000).
- An advection-dominated response during the time when the shelf-break flow is reasonably steady. It is strongly dependent on the canyon topography and flow strength (Allen, 2004). For weaker flows it can be greatly enhanced if strongly convergent isobaths occur over the canyon (Allen, 2000; Waterhouse *et al.*, 2009).
- A relaxation phase, when the shelf break flow decreases. A strong, generally cyclonic flow occurs within the canyon (Hickey, 1997).

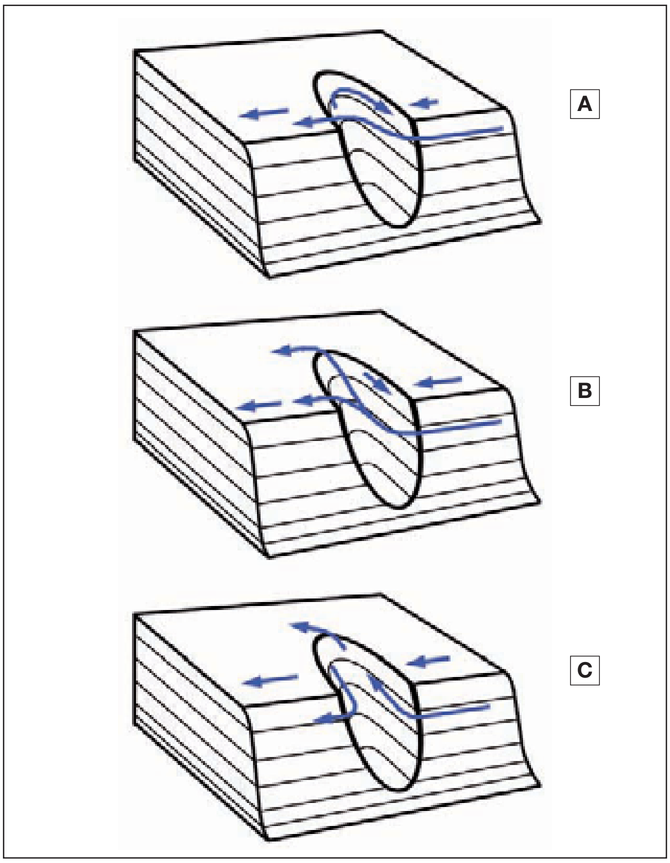


Fig. 9:

Schematic representation of three upwelling mechanisms within submarine canyons:

A) isobath convergence,

B) advection and

C) time dependence of the flow

(modified from Waterhouse *et al.,* 2009).

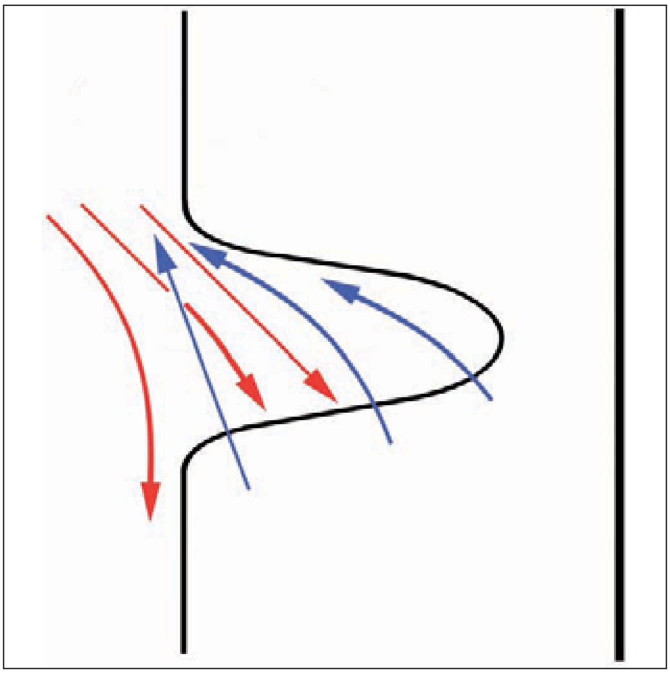


Fig. 10:

Plan view sketch showing differences between the positive (blue) and negative (red) phases of oscillating flow for the Northern Hemisphere. The black line is the shelf-break isobath, the straight line on the right indicates the coast, and the blue and red arrows represent positive and negative phase flow respectively.

During the second phase, upwelling is generally stronger than downwelling. This last is driven by positive flow and does not impede the along-isobath flow. On the other hand, upwelling flow opposes the shelf current leading to a strong cross-isobath flow over the canyon walls (Fig. 10). Thus, in the positive flow phase, the current diverges from the upstream wall and flows out of the canyon along the downstream wall. In the negative phase, the flow follows the upstream wall into the canyon and upwells along the downstream wall (Pérenne *et al*., 2001).

This generalized pattern can be modified by various factors: in Blanes canyon, for example, the presence of cold and fresh waters coming from the Gulf of Lion continental shelf causes the flow reversal above and just below the thermocline (Flexas *et al*., 2008). This fact reinforces the observation that no individual canyon is identical to another.

Inputs from landmasses strongly influence Mediterranean ecosystems, as a huge amount of organic and inorganic matter from continental and shelf sources can reach the deepest basins by means of fast, dense, organic-matter-rich and sediment-laden near-bottom currents occurring from winter to early spring, through continental margins and submarine canyons.

Seasonal cooling and evaporation generate denser seawater at the uppermost layers; favoured by a decrease of river discharge reducing their buoyancy, the surface water masses sink. The northern shelves of the Mediterranean (i.e. the Gulf of Lion, Adriatic Sea and Aegean Sea, more exposed to cold and intense northerly winds) are the main source areas of these density-driven currents (see also Company *et al*., this volume), which are known as Dense Shelf Water Cascading (DSWC). Cascading may last for several weeks, and waters sink until their density equilibrium is reached. Intense DSWC events, which can carry shelf waters to the deepest parts of the Mediterranean basin, seems to occur at subdecadal frequency (Canals *et al*., 2009).

Submarine canyon size controls the volume of cascading waters, on the other hand cascading acts on canyon morphology, enhancing erosion or sedimentation. A canyon degrades and sooner or later becomes buried when it loses its sediment transport capacity; a canyon enlarges or increases laterally and longitudinally if it maintains its sediment transport efficiency.

Canals *et al*. (2006) developed the concept of “flushing submarine canyons” in order to describe the role of canyons as main conduits for cascading. When the water volume is too large, the canyon, depending on its size, cannot accommodate it, therefore waters overflow the canyon rims as “laminar flow” sweeping the continental slope before spreading over the deep basins.

As cascades may simultaneously occur with spring phytoplankton blooms, their consequences on the deep ecosystem of the Mediterranean Sea and their role as a natural mechanism for carbon sequestration in shallow ocean layers will need better knowledge in the coming years (Canals *et al*., 2009).

EFFECTS ON BIODIVERSITY

The abundance and diversity of marine life can be enhanced by canyons through their effect on local circulation, by funnelling sediment transport and by providing more varied and complex physical habitats than surrounding slope areas, because canyons often have steep slopes, rocky outcrops, and faster currents that can support fauna with diverse habitat requirements.

As stated above (see previous chapter), no individual canyon is identical to another, and this is reflected by differences in fauna between canyons even located along the same stretch of the shelf (Hecker, 1990; Rogers *et al*., 2002)

By concentrating organic detritus moving along continental shelf and slope, submarine canyons concentrate sediments rich in organics and contain denser deposits of phytodetritus (Garcia *et al*., 2008*).* Given such enhancement of trophic resources, canyons may be favourable habitats for benthic consumers and suspension feeders.

The canyon's topographic complexity enhances habitat heterogeneity, therefore greater abundance and diversity of fishes may be associated with margins where canyons are common (Marques *et al*., 2005; Morais *et al*., 2007). Areas of highly rugged canyon topography can generally provide important habitats and critical nursery areas for fish species living over continental margins (Stefanescu *et al*., 1994; Brodeur, 2001), with some species preferentially spawning inside them (Schlacher *et al*., 2009).

Inside the canyons, faunal assemblages and species composition can be markedly different from those on close open slopes. Species biomass and abundance can be from 2 to 15 fold higher than in the surrounding areas at the same depths. Meiofaunal assemblages generally show lower diversity with high dominance of a few species within the canyon: nevertheless, canyons can be considered as hot spots of diversity because of the high megafauna diversity and high rates of endemism. In oligotrophic areas, such as Mediterranean Sea, canyons can play an important role for their efficiency in energy recycling at different scales (Danovaro *et al*., 2010).

Each Mediterranean submarine canyon reveals high levels of fauna specificity: a more detailed description of this aspect can be found in the case study section in this volume, in particular in the papers by Özturk *et al*. on submarine canyons off the southern coast of Turkey; Vella *et al*. on Maltese escarpment; Watremez as well as David and Di Meglio, on the Gulf of Lion; Madurell *et al*. and Company *et al*. on canyons off the Catalan coast, and Baro *et al*. on the Alboran sea. One of the most relevant aspects is the relationship between the number of species, the number of individuals of endemic species and the ecological features of submarine canyons (Palanques *et al*., 2005).

In the Foix, Lacaze-Duthiers and Planier canyons, seven new species of medusae were found (Gili *et al.,* 1999) and, since all species were restricted to each of the canyons, this fact may demonstrate an isolation effect related to specific hydrodynamic processes and canyon morphology. Thus, ecological differences between canyons could be responsible for allopatric speciation, as demonstrated by the dominance of an elasipod holothurian species in the Palamós canyon; in fact, this holothurian has not been found in other canyons or elsewhere in the Mediterranean.

One of the main factors responsible for the high diversity of deep-sea fauna seems to be the fluctuation in the amount of food reaching the bottom as indicated by the discovery of underscribed benthic non-swimming species, which characterise the polychaete fauna in the same canyon sediments (Palanques *et al.,* 2005).

Considering the huge ecological variations during the geological history of the Mediterranean, isolation and speciation in submarine canyons should be investigated, also in terms of geographic distribution and ecological features in geological times; for instance, some species sampled from Mediterranean canyons have been considered Tethys relicts (Gili *et al*., 1999).

Cold-water coral *Madrepora oculata* (Fig. 11 a) and *Lophelia pertusa* reefs (CWCs) (Fig. 11 b) are among the most remarkable and fragile communities living deep in the Mediterranean. Using new visualization technology, the HERMES project discovered unknown coral sites on narrow shelves, canyon walls, escarpments and seamounts, leading to a re-evaluation of the general perception of the assumed paucity of white corals in this sea (Freiwald *et al*., 2009). For example, CWCs have been found to be the most conspicuous animal group in the hard substrate of the Cap de Creus canyon (Orejas *et al*., 2009). Here, colonies predominate on the large areas of hardrock outcrops and steep walls along the southern flanks, which are characterized by dense water cascades in winter (Puig *et al*., 2008*)*, while CWC occurrence is scarce on the northern side, where high sediment accumulation rates have been observed. Coral distribution in this canyon, as well as in other systems, seems to be related to the amount of nutritive particles in suspension, made periodically available by energetic current flows from the shelf environments (Canals *et al*., 2006), and by episodic cascading processes and internal waves at the edge of the Gulf of Lion*,* which can reduce sediment accumulation rates (De Geest *et al*., 2008) and control the resuspension, advection and mixing of organic matter in the canyon head (Ogston *et al*., 2008), thus providing a food supply to the coral colonies.

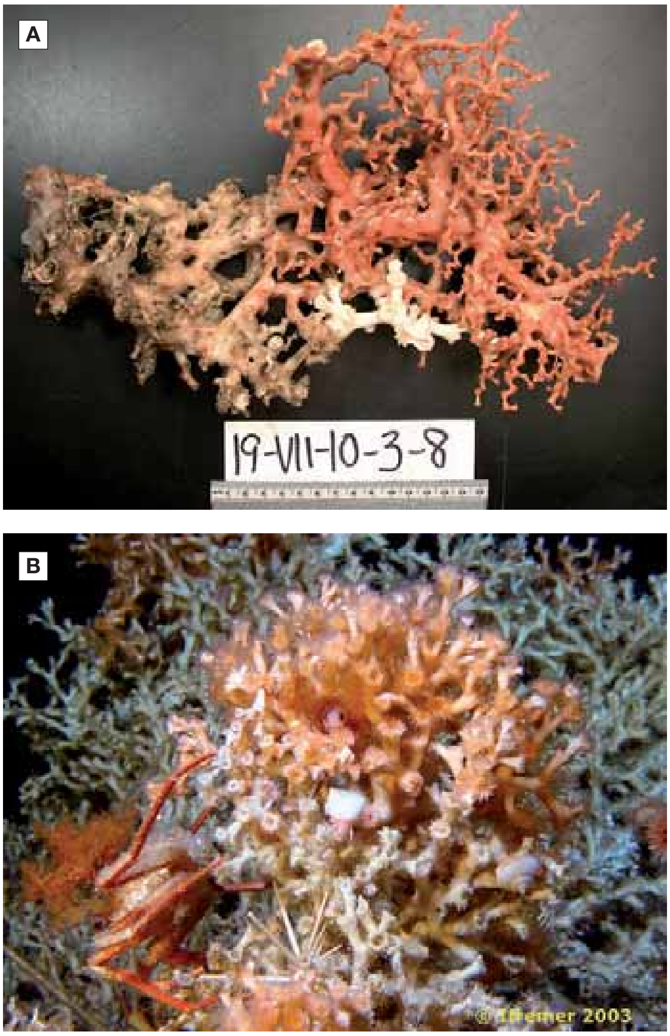


Fig. 11:

A) *Madrepora oculata.*

B) *Lophelia pertusa*.

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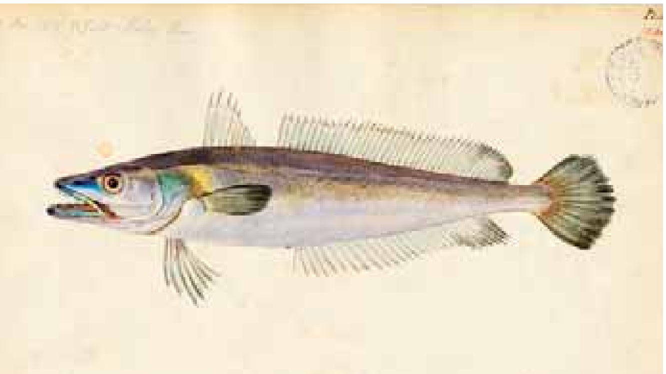
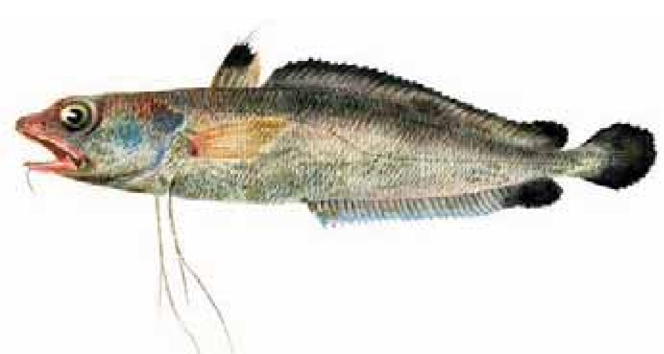
In the western Mediterranean, recruiting grounds and mature specimen reservoirs of the deep-water shrimps *Aristeus antennatus* and *Aristaeomorpha foliacea* are mainly located around the white-corals biocenosis, as well as on the margin of submarine canyons. Allowing a number of specimens to escape trawl fishery, these areas can play the role of “spawning refugia” (Caddy, 1993; Farrugio, this volume), where a portion of a heavily exploited stock can annually sustain recruitment (Sardà *et al*., 2004).

Deep-water rose shrimp *A. antennatus* fishing grounds in the Blanes canyon are mainly located between 600 and 900 m, where the shrimp occurrence appears to be driven in a non-linear manner by environmental conditions including: local temperature, relatively salty waters (Levantine Intermediate Water) and low currents with moderate variability (Sardà *et al*., 2009).

Company *et al.* (2008) have found that dense shelf water cascades may cause the disappearance of *A. antennatus* from fishing grounds and produce a temporary fishery collapse (see also Company *et al.,* this volume). This initial negative effect is followed, 3-5 years later, by an increase in juveniles and subsequently by an increase in landings. It is suggested that particulate organic matter transport associated with cascading enhances the recruitment of this deep-sea living resource, mitigating the effects of overexploitation*.* On





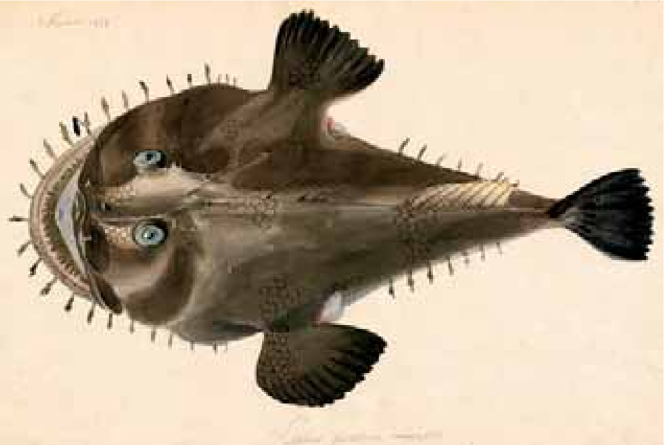


Fig. 12: *Merluccius merluccius*.

Fig. 13: *Phycis blennoides*.

Fig. 14: *Helicolenus dactylopterus*.

Fig. 15: *Lophius budegassa* (drawing of *L. piscatorius,* a very similar looking species). Vincent Fossat (1877 and 1878,
Coll. Muséum d'Histoire naturelle de Nice.

the other hand, the rapid sinking of cold dense waters can increase organic matter content in the deep basin, reduce benthic abundance and modify benthic biodiversity, producing very different effects at regional and basin scale. Comparative studies carried out in the Gulf of Lion and the Aegean Sea reveal different resilience times in the two regions: the first area has a very fast recovery, whereas the second shows much longer resilience time (more than 5 years). Under environmental and climate change scenarios, cascading of dense water from continental shelves could have a stronger influence on Mediterranean deep-sea ecosystems than previously thought (Pusceddu *et al.*, 2010).

Increased food availability within the canyon due to enhanced deposition of organic matter can also enhance demersal fish abundance and biomass. Stefanescu *et al.* (1994), investigating fish assemblages within the "Rec del Besós" submarine canyon (Catalan Sea, western Mediterranean), observed much higher values in abundance and biomass inside the canyon than outside, and suggested higher food availability there. Lower mean fish weight was also noted inside the canyon, and the analysis of size distributions in the commonest species along the upper slope showed that the submarine canyon acts as a recruiting ground for some of them.

Different food availability during day-night cycle drives the predatory species' movements inside the canyon where they find suitable conditions for finding food by reaching different depths over a relatively short distance. In the Quirra Canyon (off the south-eastern coast of Sardinia), analyses carried out by Sabatini *et al.* (2007) distinguished fauna assemblages characterised by indicator species whose abundance is clearly linked to depth and time of the day. They identified four species groups: early in the night, lesser depths are typified by hake (*Merluccius merluccius*) (Fig. 12), which is substituted by the small-toothed argentine (*Glossanodon leioglossus*) during the light hours and later in the night; at greater depths during light, the red shrimp *A. antennatus* (and *A. foliacea*) characterize the third assemblage, even if these shrimps move toward the upper level along the canyon wall during the night, while the shortnose greeneye (*Chlorophthalmus agassizi*) identifies the fourth group which shows vertical movement, even if confined within deeper waters than the previous group. This pattern is not followed by ubiquitous species such as the greater forkbeard (*Phycis blennoides*, Fig. 13) and blackbelly rosefish (*Helicolenus dactylopterus*, Fig. 14), while the blackbellied angler (*Lophius budegassa*, Fig. 15) and glass shrimp (*Pasiphaea multidentata*, Fig. 16) have been found to stay at 350 m depth during the day and to move to deeper waters during the night. During the night, larger specimens of *P. multidentata* stay close to the bottom feeding on benthic gammarid amphipods, isopods and macruran decapods: in contrast, the specimens collected during the daytime exhibited remains of pelagic prey (hyperiids, fishes, euphausiids, chaetognaths). Such behaviour furnishes evidence of energy transfer from the benthos to the planktonic system especially within submarine canyons, where the feeding rate of shrimps is higher and the diet also more specialised (Cartes *et al.*, 1994).

The complex circulation in submarine canyons supports increased biological production and these areas are also ecological "hot spots" for pelagic life diversity and abundance. Canyon upwellings attract a variety of migratory top pelagic predators such as tunas, sword fishes, sharks, turtles, birds and cetaceans, both for feeding and breeding, by enhancing food availability for midwater prey, such as euphausids, mesopelagic fishes (Myctophids, Fig. 17), shrimps (Pasiphaeids and others) and squids, which have been found in abundance along the canyon walls. The concentration of prey, due to their "entrapment" within the canyon walls, is the key biological factor making the submarine canyon ecosystem so attractive for a variety of these tertiary consumers. Considering these processes, two aspects must be stressed: first, the shortening of the distance covered during migratory movements by epipelagic, mesopelagic prey; second, the fact that those movements are forced within the canyon boundaries, both due to the steep slope of the canyon walls and internal current flows. Thus, micronektonic prey accumulate during their nocturnal upward migration along the canyon rims and over the canyon heads, where they are trapped after their morning descent into the canyon. Moreover, by night, neritic (living inside the continental shelf) benthopelagic fauna may be advected offshore over the canyon during their surface stratification, thus contributing towards an increase there in prey biodiversity and biomass (Macquart-Moulin and Patriti, 1996).

As circulation inside the canyon has seasonal variations, predator presence and abundance may be linked to prevailing patterns. In winter, northern winds favour downwelling processes, while during the summer the basin's general cyclonic gyre flows (right-bounded flow) have a stronger effect than wind stress and generate conditions for upwelling over the downstream walls and outer part of Mediterranean canyons. This may be the reason why most pelagic top predators are sighted during the summer within or near the canyon area (see also Aissi *et al.*, David and Di Meglio, in this volume). During cetacean surveys in the canyon of Cuma, Mussi *et al.* (2001) ascertained the presence of some pelagic fishes such as *Mobula mobular*, *Thunnus* sp., *Xiphias gladius* and sea birds such as *Calonectris diomedea*, *Puffinus puffinus*, *Larus ridibundus*, and they regularly observed summering groups of common (*Delphinus delphis*), striped (*Stenella coeruleoalba*), bottlenose (*Tursiops truncatus*) and Risso's dolphins (*Grampus griseus*) and also fin whales (*Balaenoptera physalus*), which use the area as a feeding ground (see also Pace *et al.,* in this volume).

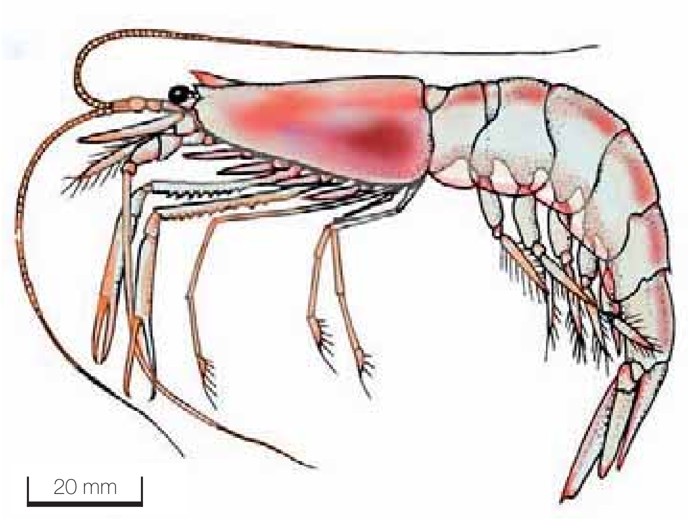


Fig. 16: *Pasiphaea multidentata.*
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Finally, according to Smith *et al.* (2010), submarine canyons may serve as ecological refuges from the impact of warming ocean temperatures for cetaceans. The refuge role within relatively circumscribed environments may be especially important, as in the Mediterranean Sea, where climate change effects have a stronger impact than in the open oceans and northern range shift is impossible due to geographic barriers.

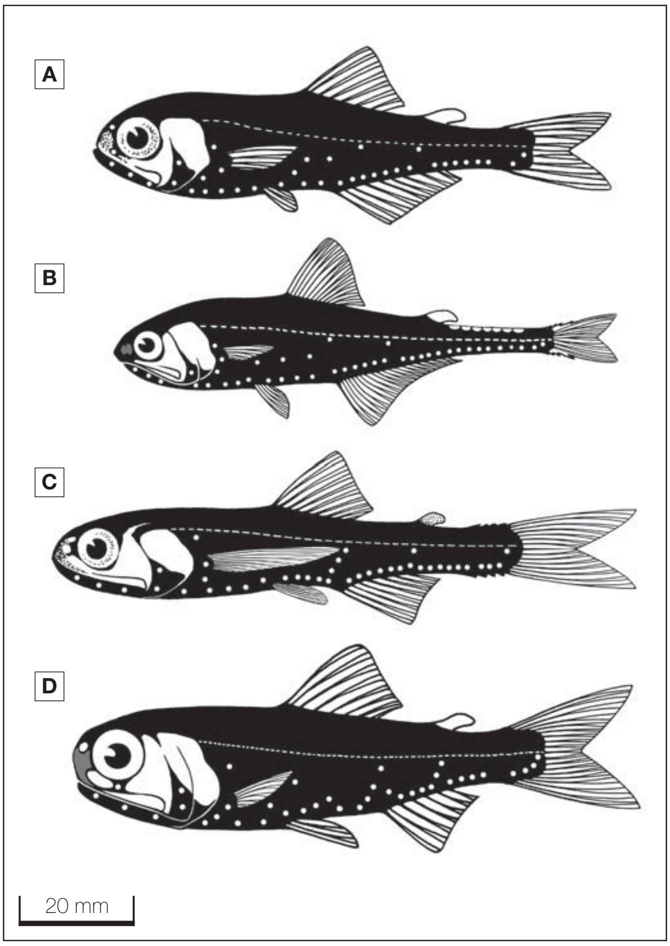

Fig. 17: Myctophidae, © Maurizio Würtz – Artescienza s.a.s.
A) *Benthosema glaciale;*
B) *Gonichthys cocco;*
C) *Ceratoscopelus maderensis;*
D) *Diaphus* sp.

TOWARD A MEDITERRANEAN CANYON INVENTORY

The importance of an effective marine environment cadastre representing the multidimensional nature of reality as closely as possible in order to facilitate good governance (see also Chalabi, in this volume) has been already pointed out by Ng'ang'a *et al.* (2001). The physical, biological, socio-cultural and economic nature of the environment may be linked with information for jurisdiction (which has a particularly complicated pattern in the Mediterranean, see also Ros, in this volume) and the effects of its formal law and community interests on the marine environment to give the cadastre a multipurpose function: "*ideally, the marine cadastre would be based on a marine parcel that would be the focus of information collection, storage, analysis, retrieval and dissemination*".

Within the highly variable pelagic realm, habitats such as submarine canyons could provide an easier field for application because of their "*static nature".* Their particular density in the Mediterranean area, as well as their fundamental role in ecosystem functioning, could drive the need for an inventory. Obviously, the first step for a complete Mediterranean submarine canyon list is to have an idea about their number and current names.

At present, various heterogeneous sources of information can help this task: several canyon names and positions can easily be found on Google Earth, which is based on SIO, NOAA, US Navy, NGA and GEBCO datasets; Harris and Whiteway (2011) listed 518 canyons by using morphological criteria applied to ETOPO1 and Mediterranean Science Commission bathymetric datasets; on the other hand, less than 270 have been identified through detailed geological maps of the Mediterranean sea floor.

Several Mediterranean submarine canyons have been investigated from many angles, i.e. circulation, tsunami effects, mass transport, turbidite systems, bottom morphology, biodiversity, cold water biocenoses, fishery impact as well as nursery and recruitment for commercial species, pollution, coast and deep sea exchanges etc. Information on names, numbers, geographical position, morphology, physical and biological processes of the main submarine canyons can thus be now obtained from a broad range of scientific sources covering several Mediterranean areas.

Without exceeding the limits imposed by this review, in this paragraph a very provisional list of canyon names is proposed. The list has been obtained by crossing the above-mentioned datasets with scientific and other sources of information (most can be obtained more or less easily through internet). Canyon names with some reference in literature are in italic style, an asterisk follows the name when it is arbitrarily assigned according to its correspondence with a bay, cape, island, promontory, river, coastal settlement, city or other conspicuous geographical feature. The list also includes canyons still without names, but with some reference to their existence, mainly from the map of (Fig. 1) in Migeon *et al.*, in this volume).

South Eastern Iberian Margin

From west to east, the presence of 51 submarine canyons is well documented: *Algeciras*, *La Linea*, *Guadiaro*, *Estepona*, *Bóvedas*, *Baños*, *Torrenueva*, *Fuengirola*, *Almuñecar, Motril*, *Carchuna (Sacratif)*, *Calahonda*, *Dalias*, *Almería*, *Andarax*, *Gata*, *Alias Almanzora*, *Palomares*, *Jolocular*, *Aguilas*, *Cabo Tiñoso*, *Cartagena*, *Negrete, Palos*, *Alicante*, *Benidorm*, *Valencia*, *Hirta*, *South Columbretes*, *North Columbretes*, *Benicasim*, *Ebro*, *Oropesa*, *Alcalá de Chivert*, *Benicarló*, *Marta*, *Peñiscola*, *Torreblanca*, *Tortosa*, *Tarragona*, *Foix*, *Cunit*, *Valldepins*, *Berenguera*, *Morràs*, *Besós*, *Arenys*, *Blanes*, *San Feliu*, *Palamos (La Fonera)*, *Cap Creus.*

According to Harris and Whiteway (2011), type 2 canyons (incising the shelf without connection with rivers) are located on the eastern and western side, while those confined to the slope (type 3) seem to be mainly from Gata Cape to the mouth of the Ebro.

Balearic Margin

No submarine canyons exist in the north-western slope of the Balearic Islands, while the southern margin is shaped by 4 main canyons: *Pitiusas (Formentera), Mallorca-Cabrera, Pera*, *Menorca*. It is also deeply incised by at least 15 short, rectilinear canyons, from Mallorca to Ibiza.

Alboran Island

Three main canyons can be identified on the south and eastern slope off the Alboran Island: Al *Borani, Piedra Escuela* and *Castor.*

French mainland coast

Along the French coast from Cerbère to Menton, 28 canyons can be counted, those of the Gulf of Lion mainly belonging to type 2 (Harris and Whiteway, 2011). From west to east: *Lacaze-Duthiers, Pruvot, Bourcart (Aude), l'Hérault, Sète, Catherine-Laurence, Marti, Montpellier, Aigues-mortes, Petit Rhône, Grand Rhône, Estaque, Marseille, Couronne, Planier, Cassidaigne, Cassis, Sicié, Toulon, Porquerolles, Stoechades, Pampelonne, Saint-Tropez, Estérel, Cannes, Var, Paillon* and *Monaco*.*

Corsica

The narrow continental shelf around the Island of Corsica is incised by at least 16 canyons: *Centuri*, Saint-Florent, Île-Rousse, Calvi, La Revellata*, Galéria, Porto, Peru*, Sagone, Lava*, Ajaccio, Valinco, des Moines, Porto-Vecchio*, Aléria** and *Cervione*.*

Italian mainland coast

Combining information obtained from various sources, 49 canyons can be identified on the Ligurian, Tyrrhenian and Ionian margin, and two in the southern Adriatic sea. It must be pointed out that in many cases a single name corresponds to a system rather than a single canyon: *Roja, Nervia, Taggia*, *Verde, Mercula, Bordighera*, Laigueglia, Centa, Varatella, Imperia, S. Bartolomeo, Capo Mele, Pora, Finale, Noli, Vado, Polcevera, Bisagno, Di Levante, Civitavecchia, Gaeta, Garigliano, Volturno, Cuma, Punta Cornacchia, Magnaghi, Dohrn, Salerno, Maratea, Capo Suvero, Angitola, Gioia Tauro, Bovalino, Siderno, Gioiosa, Roccella Ionica, Caulonia, Stilo, Soverato, Catanzaro, Squillace, Corigliano, Neto, Lipuda, Cirò Marina, Taranto, Otranto, Bari*.

Sardinia

A complex system of 29 canyons incises both the western and eastern slopes of the Island of Sardinia: *Caprera, Posada, Gonone, Orosei, Arbatax, Quirra, San Lorenzo, Capoferrato**, *Carbonara, Cagliari, Spartivento* (2 canyons), *Teulada, San Antioco* (2 canyons), *Toro, Carloforte* (4 canyons), at least 4 canyons off the south-western coast (Costa Verde), *Oristano, Il Catalano*, and at least 3 canyons off the coast from Bosa to Capo Caccia, *Castelsardo*.

Sicily

Around Sicily, 21 canyons are mainly located off the northern and eastern coasts: *Egadi, Stromboli, Patti, Messina, Milazzo, Castellammare, S. Vito, Cofano, Zafferano, Eleuterio, Oreto, Arenella, Priola, Addaura, Mondello, Favignana, Pantelleria-Mazara**, *Scoglitti**, *Capo Passero* and *Catania*, which indicate canyon systems.

Malta

Heron is the canyon name located off the south-eastern side of the shelf around the Maltese archipelago. This canyon is divided into two branches in its deepest portion.

Tunisia

The long *Bizerte* canyon cuts the channel northward between Sardinia and Tunisia, while its eastward branch reaches Rass Sidi el Mekki (Cape Farina). Another 3 canyons carve the shelf around the Galite Island.

Algeria

The Algerian steep slope is shaped by 24 canyons. References to *Annaba, Skikda, El Kebir, Nil, Bejaïa, Dellys, Sebaou, Nif, Sefsaf, Algiers, Dahra, Guelta*, and *Khadra* canyons can be found in both scientific literature and the Google Earth digital atlas. Between Algiers and Dahara, at least 11 unnamed canyons can be identified.

Morocco

The southern portion of the Alboran sea is mainly characterized by submarine hills and banks: the only submarine canyon is close to *Ceuta.*

Greece

The Hellenic Trench, stretching from the Ionian Islands to Rhodes (southern Aegean arc), is characterized by numerous canyons, as is the northern part of the Aegean sea: *Kerkyra, Paxoi*, Lefkas, Kefalonia, Zakynthos*, *Pirgos*, Kiparissiakos*, Proti*, Messini*, Kalamai*, Kyparissia*, Kalamata*, Skoutari*, Mirampelou** (Crete), *Samaria* (Crete), *Paximades*, *Sfakia** (Crete), *Ptolemy* (Crete), *Lithinon* (Crete), *Pliny* (Crete), *Strabo* (Crete), *Nereus* (NW Rhodes), *Brigitte* (NW Rhodes), *Trianta* (NW Rhodes), *Kallithea**(NE Rhodes, 2 canyons), *Psalidos* (NE Rhodes), *Pera* (NE Rhodes), *Lutani** (NE Rhodes), *Tsampika** (NE Rhodes, 2 canyons), *Malóna**(NE Rhodes), *Vlichá**(NE Rhodes), *Lindos** (NE Rhodes), *Samoträki** (2 canyons), *Strymonik*, Thermaikos* (2 canyons). Very likely the number of canyons in this area is underestimated.

Turkey

At least 11 main submarine canyons can be identified off the western and southern Turkish coasts, as for Greece, their number may be greatly underestimated: *Xeros**, *Bosphorus, Sarköy, Anadolu, Fethiye, Megisti**, *Finike, Antalya, Anamur, Boziazi**, *Antakya**.

Cyprus

Around Cyprus 5 canyons have been identified: *Famagusta*, Larnaka*, Akrotiri*, Chrysochou** and *Morphou**.

Middle East coast

Latakya, Baniyas, Tartus and *Sour* are the names identifying submarine canyons off the Syrian coast and *Junieth, Saint Georges, Beirut, Zahrani, Sayniq* off the Lebanese coast. *Akhziv, Saar, Nahariya, Shomrat, Hilazon, Qishon, Haifa, Atlit, Cesarea, Hadera, Netanya, Ashdod* and *Afiq* are the names of the canyons off the coast of Israel which are mainly cited in geological literature.

Egypt

The Egyptian passive margin is incised by 12 canyons: *Damietta** (a system with at least 7 branches), *Rosetta* (a system with at least 9 branches), *Alexandria*, Ras Alam er Rum, Solum** and *Habu Ashafa**. At least 6 canyons from Solum to Habu Ashafa still remain unnamed.

Lybia

Canyon density is higher off the eastern coast: many of them have been named arbitrarily or are still unnamed: *Tobruk**, *Derna** and at least five canyons in between, one canyon west of Derna. *Susah** and another four canyons to the west before *Melita*, *Misratah* and *Tripolitanian.*

CONCLUDING REMARKS

Roughly, a total of 348 submarine canyons or canyon systems can be allocated on the slopes of the eastern and western Mediterranean basins, and 237 have a name quoted in scientific literature or other sources of information. The geographic position of the remaining 111 can be identified, but it has not been possible to find references in order to assign a shared name: nevertheless 47 of them have here been arbitrarily attributed a nomenclature. Comparing these figures with the results obtained by Harris and Whiteway (2011), this list greatly underestimates the number of Mediterranean submarine canyons, mainly for the southern Tyrrhenian coast of Italy, Algeria, the south Aegean Arc and Turkey. It must be stressed that this very provisional inventory is roughly based on the available information obtained from scientific literature and other kinds of sources; it does not fit specific criteria in order to identify various types of canyons and, sometimes, canyon systems from a single canyon. Even if available in some cases, data such as the geographic position (i.e. head and mouth coordinates), length, shape (V or U shaped), type (i.e. shelf incising, shelf incising with river connection, slope confined), habitat type (i.e. sandy, muddy, rocky), biocenoses (i.e. cold water corals), role for fisheries (i.e. nursery, breeding, ground), threats, exploitation for non-renewable resources, pollution, conservation status etc. have not been considered at the moment. Obviously, a Mediterranean submarine canyon inventory exceeds the objectives of this review: nevertheless, considering the fundamental role of such structures for shelf and open sea exchanges, it could be a priority tool for better governance of the entire Mediterranean ecosystem.

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1.2. Mediterranean submarine canyons and channels: Morphological and geological backgrounds

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INTRODUCTION

Submarine canyons are the most common conduits for erosion derived particles, organic matter and nutrients transported from land to the base of continental margins (Normark and Carlson, 2003; Shepard, 1981; Twichell and Roberts, 1982). They are commonly interpreted as pure erosive features, meaning they are zones of sediment bypassing with little or no sediment accumulation until the canyons cease to be active conduits. The largest canyons are classically 1000-1500 m deep, 20-50 km wide and several tens of kilometers long (Normark and Carlson, 2003). Depending on their morphology and evolution through time, two main types of canyons can be discriminated (Goff, 2001; Twichell and Roberts, 1982): (1) mature canyons that are large features deeply indenting the continental slope and the continental shelf, and fed by more or less continuous sediment supply originating from river inputs or coastal currents, and (2) immature canyons that are smaller and straighter features organized in clusters, restricted to the continental slope and mostly fed by submarine failures.

Morphologies of canyons are usually divided into four geomorphologic domains: head, axe, walls and distal reaches (Cronin *et al.*, 2005).

(a) Canyon heads are described as amphitheater-like features with abundant scars related to small-scale mass-wasting processes (Green *et al.*, 2007); they are active areas in term of current activity and sediment transfer which erode upslope and will ultimately erode across the shelf.

(b) Canyon axes could be either straight or sinuous depending on local slope angles and volume of sediment supply; their general trend can be largely controlled and deflected by active faults, fault escarpments and margin tectonic deformation (Laursen and Normark, 2002).

(c) Canyon walls are often abrupt (30-40°) or nearly vertical; they are affected by intense failure and erosional processes, but depositional areas, related to the presence of terraces and confined levees, can also develop (Babonneau *et al.*, 2004).

(d) Transition between the distal parts of canyons and depositional channels is still difficult to discriminate from subsurface data. This area can be characterized by the development of thalweg channels where the canyons lost their well-developed topographic expression (Cronin *et al.*, 2005).

The origin of canyons is still a matter of debate. Even if canyons are often superimposed on previous tectonic lineaments, it is usually admitted that their development can result from various processes, which can be combined, and particularly:

(1) aerial (or fluvial) erosion during low-stand sea levels (an extreme case being the low stand related to the Messinian Salinity Crisis in the Mediterranean Sea),

(2) retrogressive erosion within the canyon heads related to the triggering of submarine landslides,

(3) repeated and continuous action of gravity flows such as debris flows, turbidity currents and hyperpycnal flows, and/or up-and-down currents related to tides or internal waves. In the Mediterranean, cascading currents, related to formation of dense waters, are also now identified as a key player generating local seafloor erosion, depositing substantial volume of sandy particles and maintaining the thalweg morphology (Gaudin *et al.*, 2006; Trincardi *et al.*, 2007).

Based on a morpho-bathymetry synthesis of the Mediterranean Sea, we present in this paper an overview of submarine canyons around the Mediterranean. Their distribution and morphology are described with respect to the types of substratum they built on. Two case studies, the example of the Ligurian continental margin and that of the Nile submarine delta, are then briefly discussed to illustrate more clearly the various processes of canyon formation and the key factors controlling them.

MEDITERRANEAN CANYONS: AN OVERVIEW

A recent systematic detailed bathymetric mapping of the Mediterranean continental margins and deep basins (Brosolo *et al*., 2012) (Fig. 1) has made it possible to highlight strong contrasts between various submarine canyon networks cutting across the Western and Eastern Mediterranean continental slopes.

The Western Mediterranean

Along the Western Mediterranean continental slope, we can distinguish several areas characterized by strongly contrasted canyon morphologies, even if parts of this contrast can be referred to differences in the availability of precise bathymetric data; it clearly appears that the most important and widespread canyon systems are observed along the northwestern Mediterranean Sea continental slopes.

Along the northern coasts, and from West to East, we first distinguish a network of canyons running across the Gulf of Valencia and Catalonia slopes, and merging at depth into a meandering channel through which most of the Ebro sediments are transported into the abyssal plain. From the Pyrenean borders to the vicinity of Marseille, the Gulf of Lion is itself characterized by numerous canyons cut into a thick Pliocene and Quaternary sedimentary blanket deposited by the bordering rivers and particularly the Rhone. Available seismic data show that most of these canyons are, however, superimposed on former submarine/sub-aerial valleys created during the Messinian Salinity Crisis (roughly between 6 and 5 My ago), when the sea level dropped by more than 1200/1500 m as a consequence of the closing of the oceanic connections between the Mediterranean and the Atlantic. These canyons, being entailed into relatively unconsolidated sediments show drastic morphologic and hydrologic regime contrasts with the Catalonia canyons, but are comparable to most of the canyons off Valencia, also cut into thick, soft sediments. The meandering canyons and deep sedimentary channels seen along the Gulf of Valencia and Gulf of Lion continental margins thus participate in the sedimentary drainage mechanism towards the deep surrounding basins. Further East, from Marseille to Genova, the canyons, also mainly inherited from the Messinian low stand sea level (and subsequent aerial erosion), cut across various geological formations consisting either of massive limestone (east of Marseille), metamorphic, volcanic rocks (from Toulon to Fréjus) or various alpine tectonic units (from Cannes to Genova). Most of these basement rocks are often directly exposed on the seabed.

A comparable setting characterizes western Corsica, and probably the western continental slope of Sardinia, where the Messinian erosion may have been superimposed on previous canyon features inherited from the formation of the continental slope, some between 25 and 11 My during the rifting of a subsequent opening of the Western Mediterranean basin; today the majority of these canyons appears almost devoid of sediments, while along the eastern margin of Corsica the canyons drain most of the erosion products towards the Corsica channel between the Corsican mainland and island of Elba. Except along part of the Sardinia and North Sicily margin and off western Calabria, we cannot observe significant canyons around the Tyrrhenian Sea; this is probably due to the very recent age of this basin, which formed only in the last 5 to 1 My, and the majority of whose continental slopes were thus not subjected to the Messinian crisis or aerial erosion.

By opposition to the northern Mediterranean Sea margins, the North African margins exhibit only short and sub-linear canyons, deeply imprinted on a quite narrow, geologically active, and probably uplifting, continental slope. Moreover the onshore drainage system consists mainly of short-lived rivers without regular water supply.

The Eastern Mediterranean

Around the Eastern Mediterranean Sea, only the Calabria, Cyrenaica and Western desert (Western Egypt) continental slopes show significant canyon networks.

Off Calabria, and as a consequence of the virtual absence of a continental shelf, the few existing canyons are directly connected to small mountain-supplied rivers and are subjected to strong erosion, itself the consequence of an active general coastal uplift. Only a few significant canyons can be observed West of the Peloponnese, South of Crete and Turkey and off the Levantine coasts. Little is known on these canyons also located in active tectonic areas. Relatively numerous short canyons can be observed off Cyrenaica and the Western desert (Egypt). We believe that most of these features originated during the Messinian low stand but, not being connected with any aerial drainage system, they probably did not evolve since that time, except maybe during various pluvial periods in Quaternary times. Off the Nile delta, the Egyptian continental margin shows a rather specific case where today a unique and wide canyon can be seen just at the mouth of the Rosetta branch of the Nile river; this canyon, the Rosetta canyon, feeds a complex turbidite and meandering channel system, through which most of the erosion products and nutrients originating from the Nile drainage are dispersed into the deep Herodotus abyssal plain several hundred kilometers away from the coast line. The present-day Rosetta canyon is the last morphological expression of various similar canyons cut by the Nile River since the Lower Pliocene (5 My) but now deeply buried below the Quaternary deltaic deposits.

With the exception of a few short canyons in tectonically active areas, such as in the Marmara Sea and North Anatolia trough (North Aegean), no significant canyon can be observed within the shallow Aegean Sea.

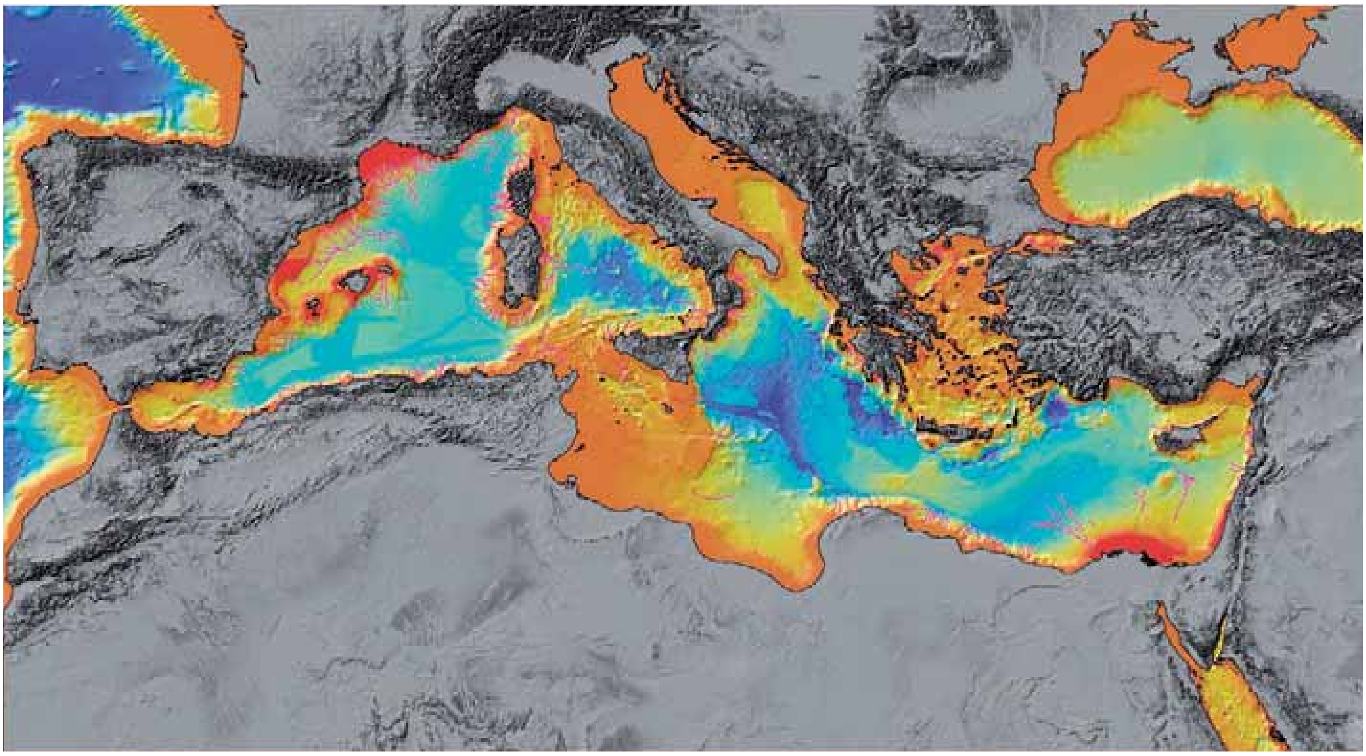


Fig. 1:

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

CASE STUDIES

Two case studies are considered here: the northern Ligurian margin in the Western Mediterranean, and the Nile deep-sea fan in the Eastern Mediterranean. These two areas are different in terms of canyon morphology, evolution through time and number, and in terms of the tectonic and climatic context of formation.

The northern Ligurian margin

Along the northern Ligurian continental margin (Fig. 2), the continental shelf width ranges from a maximum of 2 km to less than 200 m at specific locations, as along the “Baie des Anges” in front of the city of Nice. The shelf break is located quite close to the coastline, at an average of 50-100 m water depth, but could be shallower, i.e. less than 20 m of water depth, as in front of Nice airport (Dan *et al*., 2007). The continental slope is steep and extends over no more than 20 km to a water depth of 2000 m with an average angle of 11° (Cochonat *et al*., 1993). The base of the slope is characterized by a sharp decrease in the slope angle, to less than 3°. In the deep part of the basin (2600 m of water depth), the bathymetric gradient decreases to 1° or less. The marked steepness of the continental slope is partly explained by a tectonic inversion of the margin implying reactivation of inherited transverse structures and development of new faults (Béthoux *et al*., 1992; Larroque *et al*., 2009). Such tectonic reactivation is believed to be responsible for the uplift of the margin which is evidenced by the deformation to the north of the Messinian erosional surface. Uplift is particularly pronounced off the city of Imperia (Italy) (Bigot-Cormier *et al*., 2004; Sage *et al*., 2011). Reactivation is also responsible for an enhanced activity of gravity processes on the continental slope (Migeon *et al*., 2011).

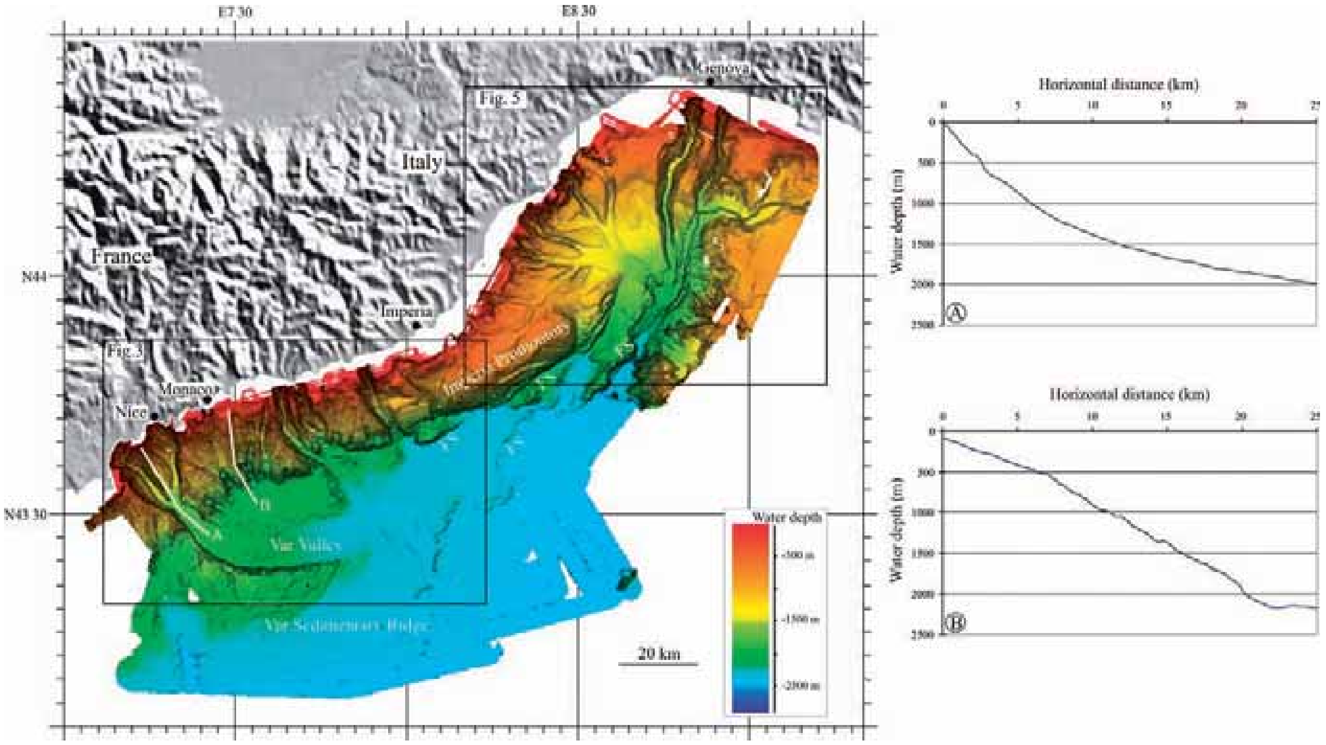


Fig. 2:

Shaded bathymetric map of the northern Ligurian margin.

A is an example of a concave-up topographic profile as observed in the Var-Paillon canyon area.
B is an example of a convex-up topographic profile as observed in Roya-Nervia-Taggia canyon area.
FS is Fault Structure.

Small mountain-supplied rivers feed the western Ligurian margin; they are, from west to east, the Var, Paillon, Roya, Taggia and Argentina Rivers. On land, the rivers drain catchments that are usually 200-300 km^2 and consist of either metamorphic rocks or calcareous and marls formation. The Var River is an exception in terms of its catchment area: it forms in the Southern Alps, at an altitude of 2352 m and 120 km inland, and drains a basin of 2822 km^2. All these rivers experience violent flash floods every year, during the fall and spring. The average water discharge of the Var River, about 50 m^3/s, can increase tenfold during floods, and suspended sediment concentration can reach tens of kg/m^3. From the rating curve of the Var River (Mulder *et al.*, 1998), it is estimated that hyperpycnal currents could be generated during river floods, with a return period of about 2 to 5 years. Such turbulent flows are generated at the river mouth when the density of fresh water transporting suspended particles exceeds the density of the ambient seawater. In the case of the Var River, a critical concentration of suspended particles of 40-44 kg/m^3 and a critical river discharge ranging from 620 to 1250 m^3/s are required to produce hyperpycnal flows.

Based on morphological characteristics of the present-day seafloor, the Ligurian margin can be divided in two western and eastern segments separated by a SW-NE trending ridge or Imperia Promontory (Larroque *et al.*, 2011). From the city of Nice (France) to the Gulf of Genova (Italy; Fig. 2), seventeen canyons can be identified along the continental slope. They are, from west to east, the Var, Paillon, Roya, Nervia, Taggia, Verde, Mercula, Laigueglia, Cuenta, Varatella, Pora, Finale, Noli, Vado, Polcevera, Bisagno and Levante Canyons. These canyons initiate either at a shallow water depth, directly at the mouth of some of the rivers feeding the Ligurian continental slope and basin, or at greater depth, along the outer continental shelf or even on the upper continental slope.

The Var, Paillon, Roya, Nervia, Taggia and Verde canyons cut the western margin segment, between Nice and Imperia (Fig. 3). Most of these canyons initiate at very shallow depths (< 10 m) and connect directly to the mouth of the respective Var, Paillon, Roya, Nervia and Argentina Rivers. The Verde canyon initiates at a greater depth (about 130 m), at the transition between the outer continental shelf and upper continental slope; no river valley or river deposits, following the same direction as this canyon axis, have been identified on land. Most of these canyons are on average 500-m deep and 2-5 km wide. They exhibit a V-shaped

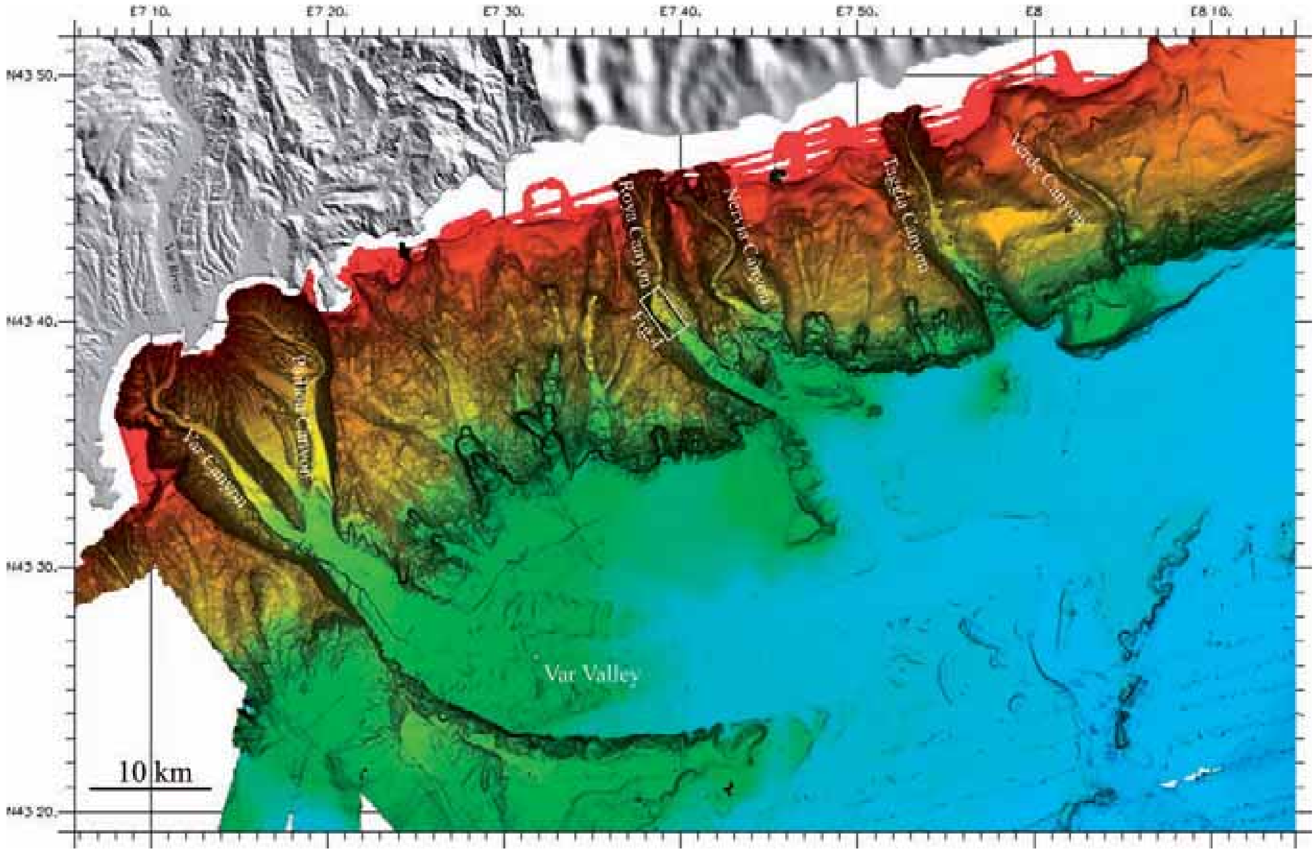


Fig. 3:

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

cross-section profile, suggesting intense and active erosive processes, or a U-shaped cross-section profile associated with thick accumulation of sediments on both sides of the canyons and along their axis. This type of cross-section profile also correlates with the general along-axis longitudinal profile of each canyon. For example, the Var and Paillon Rivers exhibit a concave-up profile, suggesting they reached a "state of equilibrium", and are mostly characterized by U-shaped profiles. The Roya, Nervia and Taggia canyons exhibit convex-up profiles suggesting that erosional processes must still be active within these canyons. They have not yet reached a state of equilibrium, and V-shaped cross-section profiles are predominant. Along the Verde canyon, the change from a U-shaped (upslope) to a V-shaped (downslope) profile attests to distinct dynamic behaviors occurring along a single canyon.

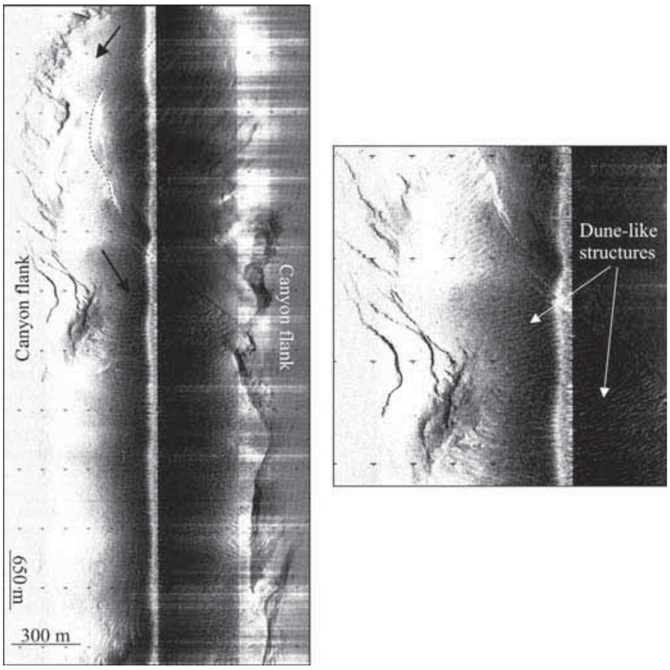
Several factors may explain these differences. The present-day pathway of canyons is largely controlled by the pre-existing topography inherited from the Messinian erosive period:

(1) V-shaped canyons are located in pre-existing narrow valleys that channelized gravity flows within and along constricted conduits which increased their erosive power;

(2) U-shaped canyons developed in wider pre-existing valleys that allowed gravity flows to spread laterally, reducing their erosive power and favoring sediment deposition.

Faults that were active, at least during the Pliocene era, are associated with V-shaped canyons and were weakness areas that favored stronger erosion processes. Then, the uplift of the margin, mainly in front of Imperia during the Plio-Quaternary, caused a gradual increase of the continental-slope angle and a continuous change of its longitudinal topographic profile. Incision of canyons will thus increase to re-establish an equilibrium (concave-up) profile. Just after a modification of the margin topographic profile, erosion will first start at the base of the canyon and then propagate in an

Fig. 4:
Side-scan sonar image obtained in the Roya canyon.
Note the presence of dune-like structures flooring the canyon.
The black arrows indicate the direction followed by gravity flows.



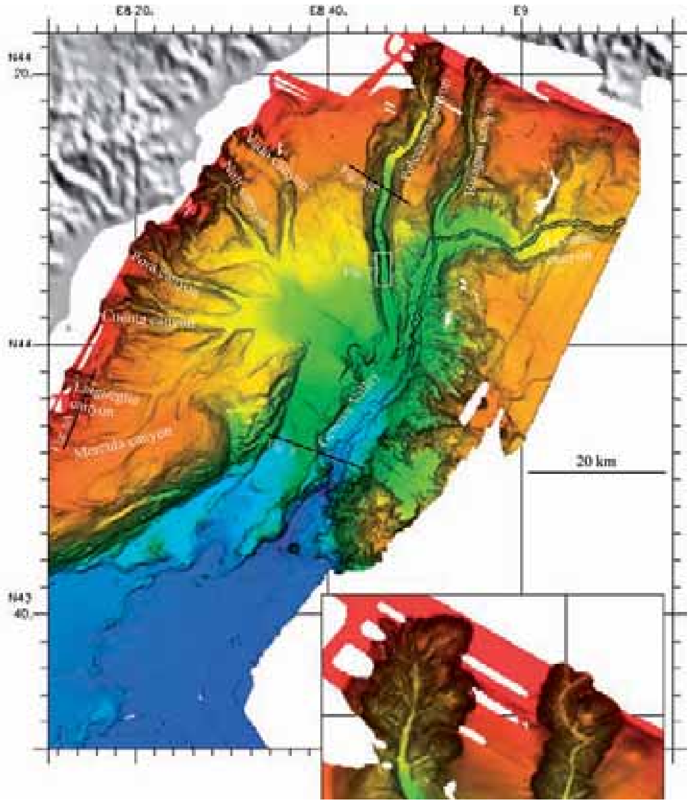


Fig. 5:
Shaded bathymetric map
illustrating the morphology
of the eastern Ligurian margin.

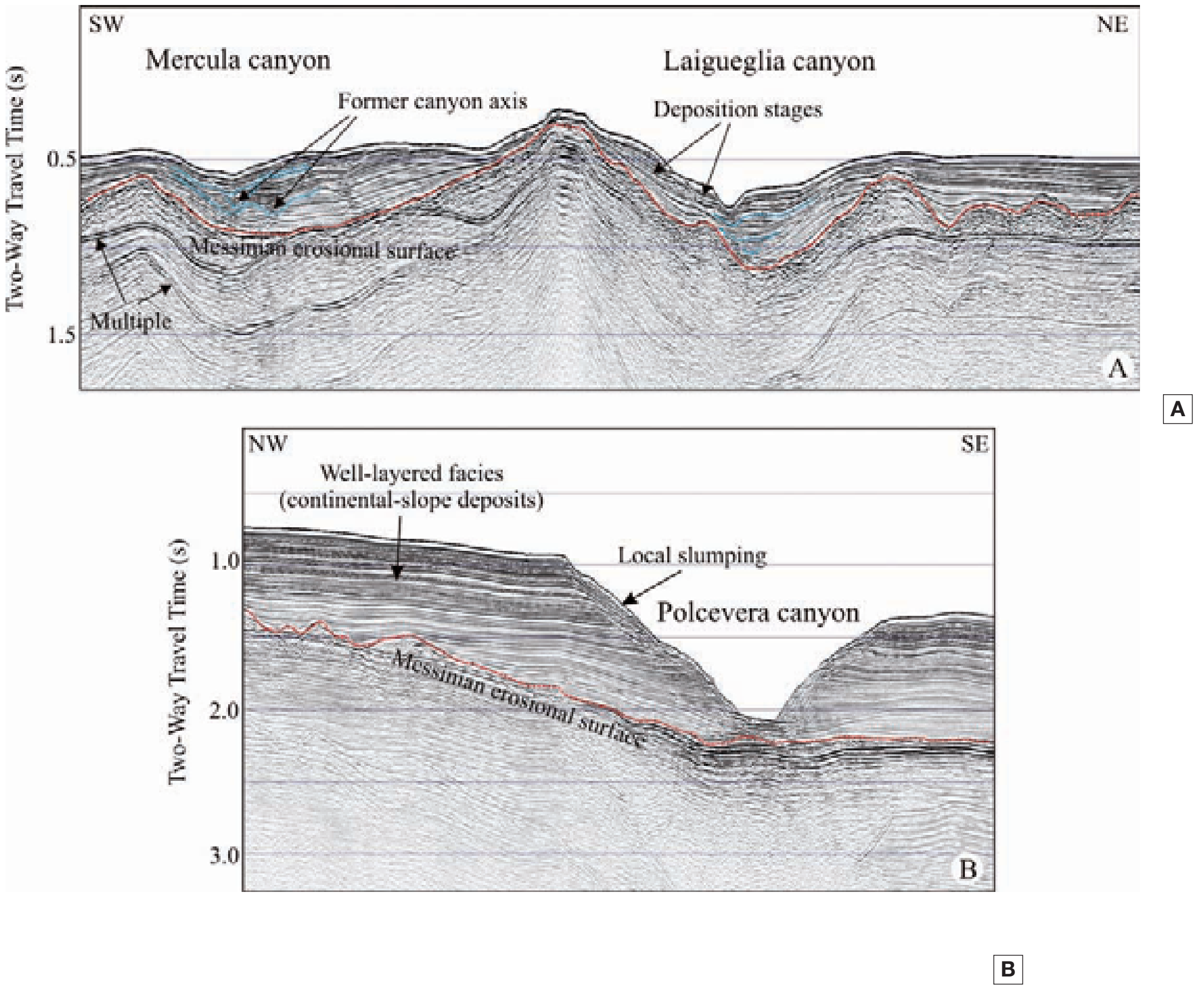
upslope direction. This could explain the increasing downslope erosion observed in the downstream part of the Verde canyon (V-shaped cross-section profile) as compared with the depositional pattern (U-shaped profile) characterizing its upstream sector.

The Var, Paillon, Roya and Taggia canyons are still active nowadays in term of sediment transport. This is evidenced on side-scan sonar images by the absence of hemipelagic drape on the floor of their axis and the presence of coarse-grained (probably sand to boulder) accumulations such as dune-like structures (Fig. 4).

On the segment of margin comprised between Imperia and Savone, the network of canyons exhibits a SW-NE to W-E trend, i.e. oblique to the general margin trend (Figs 2 and 5). This unusual pattern is due to the presence of a tectonic ridge, the Imperia Promontory, and its progressive uplift during the Plio-Quaternary (Larroque *et al.*, 2011; Sage *et al.*, 2011). In this area, the canyons are 50-m deep or less and 1-2 km wide. All these canyons exhibit a linear along-axis topographic profile, suggesting they have not yet reached their equilibrium profile and that erosion may be still active within their axis. Conversely, they exhibit a U-shaped cross-section profile which suggests depositional processes. In fact, seismic-reflection data collected perpendicular to the canyon axis document alternations between short phases of erosion and longer phases of deposition and vertical aggradations (Fig. 6A). Phases of erosion are associated with a lateral migration of the canyon axis. Such alternations between erosion and deposition are probably related to stages of uplift of the Imperia Promontory or to sea level fluctuations during the Quaternary era.

Fig. 6:

Seismic-reflection profiles illustrating the architecture of some of the canyons present along the eastern Ligurian margin.
Profile location shown in Figure 5.
The dotted red line represents the Messinian erosional surface.
The dotted blue lines highlight phases of canyon erosion.



The two largest canyons of the Ligurian margin lie offshore of Genova: the Polcevera and Bisagno canyons (Figs. 2 and 5). These features are more than 700-m deep, 20-km wide and about 60-km long. They are straight in the direction of the main slope angle. The two canyons exhibit a linear along-axis topographic profile, suggesting once more that erosive processes must predominate within their axis. They mostly exhibit a V-shaped profile along their pathway (Fig. 6B), confirming that erosion should be prevailing. Their steep walls are also strongly affected by landsliding processes (Fig. 6B). The present-day heads, which exhibit a well-developed cauliflower-like pattern (Fig. 5), incise the outer continental shelf and the upper continental slope. Such specific morphology results from the repetitive triggering of small-scale submarine retrogressive failures. Nowadays, the two canyons are not connected to fluvial inputs, though side-scan sonar images, collected within their axis, highlighted the presence of fresh erosional scours (Fig. 7). This suggests a recent activity of particle transfer. We thus believe that the local failure processes, affecting both the heads and flanks of the canyons, maintain the present-day activity of sedimentary processes and gravity flows within the canyons.

East of the Bisagno canyon, the Levante canyon exhibits first an east-west trend, then merges with the Bisagno canyon and finally pirates its main pathway (Fig. 5). The Levante canyon, about 300-400-m wide and 50-70-m deep, displays an unusual meandering plan-form pattern that usually corresponds to deep-sea turbidite channels. The three canyons coalesce downslope to form the 5-km wide and 400-600-m deep Genova Submarine Valley (Fig. 5). It exhibits a U-shaped cross-section profile (Fig. 8) and its pathway is clearly constrained by the presence of major faults bordering its right-hand side (looking down valley).

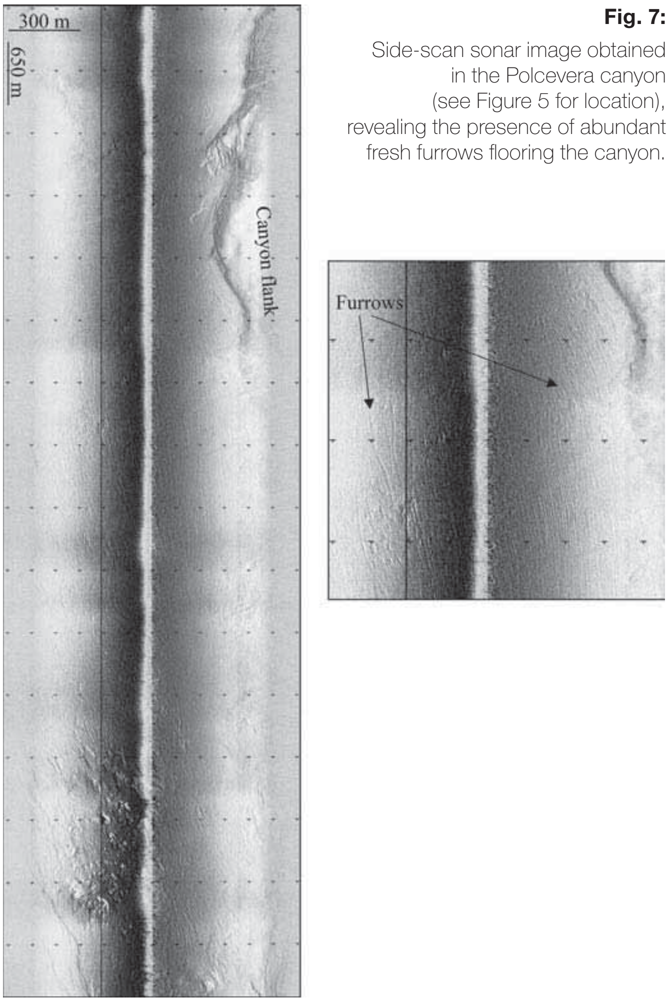
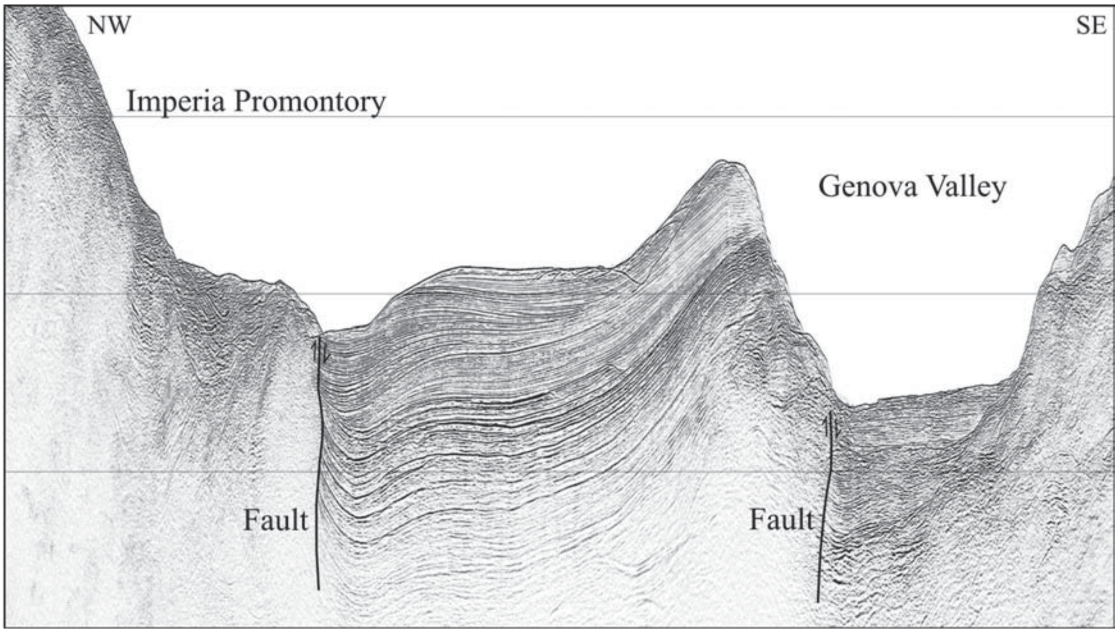


Fig. 7:
Side-scan sonar image obtained in the Polcevera canyon (see Figure 5 for location), revealing the presence of abundant fresh furrows flooring the canyon.

Fig. 8:
Seismic-reflection profile crossing the Genova Valley near the base of the continental slope. Profile location shown in Figure 5. Note the presence of faults constraining the location of the right-hand (western) side of the valley.



The Nile deep-sea fan

The Nile deep-sea cone (see Fig. 1) is the largest Plio-Quaternary silico-clastic accumulation of the Mediterranean Sea. The Nile River has delivered particles to the deep sea since the Messinian Salinity Crisis at least. The present-day Nile deep-sea fan, which built outwards over the Messinian evaporite, forms a 2000-2500-m thick Pliocene and Quaternary sediment bulge. Offshore the Nile sub-aerial delta, the continental shelf widens from west to east from 30 to 60 km. The continental-slope angle is usually lower than 2°. Based on morphologic data, four main morpho-structural provinces have been discriminated (Bellaiche *et al*., 1999). A Western Province, located in continuity with the Rosetta branch off the Nile delta, is characterized by a dense network of turbidite channel-levee systems and large submarine landslides that repeatedly affected the upper continental slope (Garziglia *et al*., 2008; Loncke *et al*., 2002). A Central Province displays small, progressive slope deformation of the uppermost tens of meters of sediments, and numerous pockmark fields (Loncke *et al*., 2002). The base of the slope is itself deformed by salt-related faults. An Eastern Province contrasts with the two previous areas, as it is strongly affected by active salt tectonics that have generated normal faults on the upper slope, and large-scale folds at the base (Mascle *et al*., 2006). In this area, channel-levee systems were built in relationship with the Damietta branch off the Nile River, but became inactive some 125,000 yrs ago (Ducassou *et al*., 2009). Finally, a Levantine Province is characterized by small-scale folding which deforms the Quaternary deposits, and by a few channel-levee systems that can be observed up to the deep part of the basin, east and north of the Eratosthenes Seamount (Mascle *et al*., 2006).

(Ducassou *et al*., 2009) documented that sediment dispersal across the Nile margin was strongly influenced by monsoon-driven variations in sediment and water discharges from the Nile River, as well as by eustatic sea level fluctuations. Arid periods, mostly coeval with sea level lowstands, are characterized by high rates of coarse-grained supply from the Nile. However, most of the sediment is trapped onshore due to low water discharges. Conversely, pluvial periods, coeval with sea-level highstands, and in some cases with sea-level rise or fall, produce lower volumes of finer-grained particles, but in the meantime high water river discharges lead to high-sediment transfer to the deep-sea, mainly because of reworking of former deposits accumulated during arid periods. In the case of the Nile, increased sediment supply reflects monsoonal intensity.

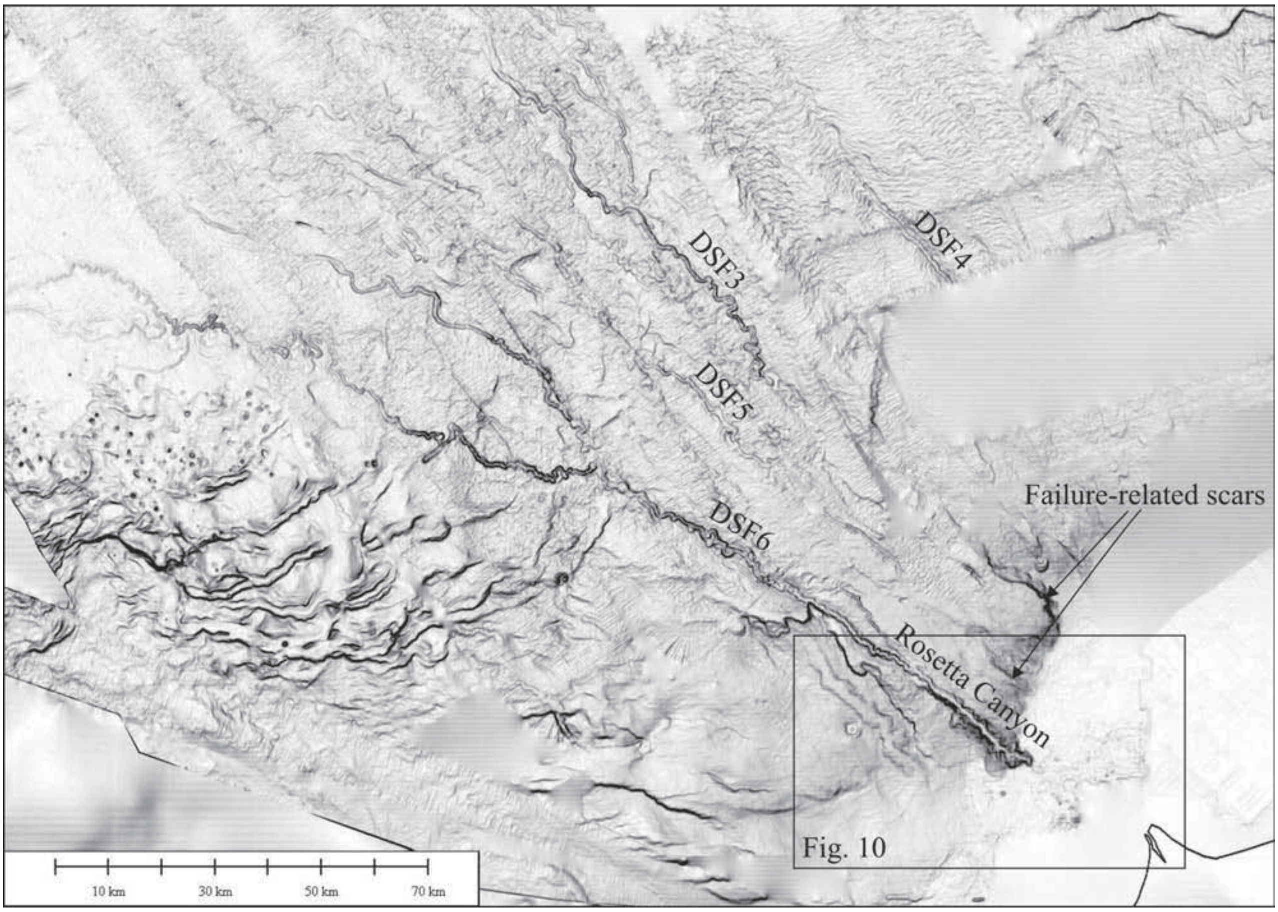


Fig. 9:

Slope-gradient map illustrating the presence of canyon, channel-levee systems and failure-related scars on the Nile continental margin offshore the Rosetta branch of the Nile subaerial delta.

In the western (or Rosetta) Province, four main channel-levee systems have been active during the last 115 ka (Ducassou *et al.*, 2009). The oldest channel-levee system (DSF3; Fig. 9) initiated about ~115 ka (Marine Isotope Stage 5). A second channel-levee system (DSF4; Fig. 9) initiated at about 73-70 ka, at the end of the Saharan Pluvial period. DSF3 and DSF4 were active simultaneously during glacial stage 4 and inter stade MIS3 (73-50 ka). DSF3 finally became inactive around 50 ka and a third channel-levee system (DSF5; Fig. 9) was built. DSF5 became inactive during MIS2 (25-14.8 ka), whereas DSF4 had reduced activity. A fourth system (DSF6; Fig. 9) initiated during MIS3 at about 40 ka. DSF6 was active during the mid and late Termination I (14.8-10 ka) and during the early Holocene (10-~5 ka), while DSF4 had residual activity until about 10 ka. Except for the most recent one (DSF6), these channels are no longer connected to their feeding canyons which are probably buried or were reworked by mass-wasting events (Garziglia *et al.*, 2008).

DSF6 is fed by the Rosetta Canyon (Figs. 9 and 10) located 30 km off the Rosetta branch mouth and breaching the upper slope through a 30-km wide scar induced by numerous slope failures. Rosetta Canyon, which initiates on the outer continental shelf at about 70 m water depth, (Fig. 10), is about 25 km long and is straight in the main direction of the continental-slope angle. The canyon is about 200-250-m deep and narrows from 8 to 5 km downslope. The canyon head consists of imbricated semi-circular scarps, 1 to 5 km wide, related to repetitive small-scale submarine failures which have merged into a typical cauliflower-like morphology (Fig. 10). Within the canyon, the longitudinal along-axis topographic profile is rather linear but the whole DFS6, from the canyon head to its distal lobe (Herodotus Plain), exhibits a concave-up profile, suggesting that equilibrium conditions were reached. In cross section, the Rosetta Canyon is characterized by U- to poorly-developed V-shaped profiles where a large number of small-scale failures affected the canyon flanks (Fig. 10). Today the Rosetta Canyon is not directly connected to the Rosetta branch of the Nile, but connection could have existed during sea level lowstands, such as in the Last Glacial Maximum. Most of the gravity-flow deposits identified at the mouth of the DSF6 channels are thus thought to originate from failures triggered in the canyon head (Migeon *et al.*, 2010).

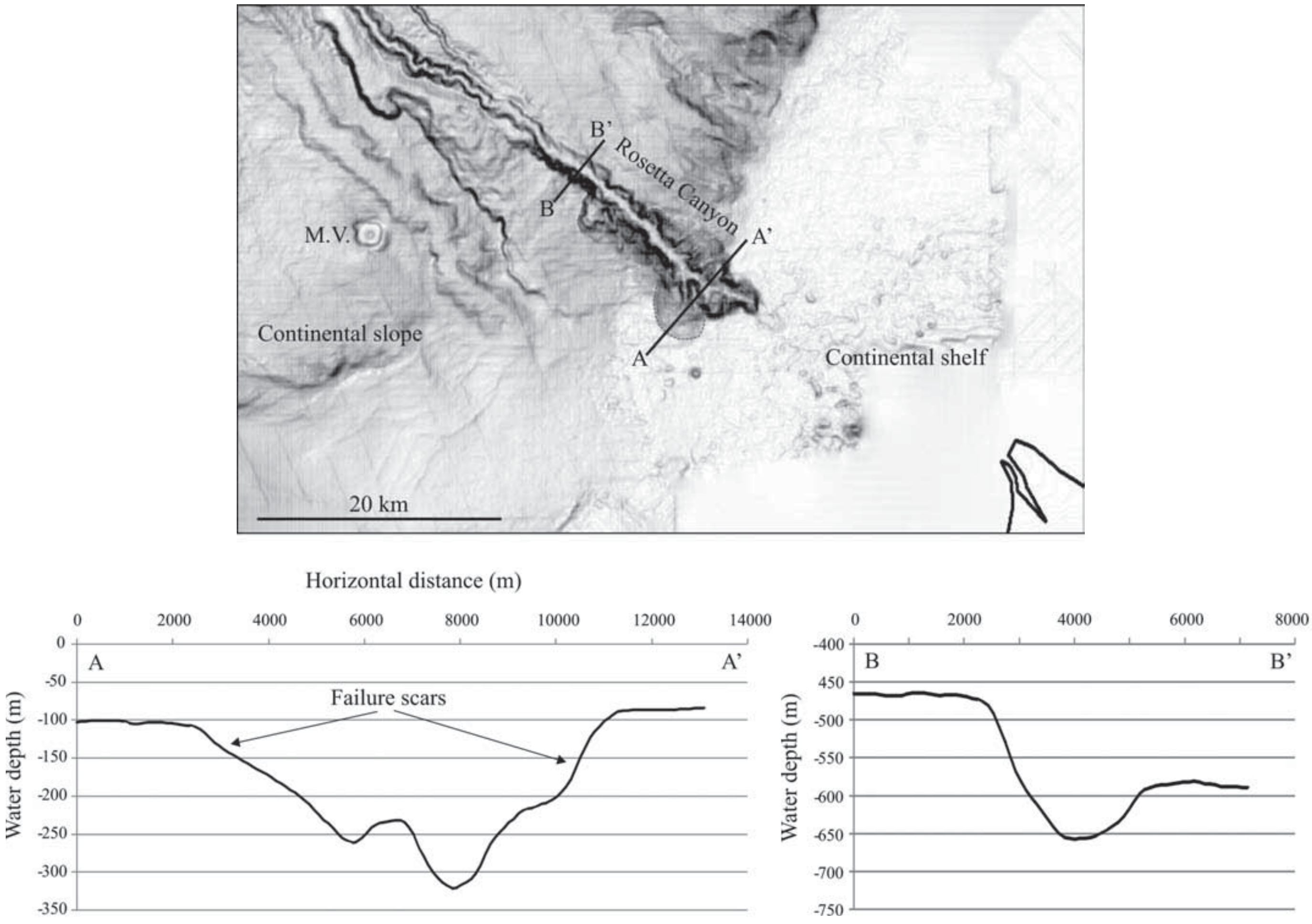


Fig. 10:

Slope-gradient map focusing on the Rosetta Canyon. M.V. is mud volcano. AA' and BB' are two cross-section topographic profiles of the Rosetta Canyon.

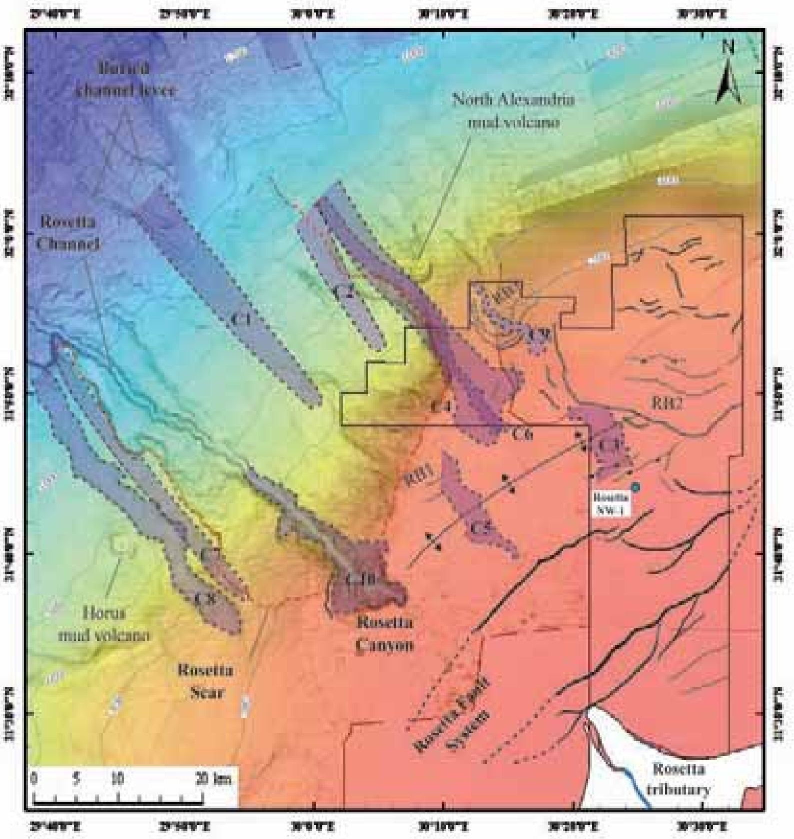


Fig. 11:

Bathymetric map illustrating the location of buried canyons offshore the Rosetta branch of the Nile delta (Rouillard, 2010).

The use of 2D and 3D seismic-reflection data makes possible to identify nine additional buried canyons in the area (Rouillard, 2010) which were built since the Upper Pliocene along a 55-km wide segment of the continental shelf and upper continental slope offshore the Nile Rosetta branch (Fig. 11). These buried canyons lie at different stratigraphic levels (Fig. 12) suggesting a diachronous character. They have no, or little, expression on the present-day seafloor. They all trend SE-NO, except the oldest identified one which trends SSE-NNO (Fig. 11). The nine canyons exhibit different sizes, shapes, sinuosity, lengths of shelf incision (Fig. 13), emphasizing various processes of formation and evolution through time. We describe below a few canyons whose morphologies are representative of the entire set of identified canyons.

Canyon C3 (Figs. 11 and 12) is located within the upper Pliocene sedimentary section, at depths varying between 750-1200 m below the seafloor. Recognized over a distance of 9 km, this canyon is relatively straight and exhibits in cross section a U-shaped profile with a mean width of 3.5 km, and an axial incision varying between 200 and 350 m deep. Numerous semi-circular and imbricated scars, 0.2-1.5-km wide, affect its flanks (Fig. 13). C3 has incised the paleo-continental shelf over a distance of 6 km (Fig. 13).

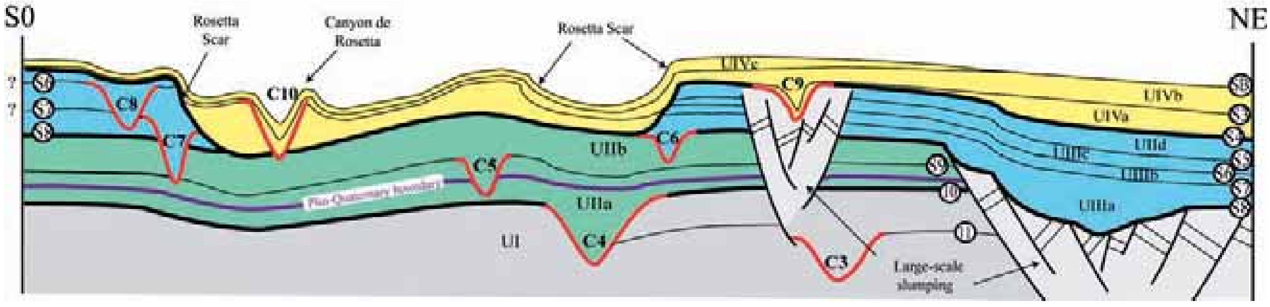


Fig. 12:

Schematic graphic section illustrating the stratigraphic location of the identified canyons offshore the Rosetta branch of the Nile delta (Rouillard, 2010).

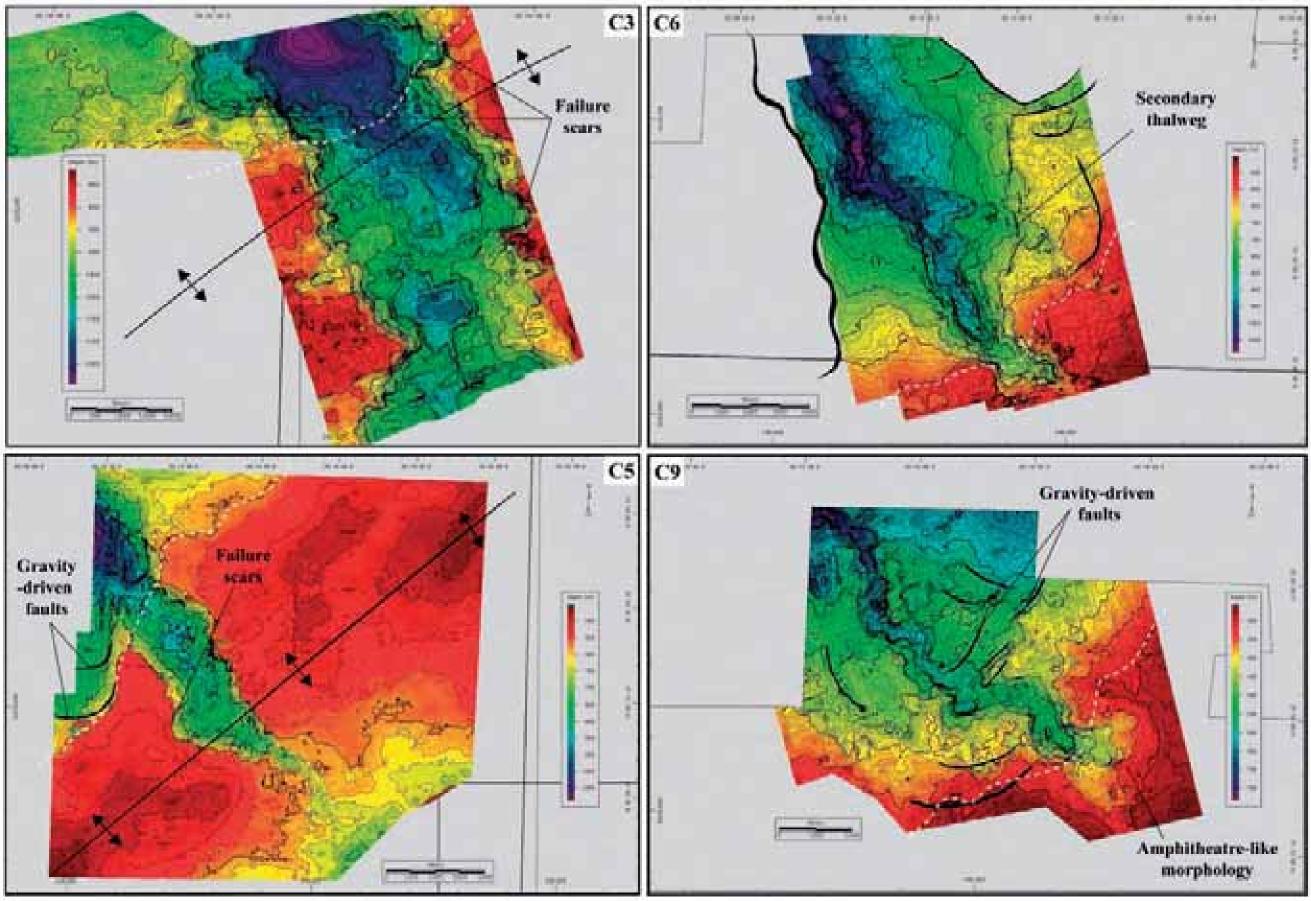


Fig. 13:

Maps of the basal erosion of canyons C3, C5, C6 and C9.

The white dashed line shows the location of the paleo-shelfbreak. Thick black lines represent fault escarpments (Rouillard, 2010).

Canyon C5 is located between the present-day Rosetta Canyon and canyon C3. Mapped over a distance of 10 km (Fig. 11), it is located at depths between 500 m and 1050 m below the seafloor, at the transition between the Pliocene and Pleistocene sedimentary sections. This canyon exhibits in cross-section a U-shaped profile and a longitudinal concave-up topographic profile close to the theoretical equilibrium profile. It is about 3-km wide, 120-m deep and shows a relatively straight plan-form pattern. Its width decreases from 3000 m to 500 m toward the continent, and its head has cut the paleo-shelf over a distance of more than 8 km (Fig. 13). A few semi-circular scars, 100-500-m wide, can be detected on the canyon flanks (Fig. 13).

Located north-east of the present-day Rosetta Canyon and canyon C5, canyon C6 is buried along the present-day eastern edge of the wide scar seen on the upper continental slope (Figs. 9 and 11). Mapped at depths between 550 m and 1050 m below the seafloor in the Quaternary cover, it extends over a distance of 12 km. Its head, characterized by numerous semi-circular scars (cauliflower-like plan-form pattern), incised the paleo-shelf over a distance of at least 2 km (Fig. 13). The head gradually widens downslope, from 500 to 2000 m at the paleo-shelf break. Then, the canyon rapidly widens toward the basin to reach a width of 4 km (Fig. 13). The axial incision exhibits a V-shaped cross-section, 100-200 m deep, and is slightly sinuous.

Finally, buried canyon C9 is located about 10 km north-east of canyon C6 (Fig. 11). Mapped within the Quaternary section over a distance of 12 km and at depths between 250 and 800 m below the seafloor, this canyon has a head 1.5-km wide and about 250-m deep (Fig. 13) which also shows a typical cauliflower-like plan-form morphology due to coalescing semi-circular small scars (Fig. 13). C9, which has incised the paleo-shelf over less than 2 km, exhibiting a V-shaped cross-section profile and a well-developed sinuous plan-form pattern.

From these morphological analyses, one can distinguish two types of canyons: (1) canyons characterized by cauliflower-like heads restricted to the upper continental slope/outer shelf (C6, C9, Rosetta Canyon), and (2) canyons with a rather straight head incising the continental shelf towards the coastline over much longer distances (C3, C5). We believe that such differences reflect different processes of canyon formation where erosion could be constrained either by local processes of retrogressive failures located at the shelf break, or by more continuous downslope processes related to high-sediment discharges delivered at the mouth of the Rosetta branch.

In addition to these four canyons, buried canyons C7 and C8, which also cut across the Quaternary section, are located southwest of the present-day Rosetta Canyon (Figs. 11 and 12). Up until now, only the present-day Rosetta Canyon can be related with confidence to the most recent channel-levees system (DSF6) described by Ducassou *et al.* (2009). DSF6 initiated about 40 ka and was still active until 5 ka. Because of its stratigraphic position and its location and direction, we suspect that C9 could have been the source point for DSF4, active between 70 and 27 ka BP. Actually, C9 and the Rosetta Canyon may thus well have been active synchronously. The potential feeding canyons of DSF3 and DSF5 have not been yet identified. As they should be located within the 30-km wide scar affecting the upper continental slope, they may have been totally erased by the successive mass-wasting events that created the scar. This suggests that more canyons were likely to have existed during upper Pleistocene times.

All these canyons show some east-west and west-east phases of lateral migration which seem to be random. Each migration was probably sudden as no intermediate position of any canyon axis has been observed between two successive phases of canyon creation (Figs. 11 and 12). Such rapid lateral migrations are probably controlled by the migration/avulsion of the sub-aerial delta branches, each avulsion leading to a more or less instantaneous displacement of the main direction of particle fluxes towards the continental shelf and slope, and of the main depocenter location. The real timing of the activity of a single canyon remains impossible to estimate in the absence of specific stratigraphic data from drilling or coring. The correlation existing between the Rosetta Canyon and DSF6, and between canyon C9 and DSF4 suggests, however, a time span for each canyon activity in the order of about 35-40 ka.

CONCLUSION

From this very rapid survey of the Mediterranean canyons and from two case studies, we can conclude that:

— (1) The majority of present-day Mediterranean canyons are, like the majority of rivers on land, mostly superimposed on tectonic lineaments, inherited either from earlier geological evolution, or, in the case of the Western Mediterranean Sea, from the various continental margin creation or re-activation periods (rifting of the north-western basin, rifting of the Alboran and Tyrrhenian Seas). Some canyons are, however, closely controlled by surrounding active tectonic, which makes strong imprints on the continental margin fabric and evolution (e.g. central Ligurian margin, Algeria, Southern Calabria, Western Peloponnesus, Crete, Southern Turkey).

— (2) Most of the upper domains of these features have been deeply eroded by retrogressive mechanisms and in aerial conditions, during the Messinian crisis when the sea level was several hundred meters lower than today (possibly up to 1.5 km locally).

— (3) In contrast to the majority of Mediterranean canyons, the Ebro, Rhone and Nile Rivers canyon systems are composed of active canyons and channels cutting, and running across, deeply sedimented platforms and continental slopes. These canyons may be, though not necessarily, locally superimposed on, or inherited from, previous canyons (e.g. Gulf of Lion). Alternatively, they may have been created in response to climatic and/or eustatic fluctuations (e.g. western Nile canyons).

— (4) In all cases, important amounts of erosion sediments are transported and distributed to the deep sea through these canyons, which in turn act as conduits for nutrients to the deep sea, particularly nearby coastlines bordering mountain chain areas, and may thus act as hot spots for biological processes.

— (5) Along several north African margin segments, such as off Libya and partly Maghreb, the canyons are almost disconnected from any river providing regular input, and may consequently only act as temporary pathways for sedimentary mass flows.

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2. SUBMARINE CANYONS AND FISHERY

2.1. A refugium for the spawners of exploited Mediterranean marine species: the canyons of the continental slope of the Gulf of Lion

Henri Farrugio

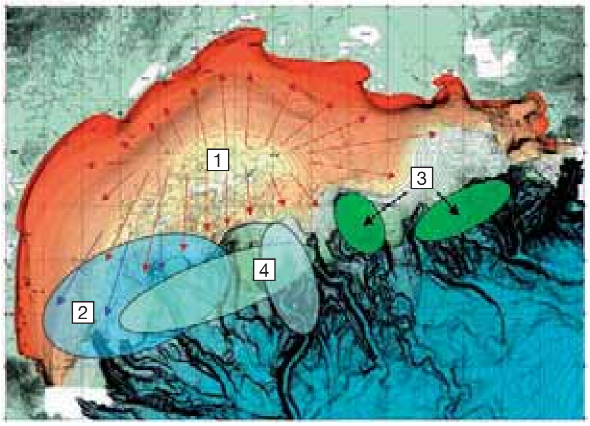
IFREMER, France

Living marine resources in the Gulf of Lion constitute a "shared stock" mostly exploited by French and Spanish trawlers on the continental shelf, and by French gillnetters and Spanish longliners on the continental slope which is incised by numerous submarine canyons (Fig. 1).

Scientific analysis of these resources is obtained from either "direct" assessments performed by oceanographic vessels during surveys at sea, or "indirect" assessments using mathematical models based on knowledge of the demography of landings, fishing efforts and the biological characteristics of the species.

These analyses suggest that maximum sustainable levels of catches were theoretically exceeded as early as 1991 in the Gulf of Lion for several species of demersal fishes, whose fishing mortality is mostly due to the practice of trawling on the continental shelf where young fish of small size are particularly abundant (Farrugio *et al.,* 1993). However, even though their levels of abundance are low, most of these species are able to renew their stocks as their catch levels have remained particularly stable over the past few decades. This production is comprised in particular of hake *(Merluccius merluccius),* red mullet *(Mullus barbatus* and *Mullus surmuletus),* monkfish *(Lophius piscatorius* and *Lophius budegassa),* conger *(Conger conger),* cod *(Trisopterus minutus capelanus),* sole *(Solea* spp.), sea bream *(Sparus aurata),* seabass *(Dicentrarchus labrax),* pandora *(Pagellus* spp.), octopus *(Eledone cirrhosa)* and squid *(Illex coindetii).*

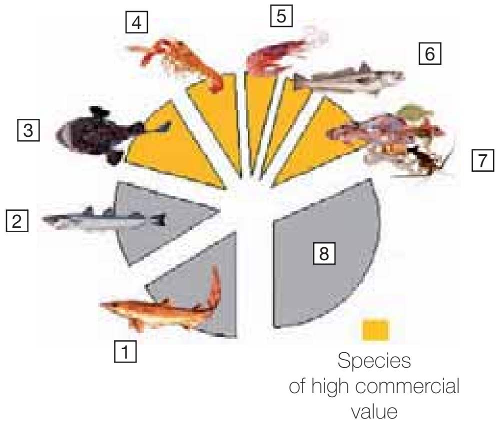
At the end of 2007, two professional Spanish trawlers were chartered by the Spanish Institute of Oceanography (IEO) to carry out an experimental trawling survey at depths of 300 to 700 m on the continental slope east of the Gulf of Lion, off the Petit Rhône and Grand Rhône (Massuti *et al.,* 2008). During this operation, samples in size and weight of 27,280 specimens belonging to 15 commercially important species showed that the sector being explored could be considered as moderately exploited, given the high yields of adult reproducers of several commercial species of fish and crustacea, particularly hake, monkfish, Norway lobster and shrimps that were obtained (Fig. 2).



1. French trawlers
2. Spanish trawlers
3. French gillnetters
4. Spanish longliners

Fig. 1:

Sectors of activity of the various components of the Franco-Spanish fishing fleet exploiting halieutic resources in the Gulf of Lion.



1. Blackmouth catshark, *Galeus melastomus*
2. Blue whiting, *Micromesistius poutassou*
3. Monkfish, *Lophius piscatorius*
4. Norway lobster, *Nephrops norvegicus*
5. Red shrimp, *Aristeus antennatus*
6. European hake, *Merluccius merluccius*
7. Miscellaneous
8. Other

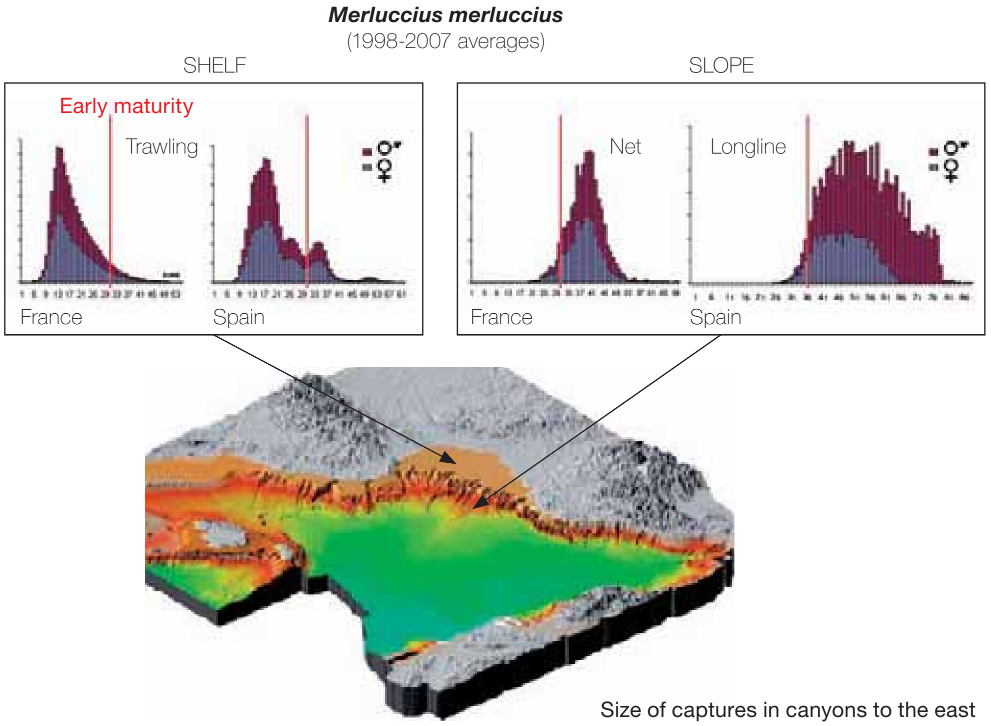
Fig. 2:

Specific composition of captures from the canyons in the eastern part of the Gulf of Lion.

These observations confirmed information gathered on experimental trawling surveys undertaken by IFREMER since 1957 to follow the evolution of the abundance of the main populations exploited by fisheries in the Gulf of Lion. Originally focusing on depths from 10 to 250 m, these surveys were extended as from 1994 to a depth of 500 m (MEDITS program). They showed that, for a considerable number of species of commercial interest, juvenile fishes move between the coast and offshore areas depending on the seasons: the coastal strip is a preferred zone for "nurseries", as is also the edge of the continental slope for certain species. The most recent surveys also showed that medium-sized fish and abundances of several target species follow an east-west gradient : the subjects concerned are smaller in the western part of the slope, where they are caught by both French and Spanish boats, than in the eastern part where there is less fishing activity and where, for most of the species of major commercial interest (including hake, monkfish and shrimps), the size of the specimens caught on the slope are at least equal to their size at sexual maturity (Fig. 3).

These observations are confirmed by observation of catches by boats using gear installed on the sea bottom, such as gillnets and longlines.

French fishermen consider that this zone should only be very moderately exploited by trawlers in order to preserve their resources. In fact, the continental slope can be thought of as a refuge sheltering fishes, which have escaped juvenile fishing on the continental shelf and which can thus reach maturity and ensure minimum replacement of stocks which are at a precarious level. Some 20 years ago, Caddy (1990) already presented the hypothesis that sustainability of the majority of Mediterranean fisheries depended on the paradigm of spawners' refugia; over the past decade, studies carried out by French and Spanish halieutic specialists have made it possible to quantify the extent of over-exploitation of growing subjects, especially in the case of hake. For this species, recent scientific recommendations (GFCM, 2010) target a 20% reduction in the capture of young hake, with the priority aim of doubling the estimated biomass of spawners, which is very low despite the refugia (3% of the virgin biomass, whereas 30% is generally considered to be the threshold below which there is a risk of recruitment collapse).



Abundance indicators on the Shelf in Kg/Km^2
(MEDITS SURVEY 2008)

Species	West	East
Merluccius merluccius	1.83	18.56
Lophius piscatorius	39.74	308.84
Nephrops norvegicus	32.51	68.12

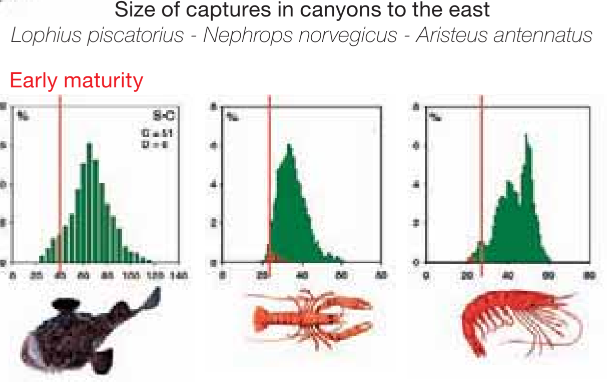


Fig. 3:

East-west gradient of density and frequency of incisions observed in captures made on the continental shelf and canyons in the Gulf of Lion.

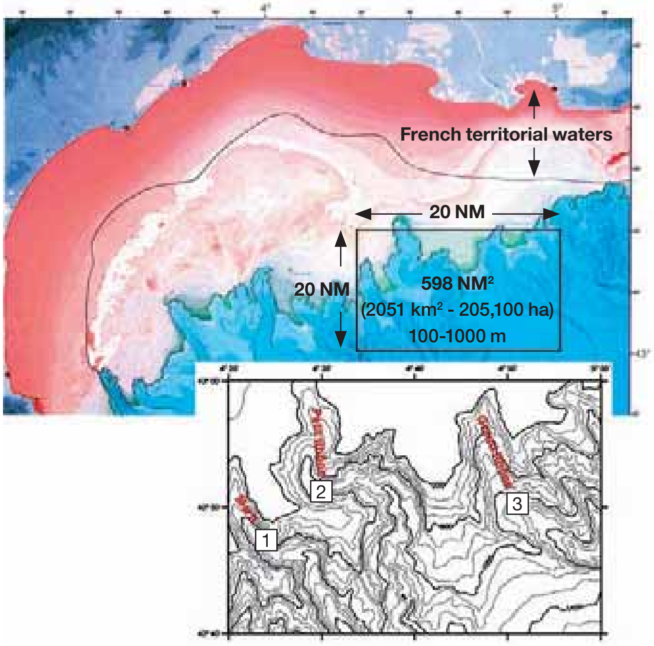
On the other hand, increased fishing activity would definitely result in very rapid deterioration of the ecosystem and, given the already intensive exploitation of juveniles on the continental shelf, a drastic reduction in terms of restocking which would jeopardize all the fisheries in the Gulf of Lion.

In this respect, the example of the Gulf of Gascony has contributed additional information : as in the Gulf of Lion today, hake fishing in the Atlantic consisted for many years of catching undersized fish (following large-scale post-war catches of adults). A certain balance seemed to have been restored, with undersized survivors capable of reproduction in refugia in the Azores. In the 1980's, fishing for spawners developed (with towed nets and longlines), without any decrease in the landings of juveniles (quite the contrary), thus impairing this balance and causing a severe drop in the levels of the stock, which led to the introduction of emergency measures and a plan to restore the balance.

A similar risk now exists for hake in the Gulf of Lion, and most probably for other important species as well.

It is particularly vital to protect "cryptic populations" of adult fish taking refuge in the canyons because large females are much more fertile, the number of eggs rising exponentially with size for most species; with age, these eggs are increasingly larger, which raises the chances of survivial for the larvae. Advanced age is also a sign of robustness, and large spawners are reservoirs and distributors of “good” genes. As Froese recommended in 2001 ("Let the mega-spawners live"), ensuring long life for a non-exploited spawning fraction of the stock thus seems to be the best guarantee against the risk of its over-exploitation.

Safeguarding the refuge zones has thus become an urgent priority.



1. Marti 2. Petit Rhône 3. Grand Rhône

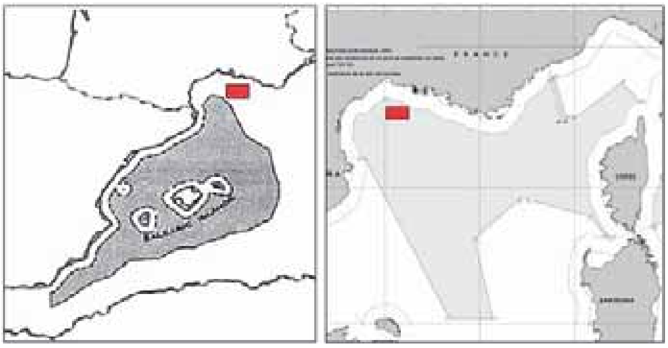
Fig. 4:

Geographic location of the fisheries area with restricted access as adopted in 2009 by the General Fisheries Commission for the Mediterranean.

In response to a proposal forwarded by French and Spanish researchers, the Scientific Advisory Committee of the GFCM – one of whose statutory roles is to develop proposals for measures promoting conservation and rational management of living marine resources – recommended in December 2008 that a fisheries area with restricted access should be set up in a quadrilateral area of 205,000 hectares off the French coast. This zone contains three submarine canyons named (from east to west) Estaque, Grand-Rhône and Petit-Rhône, and part of the Marti canyon (Fig. 4). Their slopes are steep, occasionally attaining over 20°. The inter-canyon zones are less abrupt with slopes of 2° - 3° between depths of 180 and 2000 m. The area is situated outside the halieutic protection zone set up by Spain in 1997 and inside the French ecological protection zone (Fig. 5).

This recommendation (see appendix) was adopted at the 33rd session of the GFCM held in March 2009 (Recommendation GFCM/33/2009/1: FAO, 2009); it states that the fishing effort for demersal stocks carried out by vessels using towed nets, bottom and mid-water longlines, and bottom-set nets shall not exceed the level applied in 2008 in the fisheries restricted area. To this end, Members and cooperating non-members of the GFCM are required to keep a register of vessels authorized to fish in the area, to ensure that those without any record of fishing in the area prior to December 31st, 2008, are not authorized to start fishing therein. The register must contain the list of vessels which were using towed nets, bottom and mid-water longlines and bottom-set nets in the area in 2008, and the legal provisions in force on December 31st, 2008, regarding the maximum time allowed for daily fishing, the maximum number of days a vessel can stay out at sea, and the legally compulsory time-period between the fishing vessels' exit and return to their registered ports.

The recommendation also provides for protection of the restricted access area from the impact of any other human activity, which may jeopardize the conservation of the characteristic features of this particular habitat as a zone of spawners' aggregation.



Outside the Spanish halieutic protection zone (1997)

Inside the French ecological protection zone

Fig. 5:

Location of the fisheries area with restricted access compared with zones of Spanish halieutic and French ecological protection.

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APPENDIX

RECOMMENDATION GFCM/33/2009/1 ON THE ESTABLISHMENT OF A FISHERIES RESTRICTED AREA IN THE GULF OF LIONS TO PROTECT SPAWNING AGGREGATIONS AND DEEP SEA SENSITIVE HABITATS

The General Fisheries Commission for the Mediterranean (GFCM):

RECALLING that the objective of the Agreement establishing the General Fisheries Commission for the Mediterranean is to promote the development, conservation, rational management and best utilization of living marine resources;

RECALLING Recommendation GFCM/29/2005/1 on the management of certain fisheries exploiting demersal and deepwater species and, notably, Article 1 therein;

CONSIDERING that the Scientific Advisory Committee (SAC) assesses that several stocks are overexploited, some with a high risk of collapse, and that sustainable management requires that measures aimed at limiting the capture of juveniles are implemented;

REAFFIRMING its commitment to further improving the gear selectivity of demersal trawl fisheries beyond what can be achieved by a minimum 40 mm square mesh size with a view to ensure better protection of juveniles of several species as well as to reduce discarding practices in a multispecies context;

CONSIDERING that selectivity of some fishing gears cannot go beyond certain level in Mediterranean mixed fisheries and that, in addition to the overall control and limitation of the fishing effort and fleet capacity, it is fundamental to limit the fishing effort in areas in which adults of important stocks aggregate in order to allow these stocks to deliver the necessary recruitment, thus allowing for their sustainable exploitation;

NOTING that the SAC advises to ban the use of towed and fixed gears and longlines for demersal resources in an area on the continental shelf and slope of the Eastern Gulf of Lions;

CONSIDERING that more scientific information is needed with a view to understand the relevance of other adjacent areas on the continental shelf and slope for the protection of spawners and sensitive habitats as well as to better known the level and spatial distribution of the fishing effort exerted;

PENDING the delivery of this additional information by the SAC;

ADOPTS *in conformity with the provisions of paragraph 1 (b) and (h) of Article III and Article V of GFCM Agreement that:*

1. The fishing effort for demersal stocks of vessels using towed nets, bottom and mid-water longlines, bottom-set nets shall not exceed the level of fishing effort applied in 2008 in the fisheries restricted area of the eastern Gulf of Lions as bounded by lines joining the following geographic coordinates:

42°40'N, 4°20' E; 42°40'N, 5°00' E; 43°00'N, 4°20' E; 43°00'N, 5°00' E.

2. Members and cooperating non-Members of GFCM shall communicate to the GFCM Executive Secretary not later than June 2009 the list of vessels that have used towed nets, bottom and mid-water longlines, bottom-set nets in the area referred to in paragraph 1 in the year 2008.

3. The list shall contain the following information for each vessel:

- *Name of vessel*
- *Register number*
- *GFCM unique identifier (country ISO 3-alpha code + 9 digits, e.g. xxx000000001)*
- *Previous name (if any)*
- *Previous flag (if any)*
- *Previous details of deletion from other registries (if any)*
- *International radio call sign (if any)*
- *Type of vessel, length overall and gross tonnage (GT) and/or gross registered tonnage (GRT)*
- *Name and address of owner(s) and operator(s)*
- *Main gear(s) used to fish in the fishery restricted area*
- *Seasonal period authorized for fishing in the fishery restricted area*
- *Number of fishing days exerted by each vessel in the year 2008 and number of fishing days exerted in the fishery restricted area.*

4. Members and cooperating non-Members of GFCM shall establish a register of the fishing vessels authorized to fish in the area which ensure that the vessels not having records of fishing in the area prior 31 December 2008 are not authorized to start fishing therein.

5. Members and cooperating non-Members of GFCM shall communicate to the GFCM Executive Secretary not later than September 2009 the legal conditions, as in force at 31 December 2008, as for the maximum time of daily fishing activity, the maximum number of days a vessel can stay at sea as well as the compulsory timing between the exit and return to the registered port of their fishing vessels.

6. Members and cooperating non-Members of GFCM shall ensure that fishing vessels operating in the area respect their obligation as in force at 31 December 2008 as for the maximum time of daily fishing activity, the maximum number of days a vessel can stay at sea as well as the legally compulsory timing to exit and return to the registered port.

7. For the fisheries restricted area referred to in paragraph 1, Members and Cooperating non- Members of GFCM shall call the attention of the appropriate national and international authorities in order to protect this area from the impact of any other human activity jeopardizing the conservation of the features that characterize this particular habitat as an area of spawners' aggregation.

8. Boundaries of the area and conditions to fish therein as referred to in previous paragraphs may change on the basis of SAC advice.

2.2. The fisheries importance of four submarine canyons in the spanish Mediterranean sea: Cap de Creus, Palamós, Cape Tiñoso and Alborán platform canyons

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Spanish General Secretariat for Fisheries, Ministry for Agriculture, Food and Environment.*

ECOLOGICAL AND FISHERIES IMPORTANCE OF SUBMARINE CANYONS

Submarine canyons and seamounts are "milestones" in the marine bottoms having singular characteristics in relation to the surrounding bottoms (Würtz, 2010). They are places that show high "geo-diversity". The improvement of our knowledge about marine bottoms, resulting from research undertaken over the past 20 years,_is based on a number of scientific papers on marine dynamics and the consequences from the ecological and fisheries point of view, which can be summarized in the following three points:

1. - Orography: sharp profiles such as steep slopes, zones of narrow steps or valleys, cause fundamental changes in marine dynamics and the flows of energy transfers. The area of the Cap de Creus canyon, one of the most widely studied in the Mediterranean, allows us to know more about its functions as a structure situated between the continental platform and the slope. According to the abundant scientific information resulting from diverse projects carried out in this area, the regime of cold, dry winds during a part of the year favours the arrival of nutrients to the deep zones. The canyon is thus rather like an oasis, that is to say, a zone of protection and feeding for the species, including demersal species of commercial interest.

2. – The supply of nutrients to these deep zones allows the development of significant biodiversity along a gradient of physical parameters from the upper edge to the inner parts of the bottoms of the walls. Some groups such as gorgonians, white or deep corals and some sponges, considered as habitat-builder organisms when growing in "gardens", generate biogenic structures for shelter that enhance the protection factor for spawners and their recruitment offered by the canyon.

3. - Zones protected from certain fishing gears: because of their sharp profiles, canyons are zones protected from bottom trawling. Canyons therefore promote a kind of "natural zoning" in local fisheries, i.e. they spatially segregate different gears, allowing for long-line and some artisanal fisheries activities, both proportionately more selective than bottom trawling.

Another example of zoning in fisheries, in this case "artificial", are the polygons of artificial protection reefs which, at the request of the artisanal fishing community, have mainly been deployed in the spanish Mediterranean sea by the Spanish General Secretariat for Fisheries of the Ministry for Agriculture, Food and Environment, with the aim of protecting sensitive bottoms of fishing interest, like *Posidonia oceanica* meadows in the Mediterranean. Like these artificial reefs, canyons fulfil the function of a kind of natural spatial marine planning for some fisheries.

Summing up, these three key factors describing the arrival of nutrient-rich waters inside a canyon, surfaces with structures of natural protection that offer several kind of bottoms, geogenic and biogenic, some with three-dimensional structures that form habitats and, finally, the fact that canyons are zones free from bottom trawling, allow us to see the important role canyons play as protected areas for spawning and breeding of marine species, some of them of fishing interest.

Company *et al.* (2008) defined the ecological and fisheries role of the canyons by offering the following comparison: "canyons would be for demersal fishing species the equivalent of upwellings for pelagic fishing species".

Progress in the collecting of scientific knowledge has placed protection and sustainable use of submarine canyons on international agendas as a result of the efforts undertaken by countries, multilateral organisms, the European Union and leading organisations in conservation programmes such as the IUCN. Furthermore, the extensive possibilities for exchanging information that exist today help to build a favourable background for decision-taking based on reliable data, targeting the sustainable use of the marine environment and the practise of responsible and sustainable ways of fishing, within the framework of close collaboration between coastal countries around the Mediterranean sea.

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* Before 2012, Spanish General Secretariat for the Sea.

International meetings, such as the one on Focal Points for Specially Protected Areas within Barcelona Convention held in June 2010 in Istanbul (Turkey), or the one in Procida (Italy) organised by IUCN, gather experts who contribute the most up-to-date knowledge, and constitute essential steps towards the establishment of Marine Protected Areas, and among them, those far away from shorelines, including areas beyond national jurisdictions. These meetings also call for collaboration between experts and agents in all the fields, scientists, but also experts in international law, focusing on governance and management aspects which need to be addressed (IUCN, 2010). They are quite definitely indispensable for shortening distances between objectives written into different international agendas, such as those introduced for 2012, or resulting from the Convention on Biological Diversity (CBD) or the recommendation on Marine Protected Areas issued at the V World-wide Parks Congress celebrated in Durban (South Africa) in the context of the IUCN Program 2009-2012.

In this respect, Spain and the European Union are now making an important effort within the framework of the LIFE + INDEMARES 2009-2013 project, focusing on obtaining sound scientific knowledge on ten Spanish marine areas candidates for the marine Nature 2000 Network, two of which contain canyons: the Cap de Creus in the Gulf of Lion area, and Avilés Canyon in the *"Cantábrico" Sea,* (northern Spanish Atlantic Sea).

As part of this project, the Spanish High Council of Scientific Investigations (CSIC) and the Spanish General Secretariat for Fisheries have collaborated in obtaining the fisheries "footprint" for the area of study of Cap de Creus, where we can assert that the canyons are, generally speaking, favourable areas for a marine ecosystem-based management approach, in which some fisheries of low impact take place, excluding bottom trawling.

THE FISHING FOOTPRINT IN THE AREA OF THE CAP DE CREUS CANYON, NORTHEASTERN MEDITERRANEAN

Canyons, as privileged environments for marine ecology and for fisheries, are considered good fishing grounds. So this fishing interest should be made compatible to fisheries, improved on the basis of the best scientific knowledge and minimum impact. The exhaustive knowledge of the boats and fishermen as crucial stakeholders within the framework of the protection of canyons and their potential management plans is a crucial first step towards ascertaining, in advance, the compatibility between an area's protection and sustainable fisheries activity.

The fishing footprint (Fig. 1) is the result of three steps and can be credited to collaboration from units within the General Direction of Fishing Resources and Aquaculture, with assessment provided by experts in the previous handling of fisheries data. The first step focused on an exhaustive study of the fishing sector in the area, taking artisanal fishery, that cannot be tracked through vessel monitoring system (VMS), on one hand, and the rest of the fishing fleet on another hand, this time through VMS tracking, along several years monitoring; the second step then consisted of processing the data supplied by the Spanish Fishing Monitoring Centre and data obtained via the VMS; and, thirdly, processing of all the data by CSIC experts using the Geographic Information System (GIS).

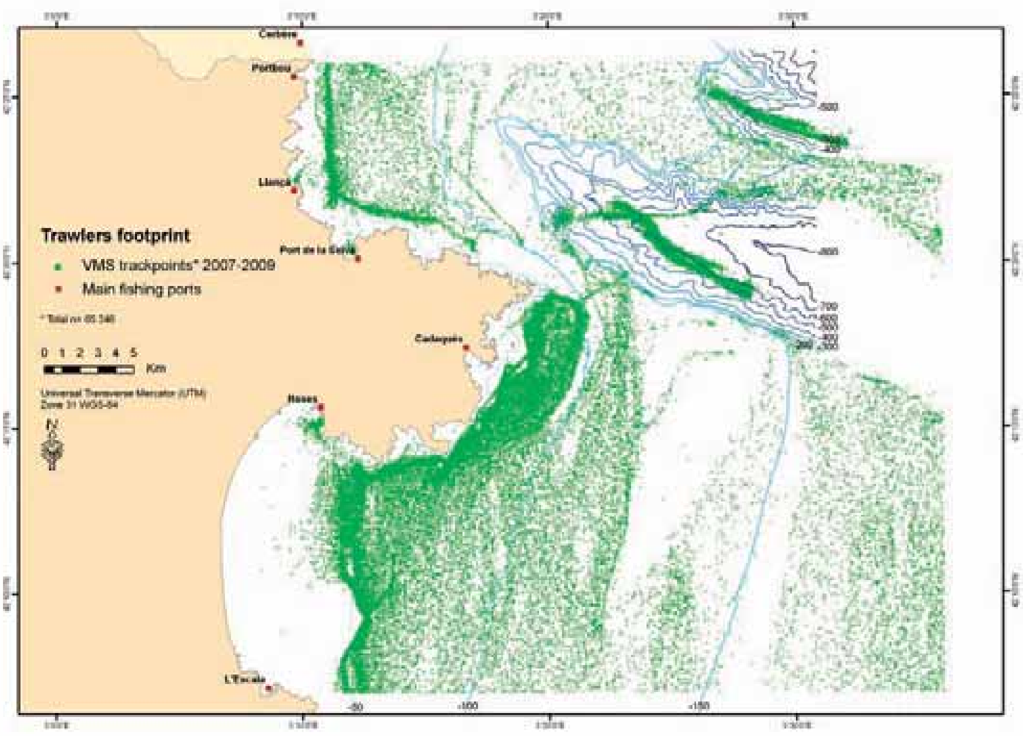

Fig. 1:

Physical and ecological characterization of the marine area of Cap de Creus: trawler footprints all year round in the area of the Cap de Creus Canyon, northwest Spain, from Gili *et al*. (2011).

The work of the LIFE+ INDEMARES project in the area of the Cap de Creus canyon has come to a very logical conclusion: the most rugged bottoms are the best conserved, as they show much less fishing activity, specially no bottom trawling. The study of the "fishing footprint" in the area of the Cap de Creus was completed at the end of the research, but experts are now keen to learn about this footprint as soon as possible in order to plan the field work, since it can be very useful in identifying potential "hot spots" inside the areas of study, that is to say, the ones showing lower fishing intensity and, therefore, areas where sampling efforts should be concentrated.

In these circumstances, we see that the fishing footprint, as it gives evidence of the zones with lower fishing pressure, has turned out to be a useful tool in order to plan future work in the sea, always very complex and costly in both time and funds.

In the case of the Cap de Creus canyon research, close collaboration between the General Direction of Fishing Resources and Aquaculture and the team of scientists from the CSIC under the direction of Dr. Josep María Gili has allowed us to establish the fishing footprint in the Cap de Creus canyon within the framework of the LIFE+ INDEMARES project, using Geographic Information Systems (GIS) tools. The report also deals with the integrated concept of *"métier"* that combines fishing gear with objective species, geographic zones and seasonality, "covering the local tradition".

In this same sense, the concept of *"métier"* helps us to identify precisely and without any doubt the fishing sector affected by the future MPA and therefore necessarily to be taken into account by stakeholders in order to tackle regulation of fisheries in the zones to be protected.

We should point out that, in the marine environment, fisheries, while not being the only human activity, are one of the most important to deal with for conservation purposes.

The basic tool in a management plan is zoning, applied in accordance with the precautionary approach, where fisheries are respectful of the habitat and carried out by the zone's traditional fishermen, and with some codes of best practices which can be incorporated by means of clear and transparent agreements between the sector and the managers in charge of the protected area. This principle is to be applied to all the stakeholders affected by the MPA, including the fishing sector, one of the most deeply concerned by sustainable fishing, making well-conserved canyons possible in all their integrity and functionality, that is to say, harmonizing protection and conservation with sustainable use.

This could be considered as a kind of ecosystem-based management approach applied to the fisheries. Spain is precisely a leader in the case of marine reserves of fishing interest focusing on the enhancement of fisheries while protecting marine habitats in a similar scheme aiming to protect canyons and their traditional uses.

FISHING IN OTHER CANYONS: THE CANYON OF PALAMÓS (GIRONA), THOSE OF CAPE TIÑOSO (MURCIA) AND ON THE PLATFORM OF THE ISLAND OF ALBORÁN (ALMERÍA)

South of the Cap de Creus, in other areas with canyons like that of Palamós off the coast of Girona, or in the canyons in front of Cape Tiñoso off the coast of Murcia, the fishing footprint has also been studied, while on the Alborán platform there are no true canyons, even though fishers talk about them as being rather deep "beaches" good for deep fisheries.

In the case of the Canyon of Palamós, south of Cap de Creus, the fishing footprint (Fig. 2) has been studied within the framework of the preliminary project for the possible creation of a marine reserve off Girona, in the surrounding area of the "Illes Formigues"- Costa Brava, since the head of the canyon is a zone of fishing interest in the northern part of the study area.

Fishermen are aware of the importance of these canyons in relation to fishing for red shrimp (*Aristeus antennatus*), of very high commercial value and whose extraction in the western Mediterranean developed fully from the 1940's or 1950's as gears began to reach greater depths (Bas, 1966). This fisheries activity with marked swings from year to year, due to the factor recently called "submarine waterfalls" by CSIC researchers, shows that the surface and marine bottoms present a greater connection than initially expected, though now already indicated in recent advances.

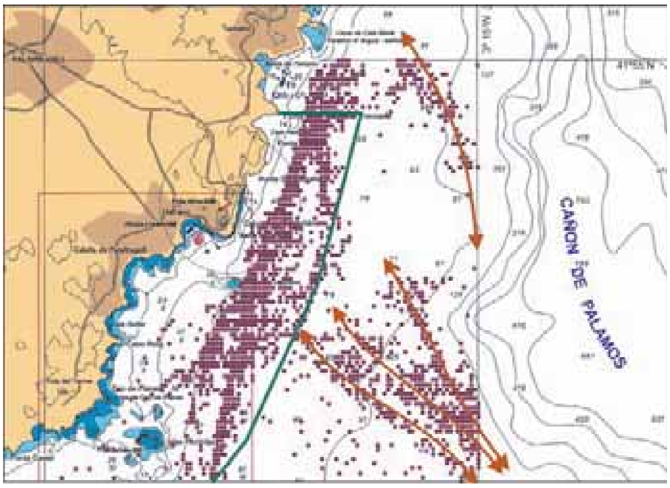

Fig. 2:

Trawlers in the Canyon of Palamós, northwest Spain.
Fishing footprint in the marine area of Illes Formigues - Costa Brava (Goutayer, 2009) on behalf the General Secretariat for the Sea.

Thus, the red shrimp would be subject to periodic processes of disappearance related to downward currents that displace the populations to deep waters, beyond 1.000 meters in depth. These privileged areas for recruitment, rich in nutrients thanks to the effect of these same currents, would seem to guarantee regeneration of the resource, subject to an important fishing effort, given its high value, and allow "re-appearances" of the fisheries with good results in catches, as a consequence of the refuge effect for species inside the canyon.

Similarly, the fishing footprint in the area in front of Cape Tiñoso (Figs. 3, 4 and 5), off the coast of Murcia, offers a clear spatial organization of fisheries, where the presence of trawlers clearly outlines the head of the canyons, whereas other gear such as drifting long-lines do not present this spatial concentration.

On the platform of the Island of Alborán (Fig. 6), no studies have yet been made on the fishing footprint, but traditional fishing grounds for red shrimp adopt the forms of the two beaches, called *"embarres"*, that run north and south around the island of Alborán, where bionomic cartography is the subject of a study forming part of the Life + INDEMARES project.

In this case, the existence of both the marine reserve and the fishing reserve of the island of Alborán, created in 1998 by the General Secretariat for the Sea, where regulated fisheries exist beyond the fully protected area around the island, known as the integral reserve, will definitely facilitate fishing activity regulations in the future marine protected area. Twenty-five years of experience in Spain with marine reserves policy show that sustainable fisheries in a marine protected area provide feed back for both conservation and production objectives.

Once again, the road map: reliable scientific knowledge from scientists and managers, and a sound governance scheme as drivers of the management tool. With this approach, the extraction sector should definitely be one of the most interested to participate, in order to have a management tool built on the best scientific knowledge of marine ecosystems and best practises, within the context of adaptative fishing management which would, no doubt, benefit all; fishermen, managers and, of course, society.

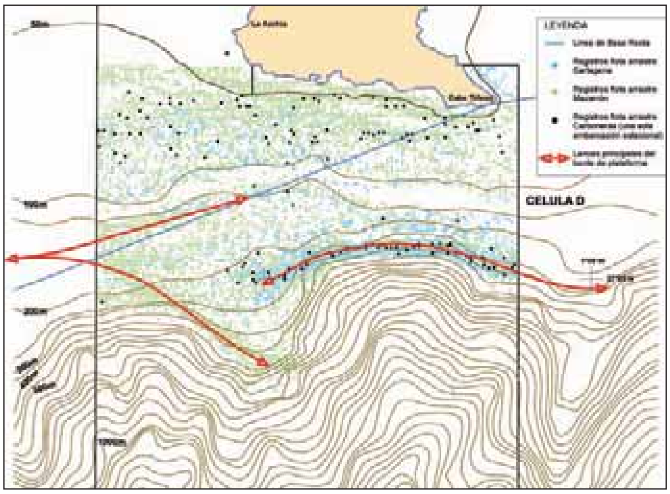

Fig. 3:

Trawling activity 2005-2010 off Cape Tiñoso, southeast Spain, from *Fisheries activity and footprint in the area off Cape Tiñoso (Murcia)* (Goutayer, 2011) on behalf the General Secretariat for the Sea.

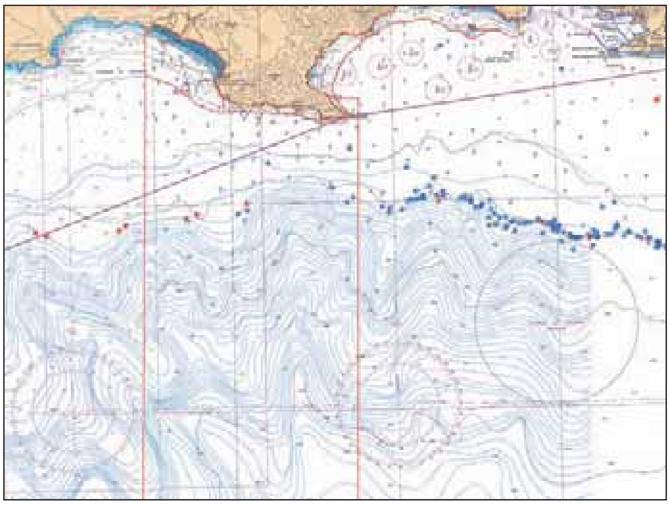

Fig. 4:

Artisanal fisheries 2005-2010 off Cape Tiñoso (Murcia) (Goutayer, 2011) on behalf the General Secretariat for the Sea.

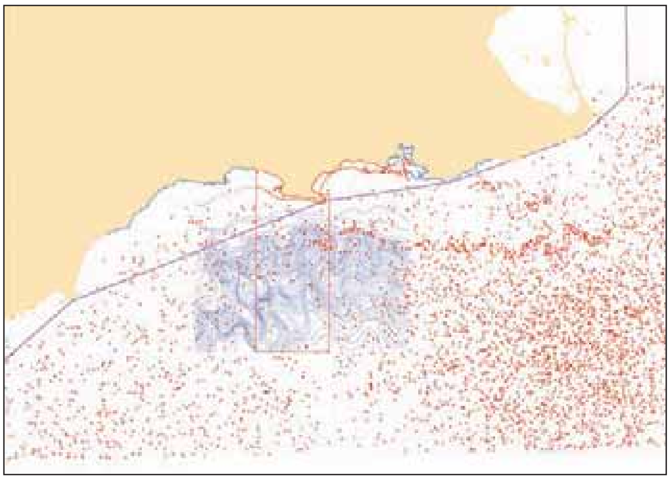

Fig. 5:

Drifting long-lines activity 2005-2010 off Cape Tiñoso (Murcia) (Goutayer, 2011) on behalf the General Secretariat for the Sea.

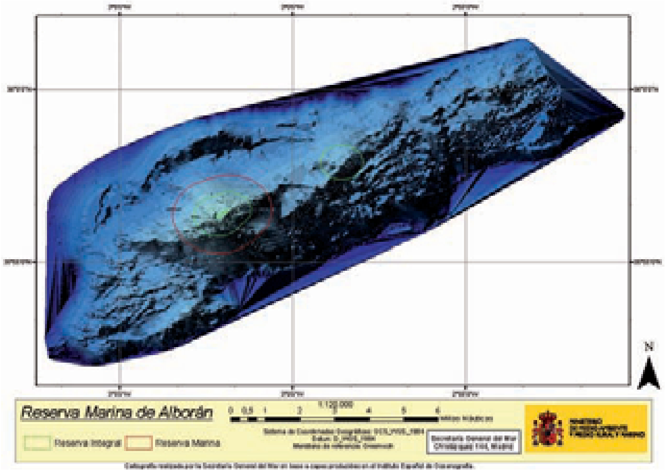

Fig. 6:

Map of the marine platform off the Island of Alborán, 2011, Marine Reserves, Spanish General Secretariat for the Sea. Geo data-base, compiled by Morán (2011).

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Acknowledgments

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2.3. Impact of fishing techniques on the continental slope and mitigation measures, primarily focusing on trawling for deep-sea crustaceans and ghost net fishing

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INTRODUCTION

Until the turn of the 1980's, fishing beyond the continental shelf was in fact carried out in the Mediterranean only in areas where the narrowness of the continental shelf limited fishing to resources on the upper part of the slope, notably in canyon heads; it was only with the appearance of modern methods of winching and positioning that it was able to progress towards deeper waters.

While most landings of Mediterranean fish are caught on the continental shelves, some fisheries thus extended their activities beyond the continental slope, motivated in particular by growing demand for high-value species such as large hake (*Merluccius merluccius*) and monkfish (*Lophius piscatorius*), as well as deep-sea crustaceans such as pink spiny lobster (*Palinurus mauritanicus*), Norway lobster (*Nephrops norvegicus*) and large shrimps (*Parapandalus longirostris, Aristeomorpha foliacea, Aristeus antennatus*).

However, even though it does not have a very long past, "deep-water" Mediterranean fishing already found itself confronted by problems of over-exploitation in the case of certain fisheries, and endangerment of large competing predators such as cetaceans and sharks.

Populations on the continental slope belong to a low-productivity ecosystem which renews itself slowly, and can therefore only tolerate very limited rates of exploitation. The apparent abundance that high commercial yields led fisheries to hope for often only derives from greater vulnerability of the targeted species to fishing gear, either due to the formation of large concentrations (spawning) or to easier access to these resources (angle of the slope, rocks etc.).

THE MEDITERRANEAN DEEP SEA FISHERY

In the Mediterranean, deep-water fishing uses trawl nets, gillnets, long-lines and traps. The first two are largely responsible for the degradation of the ecosystem of canyons and the continental slope.

The massive introduction from the 1980's onwards of cheap fishing gear from the Far East led to spectacular development of fishing with gillnets and trammel nets. Practised more in canyons and breaks in the slopes, this kind of fishing particularly targets hake (*Merluccius merluccius*) using gillnets (Gulf of Lion, Tuscany), spiny lobster (*Palinurus mauritanicus and P. elephas*) using trammel nets, red sea-bream (*P. bogaraveo*) using trammels (Ionian Sea).

More productive and easier to use, these types of fishing gear developed to the detirment of bottom lines and traps. The case of Greek fishing for red sea-bream in the Ionian Sea is one example. These fisheries, which had mostly used long-lines since the 1980's, soon turned to trammel fishing with extremely high yields attaining 46 kg/1000 m in the late 1990's, only to collapse very quickly in the following years (Damalas *et al*., 2010).

Two bottom-trawling strategies on the continental slope have made their appearance in the Mediterranean over the past 30 years: one alternating fishing on the continental slope and on steep slopes to a depth of about 200 m, and the other, more specialized, practised in soft bottoms of the slope, mainly targeting crustacean decapods (*Parapenaeus longirostris, Nephrops norvegicus, Aristaeomorpha foliacea*).

The potential for expansion of these fisheries is, however, limited due to the high cost of investment and exploitation. These fishing gears in fact require vessels large enough to undertake long fishing trips, often far from the coasts and disposing, among other things, of hydraulic winches with considerable winding capacities (over 2,000 m of towing warps), high-performance gear for detection (deep-water echo-sounders) and positioning (electronic charting, GPS).

The majority of stocks of deep-water shrimps show symptoms of overfishing (Carbonell *et al*., 2003; Campillo, 1994; Fiorentino *et al.*, 1998; D'Onghia *et al.*, 1998) or even depletion at a very early stage, as in Liguria (Orsi Relini and Relini, 1988).

Likewise, the replacement of bottom longlines by the trammel technique, more efficient and also ensuring a more intense fishing effort, led to the disappearance in just a few years of Greek fishing for red sea-bream in the south-eastern part of the Aegean Sea (Damalas *et al.,* 2010).

The impact of trawling for deep-water crustaceans (spiny lobster, red shrimp) concerns more particularly the muddy bottoms of the continental slopes. Given the low level of external disturbances that can reach these depths, these bottoms are consequently highly sensitive to trawling. Trawl otter-boards which penetrate them more deeply than in coarser sediments make a lasting impact on the sea bottom and the structure of the macrobenthos.

Given the recognized slowness of the reconstitution of these ecosystems, these modifications have more or less long term consequences, hard to quantify, on trawling exploitation, notably due to the reduction of nurseries of the targeted species and their replacement by species of lower commercial interest (Jones, 1992; Ball *et al*., 2000, in Tudela, 2004) (Fig. 1).

While the risk of degradation of the substrates is much less serious with static gear (longlines, traps, gillnets), the loss of nets can also lead to modification of the biotope by stifling and destroying fixed flora and fauna or, inversely, by serving as a fixation support for colonial invertebrates.

The importance of discards can occasionally be negligible, particularly for mixed fisheries which tend to commercialize virtually all of their catches, including those of individuals of illegal commercial size (D'Onghia *et al.,* 2003; Carbonell *et al.,* 2003).

On the other hand, for fisheries more specialized in the exploitation of deep-water crustaceans, discards often represent over 40% of the catches (D'Onghia *et al*., 2003; Duruer *et al*. 2008); a significant share of these discards consisting of elasmobranches (Tudela, 2004) and species of small size, of no commercial interest (Myctophidae, Notacanthidae, Alepocephalidae, Apogonidae, Trachichthydae, Cynoglossidae and Macrouridae).

Fisheries specializing in trawling for deep-water crustaceans are by nature more liable to produce discards than others, due to the fact that the limited capacity of the fish holds demands fastidious manual sorting, so that priority is given to keeping only shrimps, spiny lobsters and a limited number of high-value species.

Even at higher levels, fisheries using static nets (for hake, spiny lobster, red sea-bream) are also faced by problems of discards, which are more or less important depending on their ability to commercialize secondary catches and the soaktime (several days for crawfish caught with trammel nets). Non-commercialized species also include a significant proportion of elasmobranches (*Galeus melanostomus, Chimaera monstruosa, Scyliorhinus canicula, Emopterus spinax*).

In terms of size, the composition of fisheries' catches on the continental slope show that they generally consist of high proportions of large individuals of species caught on continental shelves, leading one to suppose that the canyons with their more difficult access might constitute areas of refuge (Caddy, 1990) for spawning. Consequently, over-intensive exploitation of these areas, or exploitation focusing on catching large fish, can only be harmful with regard to the sustainability of existing exploitations.

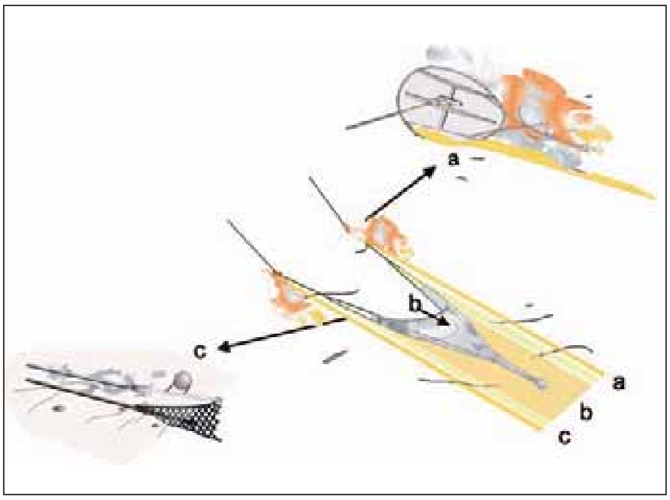

Fig. 1:

Main factors responsible for the impact of bottom trawling. (a) Trawl otter-boards cause dispersion of the softest sediment and formation of furrows; (b) the groundline scrapes the surface layer of the substrate and shears upright species; (c) the bridles also disperse sediment when dragging along the sea bottom.

Fig. 2:

Abandoned trammel net hooked on a wreck and maintaining fully its fishing surface (ROV observation, Gulf of Lion, depth 98 m).

MANAGING THE « GHOST NETS » PROBLEM AND THE IMPACTS OF DEEP SEA FISHING GEARS

The phenomenon of ghost fishing associated with deep-water net fishing has been addressed by several studies (Brown *et al.,* 2005), but unfortunately in too small a number in the Mediterranean (Sacchi in Fantared 2, 2003). The loss or abandon, either total or partial, of nets during fishing expeditions (Fig. 2), or their accidental destruction during trawling activity, leads to mortality among the targeted species (hake, monkfish, red sea-bream, capon, spiny lobster), but also non-commercial catches of invertebrates and elasmobranches (*Paramola cuvieri, Scyliorhinus canicula, Galeus melastomus, Etmopterus spinax, Chimaera monstruosa*, etc.).

For fisheries beyond depths of 200 m, these accidental catches can last several months (Mediterranean) or even several years, as along the continental slope of the Norwegian coasts (Humborstad *et al.*, 2003), due to low hydrodynamism and fouling at these depths in the water column. Comparable effects probably arise from excessively long anchoring periods or fragments of used nets being thrown back into the sea.

A certain number of technical or management measures could significantly reduce the fisheries' impact on ecosystems on the continental slope and in the canyons.

The impact of bottom trawling can be reduced by lightening the pressure exerted by the entire fishing gear, i.e. the trawl otter-boards, groundline and rigging. For a given otter-board surface, the contact zone can be reduced by lowering the length/height ratio or by using either boards made of composite material or others that do not make contact with the sea bottom. The use of soft discs or chain links separating the leadline from the bottom can also help to reduce the pressure exerted by the rest of the fishing gear on the substrate.

For gillnets and trammels, distancing the webbing from the bottom by mounting it on the leadline with a double bottom rope or large staples can significantly reduce the capture of unwanted benthic species (various benthic fish, crustaceans and predatory or necrophagous echinoderms (Fig. 3).

In the case of gillnets, choosing a mesh best-suited to the size of the targeted species is the simplest technical solution for improving selectivity; however, raising the mesh size does not always give the results expected and can lead to larger catches of secondary juvenile species (Sacchi, 2002). Tangling caused by excessively loose webbing leads to the capture of large individuals and non-fusiform species (monkfish, skate, spiny lobster) and is the major cause of landings and discarding of unwanted species (Sacchi, 2008).

The use of square-mesh codends helps to significantly reduce the quantity of juvenile commercial species that are caught and discarded, as indicated by results obtained from fisheries on the continental slope of the Balearic Islands (Guijarro and Massutí, 2006).

Whether they consist of the entire codend or an escape panel, square-mesh nets offer the advantage of remaining completely open whatever the dragging speed, avoiding obstruction by debris and constantly ensuring trawl selectivity. This technical solution has been retained by EU Regulation N°1967/2006 on technical measures in the Mediterranean and was the subject of a resolution adopted by all the Member States of the General Fisheries Commission for the Mediterranean (Res. GFCM/31/2007/3) (Fig. 4).

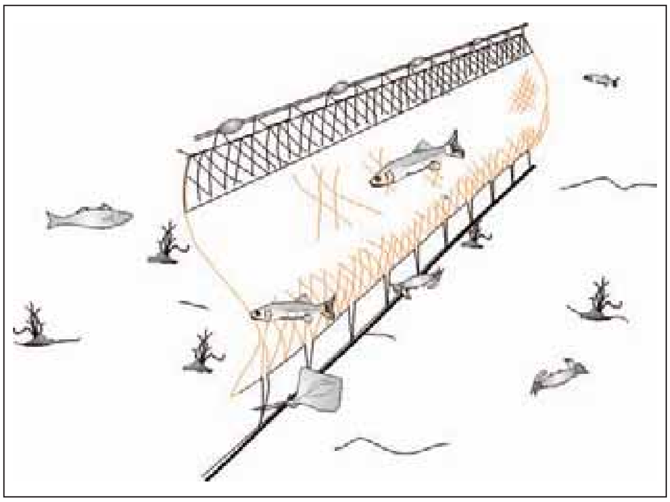

Fig. 3:

Reducing the impact of gillnets on the seabed and benthic species.

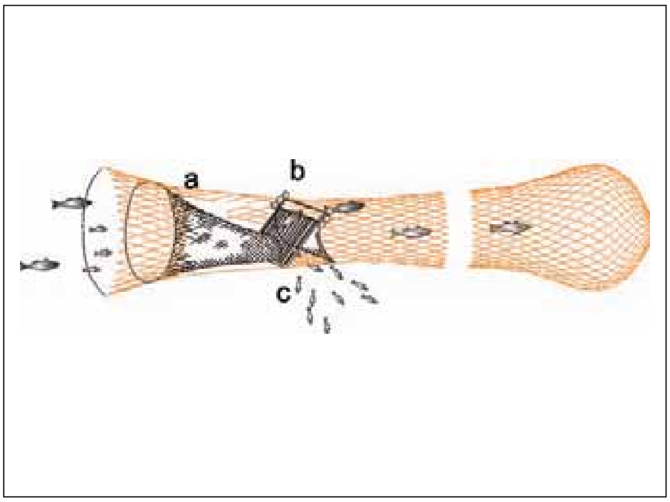

Fig. 4:

Selective grid facilitating the escape of juveniles through the lower side of the extension; (a) guidance cone; (b) grid; (c) escape outlet.

The combination of an escape outlet with a selective grid incorporated into the front of cod-ends offers another technical solution for improving trawl selectivity, tested with some positive results, particularly in deep-water fishing for crustaceans in the Catalan Sea between depths of 400 and 440 m (Bahamon, 2007). This technique, which offers the advantage of ensuring higher survival rates for individuals escaping through the grid, deserves to be perfected and applied, especially for fishing for crustaceans in the Mediterranean.

Technical measures can be recommended to reduce the capturing possibilities of lost nets, such as the use of biodegradable thread for fixing the netting to the float line so that it will be released in the event of long submersion, or the use of lead-lines that break more easily, higher hanging ratios (over 50%) to reduce the looseness of the webbing, a major cause of tangling.

In addition, nets are primarily lost due to conflicts between fishing activities, manoeuvring errors, judgment of weather conditions or the topography of the sea bottom. Mitigating the problem of ghost fishing therefore implies, above all, respect for elementary fishing regulations (for example, observance of regulations on gear marking systems) (Fig. 5).

Interest in developing new management concepts based on Protected Marine Areas (MAPs) has risen over the past ten years, underscored by the feeling that it is possible to pursue commercial fishing activities while preserving threatened species at the same time.

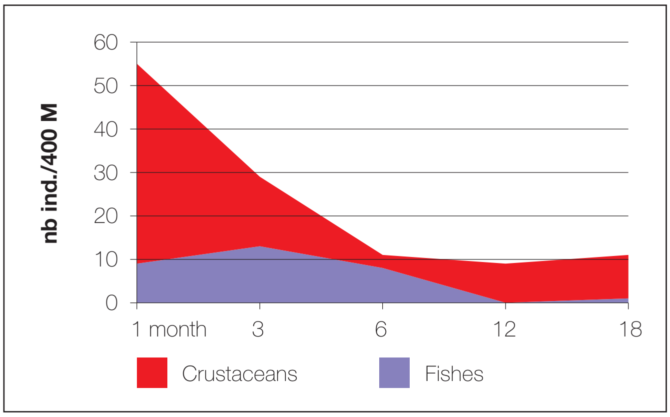

Fig. 5:

Evolution of the quantity of abandoned trammel catches of lobsters (simulation – Var canyon; Sacchi, 2003).

There is a wide panoply of marine protected areas ranging from areas where all kinds of fisheries are permanently banned (submarine seamounts, depths of over 1,000 m) to those exclusively prohibiting trawling (FRA in the Gulf of Lion) or temporary closures to protect juveniles and their recruitment (UNEP, 2003).

On the basis of a study on trawling for pink shrimps (*Aristaeomorpha foliacea and Aristeus antennatus*) on the continental slope in Maltese waters (500 – 600 m), Dimech *et al*. (2012) proposed the establishment of corridors reserved for trawling over a given time within a vast protected geographic area. This would help reduce the impact of trawling on slow-growth and low-resilience species while improving commercial yields for shrimps, with the surrounding protected areas serving as both refuges and constant sources of supply for trawlable areas.

Limitation of the fishing effort and restriction of access to waters over 200 m deep are also preventive management measures to be given close consideration, as they may help towards an effective reduction of the impact on the sea bottom and habitats, and the risk of catches of unwanted species (juveniles, protected species).

In the case of trawling, this could be achieved by means of limiting the trawl size, the number and duration of the hauls, and trawling speed.

For static fishing gear such as gillnets and trammels, the length of the nets, number of pieces of nets, the duration and number of hauls comprise the main parameters for efforts in this area on which it is possible to take action. With this in mind, EC Regulation 1967/2006 limits the length of gillnets and trammel nets, and the number of hooks and hoop-nets per fishing vessel.

Access to restricted fishing zones could be limited to a fixed number of vessels which must meet a certain number of technical criteria, such as the obligation to use only fishing gear equipped with regulatory selective devices, or systems controlling the duration and depth of anchoring.

Even though they have already furnished proof of their effectiveness in other fisheries overseas, none of these measures have yet been applied in the Mediterranean.

Moreover, there are no specific national or international regulations in the Mediterranean concerning fishing activity at depths below 200 m except for the GFCM Recommendation banning the use of dredging or trawling at depths below 100 m (Rec. GFCM/2005/1) and that establishing a fishing restricted area (FRA) in the Gulf of Lion (Rec. GFCM/33/2009/1)[1].

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[1] http://www.gfcm.org.gfcm/topic/16100/en

For this governance to be effective, the exercise of control and scientific follow-up of these protected areas could then naturally be undertaken by the bordering and exploiting countries, under the management authority responsible for their exploitation, i.e. the General Fisheries Commission for the Mediterranean.

In contrast, deep-water fishing undertaken by EC vessels in the North Atlantic is very strictly supervised and regulated by the establishment of a *numerus clausus* of authorized vessels and the introduction of a special license system (Special Fishing Permits). These vessels are subjected to satellite monitoring of their movements (VMS) and must belong to a specific scientific program ensuring follow-up of their activity, which involves the regular presence of observers on board.

One of the major difficulties lies in the implementation of effective and realistic control instruments, accepted by all of the parties concerned, especially when the areas to be protected, on which many shared stocks depend, are in international waters, as are the majority of fisheries on the Mediterranean continental slope.

The establishment of restrictions on access to resources is necessary, but not sufficient, to guarantee rational governance. Follow-up, control and monitoring are also key factors to the success of the fisheries management process. (FAO, 2003 -2011).

Such a form of governance is, in fact, only possible when it concerns clearly defined geographic areas which are large enough to cover all the activities having an impact (Halieutic Protection Zones), in which conservation goals have been clearly defined and approved by the parties concerned (exploiting countries, international bodies entrusted with conservation etc…).

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3. CASE STUDIES

3.1. The submarine canyons of the Rhodes basin and the Mediterranean coast of Turkey

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1. INTRODUCTION

The Levantine Basin is one of the three main deep basins of the Mediterranean Sea and exhibits particular geological structures such as depressions, cold seeps, shallow and deep sea marine canyons, seamounts and mud volcanoes. The eastern Mediterranean coastal zone contains very special geomorphological features due to coastal evolution and rock type (Ardos, 1979).

The morphology of the East Mediterranean seafloor is the consequence of both early formation processes of the deep basins and recent geodynamic microplate interactions. Thus, the East Mediterranean Sea constitutes the last remnant of the Mesozoic-Cenozoic oceanic basin of Tethys, now almost totally consumed by the long-term Eurasian and African plate convergence.

The arc-shaped East Mediterranean Ridge (EMR) characterizes the subregion from the south-west Peloponnesus to southern Crete and Rhodes. The EMR is 1,500 km long and 200–250 km wide and it is the result of relatively rapid Eurasian and African convergence and the subsequent subduction of the oceanic crust beneath the over-riding Aegean microplate and the deformation of its sedimentary cover. The deep trenches north of the EMR, such as the Strabo and Pliny trenches to the east, form the Hellenic Arc, which is the morphological expression of geological processes in the fault-zones. Numerous canyons and deep valleys originate from the shelf off the mainland and main islands, ending in the trenches and bordering basins. Of particular interest is the seafloor topography of the East Cretan Sea and Levantine basin, which are characterized by complex morphology with narrow canyons running between steep sloped ridges. The Hellenic Arc terminates eastward in the Rhodes basin, a relatively young basin, 4,000-4,500m deep, east of the Island of Rhodes, characterized by the cyclonic Rhodes gyre driving constant upwelling, which affects the entire productivity of the Levantine sea.

1.1. The Rhodes Gyre

The Rhodes Gyre (Fig. 1) rotates anti-clockwise forming a distinct vertical cylinder of eastern Mediterranean water to the south of the island of Rhodes. It is likely that this cyclonic gyre results from wind-driven basin circulation, and the interaction of the main currents with land masses and seafloor morphology (i.e. Rhodes Trench). This cyclonic rotation causes deep water, rich in nutrients, to rise from the bottom to the surface and in consequence the Gyre is much more fertile than the rest of the eastern Mediterranean, which is known as one of the most oligotrophic (nutrient-poor) aquatic environments in the world because of its extremely low primary production (Gaines *et al.,* 2006).

Napolitano *et al.* (2000) have studied the biological production characteristics of the Rhodes Gyre through a one-dimensional, coupled physical–biological model using single aggregated compartments of phytoplankton, zooplankton, detritus, as well as ammonium and nitrate forms of inorganic nitrogen. It interacts with the physical model through vertical eddy diffusivity. The model simulations demonstrate the importance of physical oceanographic characteristics affecting yearly planktonic structures, and shows that annual primary production in the Rhodes basin is comparable with the north-western Mediterranean. The Rhodes basin reveals a strong bloom in early spring, typically in March, a weaker bloom in early winter, typically in January, and a subsurface production below the seasonal thermocline during the summer.

The strong and permanent effect of the Rhodes Gyre on offshore primary production in the Rhodes basin is also linked to the area's particular geomorphology, which is characterized by a deep trough bordering Rhodes Island to the west, Finike seamounts (Anaximander) to the east and Finike basin to the south-east, and by the effect of the in-flow of water masses trough the Karpathos Straits as well as the presence of several submarine canyons.

Even if the processes of deep-water fertilization in this area are poorly investigated up to now, submarine canyons may have a role by enhancing the flux of nutrients from the land, as in other Mediterranean areas. Moreover, recent evidence has indicated that the current oligotrophic nature of the eastern Mediterranean may shift to a more productive system due to increased anthropogenic

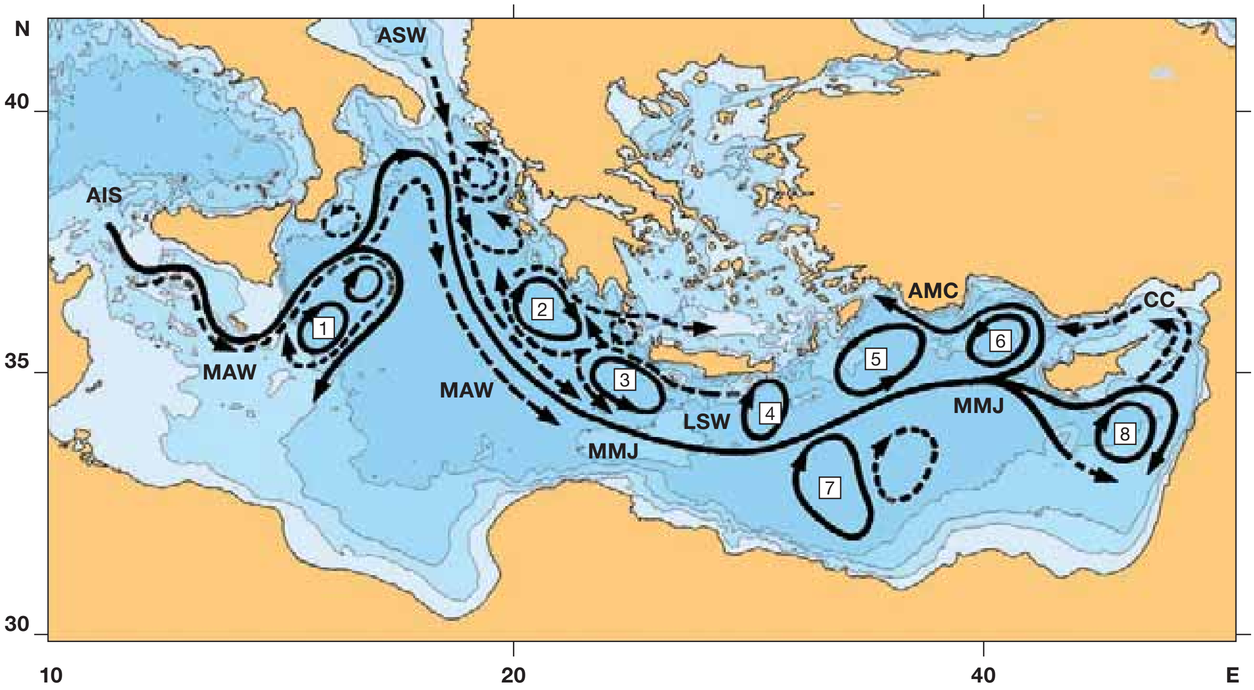

Fig. 1: Rhodes Gyre and other key oceanographic structures in the east Mediterranean Sea: AIS, Atlantic-Ionian Stream; AMC, Asia Minor Current; ASW, Adriatic Surface Water; CC, Cyprus Current; LSW, Levantine Surface Water; MAW, Modified Atlantic Water; MMJ, Mid-Mediterranean Jet. 1) Ionian Anticyclones; 2) Pelops Anticyclone; 3) Cretan Cyclone; 4) Iérapetra eddy; 5) Rhodes gyre; 6) West Cyprus gyre; 7) Mersa Matruh gyre; 8) Shikmona gyre; modified from Hogan and Saundry (2011).

influences and consequent global changes (changes in nutrient flux, CO_2, temperature). These changes may fundamentally affect the biological components of the system from primary production through all levels of the food-web.

Finally, the cyclonic Rhodes Gyre is confined by three anticyclonic gyres; Ierapetra to the south-west, Mersa-Matruh to the south and the West Cyprus Gyre to the east, thus forming a large oceanic triad system which enhances reproductive habitat suitability for small pelagic species thanks to co-occurring mechanisms: nutrient enrichment, concentration of larval food distributions, and local retention of eggs and larvae (Agostini and Bakun, 2002).

1.2 Effect of south-western Anatolia submarine canyons on biodiversity

A very narrow shelf characterizes the south-western Anatolian coast and several canyons connect the abyssal floor of the Rhodes and Finike basins with the upper shelf. Notably, these canyons and submarine landslides are active channels which have been interpreted as having been triggered by on-going faulting and which attest to substantial present-day direct clastic sedimentation from Turkey and the Island of Rhodes into the above-mentioned basins (Ocakoglu, 2011).

In the deepest part of the Levantine basin, the noticeable correlation of benthic production with distance from land masses confirms that the lateral transport of organic matter through submarine canyons plays a major role. Moreover, the patchiness of macrofauna abundance indicates that the deep Levantine Sea is an event-driven system, in which terrestrial run-off affects the functioning of the community by spatial variability in food ingression events (Türkay, 1996).

The south-western Anatolian continental slope delineates the north-eastern margin of the Rhodes Basin; here the slope face is dissected by numerous submarine canyons (Hall *et al.*, 2009).

Around the Island of Rhodes, the continental shelf on the western side appears to be generally smooth, while on the eastern side it is steeper and cut by a number of submarine canyons; here, depths of over 350 meters are encountered less than one mile seaward of the 200-meter contour.

Most of the submarine canyons are located on the north-eastern platform portion where the continental slope is inclined from 8° to 15°. A major canyon, Nereus canyon, extends to the north-east from the northern tip of the island, and two more canyons, Brigitte and Trianta, as well as several small V-shaped sea valleys, are located in Trianta Bay on the north-western side of the Island.

Goedicke (1977) identified at least ten main submarine canyons between Rhodes and Lindos, and a number of slope gullies, which seem to be associated with the on-shore topography. Within Kallithea Bay, two canyons incise the shelf; in Afántou Bay, two canyons exist in association with the mouths of the Psalidos and Pera rivers; offshore from Tsampika, the head of the major canyon was likely to have been connected with the ancient Lutani river-mouth, which was in the past to the south of Cape Vahyah, and has now shifted to its northern side; between Tsampika and Cape Archángelos, two smaller canyon heads lie near the mouth of two intermittent rivers; in Malóna Bay and Vlichá Bay, another two canyons and one main canyon offshore from Lindos (Cape Sumani and Cape Foca) have no connection with present-day river valleys. All these factors lead to the conclusion that the northernmost canyon off the east side of Rhodes Island originated due to subaerial erosion, while the southern ones are of tectonic

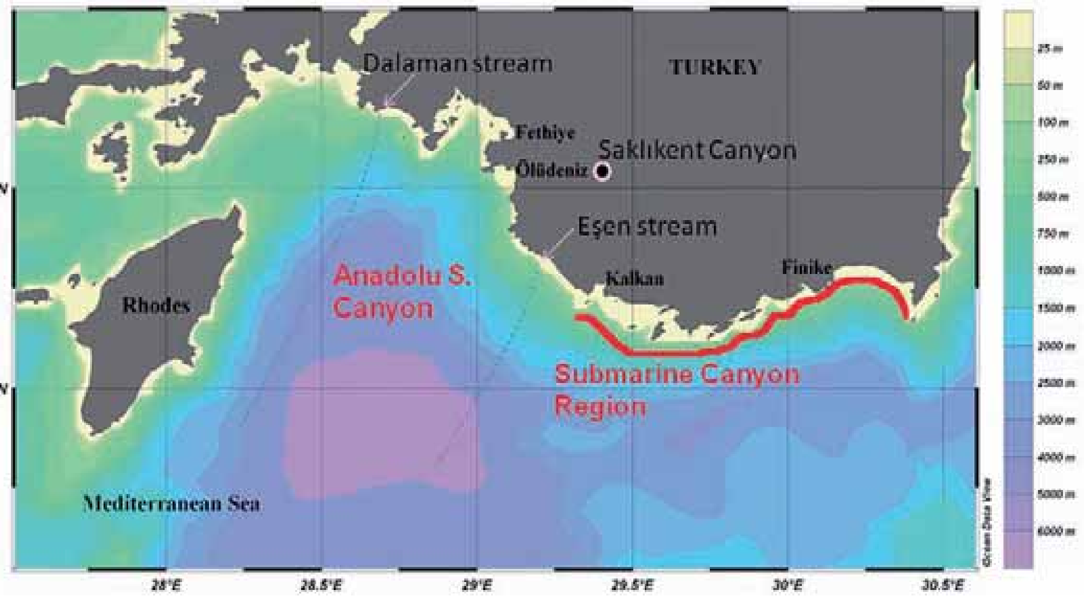

Fig. 2:

Submarine canyon region in the Turkish part of the Mediterranean Sea.

origin, being located close to a very active fault. At the present time, the canyon axes are probably the result of erosion due to submarine slumping, triggered by large, long-period waves during south-easterly winter storms (Goedicke, 1977).

The Rhodes basin can, in fact, be divided into two sub-basins: a deeper northern one, and a shallower southern one, separated by a broad, asymmetrical swell oriented east–west. The northern margin of the basin is interrupted by the large, north-east oriented Fethiye canyon, which extends into the Turkish shelf and Fethiye bay. Along the Fethiye canyon an important fault zone occurs, forming the north-eastern extension of the Pliny Trench (Ocakoglu, 2011), while the southern sub-basin lies in morphological continuity of the Strabo Trench (Woodside *et al.,* 2000).

In general, the Mediterranean Turkish shelf and slope appear to be significantly dissected and transected by canyons and gullies (Ozel *et al.,* 2007). Even if many of these canyons can be classified as blind canyons (confined to the slope) according to Harris and Whiteway (2011), some of them are the extension of canyons on land, such as Saklikent canyon, or correspond with river mouths (i.e. Dalaman and Esen Streams) (Fig. 2).

Between Kalkan and Finike, a number of shallow coastal canyons incise the upper shelf becoming deeper even very close to the shore: they play a role of stepping stones between the coast and the open sea (Fig. 3). Spawners and recruits of many fish species, which migrate from the Beymelek and Köycegiz lagoon system to off-shore habitats and vice-versa, use these coastal canyons. Coastal canyon communities generally consist of sponges *(Axinella verrucosa, A. polypoides*), some lobster species *(Scyllarus arctus* and *S. latus)*, as well as stony corals such as *Caryophilia* spp.

Evidence of macrofaunal abundance and the diverse conditions of marine invertebrates in the Eastern Mediterranean have been discussed by Danovaro *et a*l. (2010): megabenthic species have been reported at depths between 400 m and 4,264 m, including 20 species of decapod crustaceans such as the endemic geryonid crab (*Chaceon mediterraneus*); one species, *Levantocaris hornungae*, was described as new to science and *Polycheles typhlops, Acanthephyra eximia, Aristeus antennatus*, *Calocaris macaendreae, Parapenaeus longirostris* and *Geryon longipes* were found to be dominant in the Cretan Sea and Rhodes basin; *Scopelocheirus hopei, Scopelocheirus polymedus, Orchmenella nana, Orchomene grimaldi, Epimeria* cf. *cornigera* were the most abundant amphipod species recorded by baited trap, and *Ileraustroe ilergetes, Pseudotiron bouvieri, Rhachotropis rostrata* and *Stegophaloides christianiensis* are amphipod species endemic to the Mediterranean; among cumaceans, *Procampylaspis bonnieri, Campylaspis glabra, Makrokylindrus longipes, Platysympus typicus* and *Procampylaspis armata* were the most frequently collected, while *Yoldia micrometrica, Kelliella abyssicola, Cardyomia costellata, Entalina tetragona, Benthomangelia macra, Benthonella tenella* and *Bathyarca pectunculoides* were the most common benthic molluscs identified at depths greater than 1,000 m.

Fig. 3:

Map of coastal canyons in the Turkish part of the Mediterranean Sea.

The Anatolia canyon (i.e. Fethiye canyon) extends down to the deep depression of the Island of Rhodes between Turkey and Greece, hosting deep-sea fish species including *Bathypterois dubius, Nezumia sclerorhynchus, Cataetyx laticeps, Chauliodus sloani, Coriphaenoides mediterraneus, Nettastoma melanurum* and *Lepidion lepidion* were the most abundant species. In the Rhodes Basin and at depths less than 2,300 m, the most abundant shark species were *Hexanchus griseus, Galeus melastomus, Centrophorus granulosus, Centroscymnus coelolepis*, and *Etmopterus spinax*.

In recent studies, twenty-three fish species were collected or photographed in the Levant Sea at depths greater than in the Western Mediterranean, some nearly doubling the depth record of the species (Danovaro *et al.*, 2010).

Larger-scale upwelling and downwelling structures of cyclones and anticyclones, dominating circulation in the central area of the Rhodes basin and Anaximenes Mountain (Fig. 4), affect the zooplankton community (Denda and Christiansen, 2011). Zooplankton standing stocks, at a generally low level due to the oligotrophic character of the eastern Mediterranean, were found to be higher in the Rhodes Basin than on the seamount, probably also influencing the distribution of top pelagic pradators.

Cetaceans have also been observed around the Anatolian canyons. Mostly *Stenella coeruleoalba, Delphinus delphis, Ziphius cavirostris* and *Grampus griseus* have been reported. The sperm whale is strictly teuthophagus and 14 cephalopod species were found between Rhodes and Fethiye deep zone (Öztürk *et al.,* 2007). This deep-sea upwelling canyon zone provides feeding grounds for whales and dolphins, mostly for sperm whales (Fig. 5). In 2010, 34 sperm whale sightings were reported in the upwelling canyon zone between Rhodes and Fethiye. Moreover, the submarine canyons from Finike to the south-eastern Anatolia region are spawning grounds for several migratory fish species, such as scombrids and bluefin tuna (*Thunnus thynnus*). Beaches in this area are nestling grounds for sea turtles, *Chelonia mydas* and *Caretta caretta* have also been observed offshore between Rhodes-Finike and were most probably feeding (Öztürk, 2009).

2. PROTECTION PROPOSALS FOR THE EASTERN MEDITERRANEAN SEA

Four areas have been suggested for High Sea Marine Protected Areas (HSMPAs) in the Eastern Mediterranean Sea by Öztürk (2009) (Fig. 6). One of them (M1) falls between Rhodes and Finike where, as shown above, the most distinctive features are submarine canyons and the Anaximander Mountains (Öztürk *et al.*, 2010), which are characterized by unique habitats also created by mud volcanoes and methane cold seep habitats, inhabited by communities quite different from those in all other known cold seeps (Medioni, 2003). This fragile ecosystem is under threat primarily from bottom trawling, which should be banned or controlled. Here, swordfish (*Xiphias gladius*) nets also cause severe cetacean by-catch.

Another proposed spot is a channel between Turkey and the island of Cyprus (M2). Routes of highly migratory, large and small pelagic fish also cross this area. Furthermore, it is a spawning ground for bullet tuna (*Auxis rochei*), Atlantic skipjack (*Euthynnus alleteratus)* and bluefin tuna (Karakulak *et a*l., 2004). There are also nestling beaches of endangered marine turtles. In addition, (Gücü and Öztürk, 2010) reported that this area could be a north levant marine peace park.

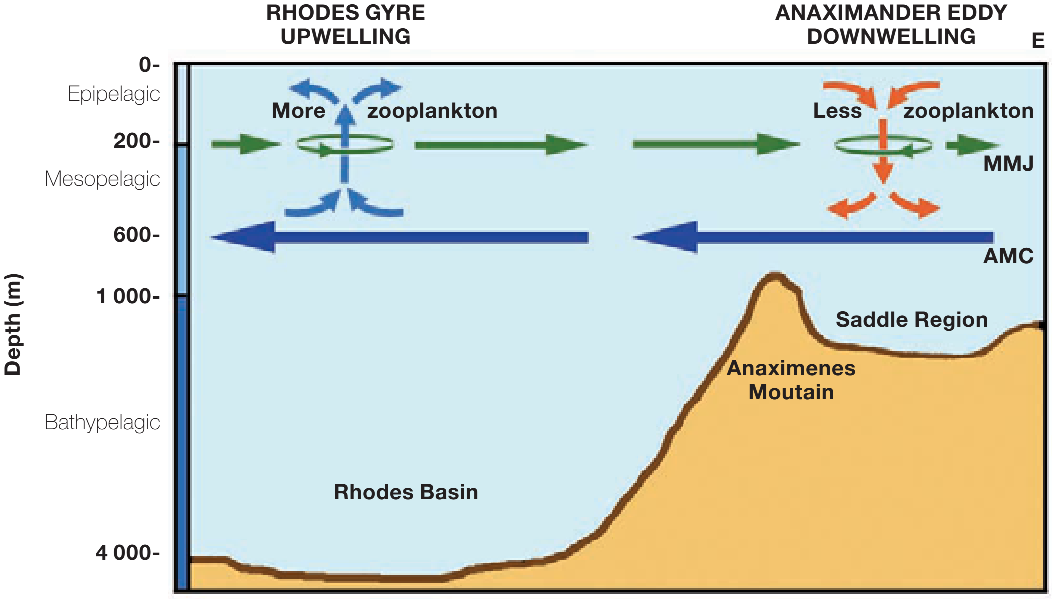

Fig. 4:

Conceptual model of water mass circulation effect on zooplankton in the Rhodes Basin and Anaximenes Mountain region.
AMC, Asia Minor Current; MMJ, Mid-Mediterranean Jet. Figure not to scale, modified from Denda and Christiansen (2011).

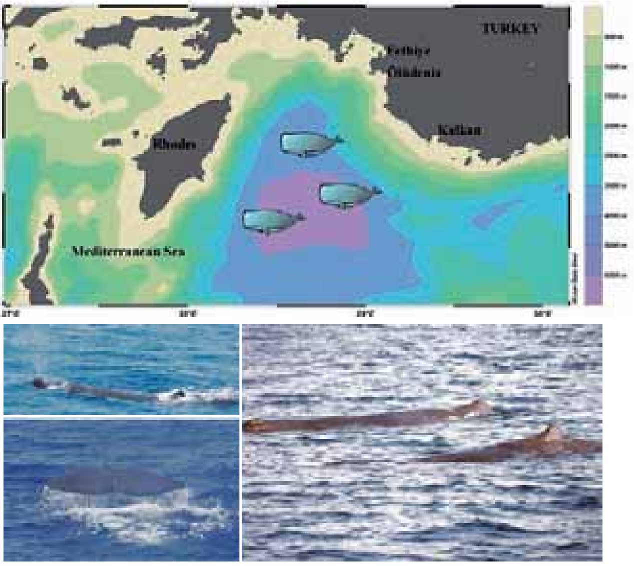

Fig. 5:

Sperm whale feeding zone in upwelling canyon zone.

The third suggested area (Turgut Reis Seamount) lies between Turkey, Syria, Lebanon and Cyprus (M3), where virgin stocks of deep sea shrimps such as *P. longirostris, Plesionika martia, Aristaeomorpha foliacea* and *A. antennatus* still exist. Furthermore, this is an area which is on the migration routes of bluefin tuna, tuna-like species, between Iskenderun and Cyprus from north to south. Common dolphins, which are rare in the eastern Mediterranean Sea, were also sighted in this area. These pristine habitats should be protected from international fishing fleets, IUU fisheries and ship-origin pollution. The area identified as A5 in Fig. 6 corresponds to the Rhodes basin, whose features have been discussed and summarized in the previous chapters.

Besides, GFCM has issues recommendations for the Mediterranean Seamount (Eratosthenes) in the Eastern Mediterranean and fisheries have been banned there according to the GFCM recommendation number 2006/3 to protect the deep sea sensitive ecosystem. This area is shared by Turkish and Cyprus EEZ and should be one of the joint SMAPI area in the eastern Mediterranean Sea. Any kind of drilling, oil exploration and seismic activities are harmful for this kind of unique habitat.

The complexity of the high sea legal regulatory regime enforced in the international waters of the Aegean and eastern Mediterranean Sea has recently caused several management problems in the region, in particular with regard to illegal, unreported and unregulated fisheries (Öztürk and Baseren, 2008). There is no appropriate management tool for sustainable fisheries of large, highly migratory pelagic species in this area. Although regional organizations such as GFCM and ICCAT, responsible for fisheries management, exist, an assessment study (Tudela, 2003) showed a steep decline of bluefin tuna spawning stocks since 1993.

For protection of the Mediterranean marine environment, there are several international and inter-governmental organizations such as ACCOBAMS, ICCAT, GFCM, IUCN, RAC/SPA and others which have implemented proposals for high sea marine protected areas overlapping or consistent with the three areas proposed for the Levantine basins. Greenpeace has already suggested some proposals and RAC/SPA/UNEP/MAP has produced a high sea SPAMI proposal. All these international initiatives are important to urge decision-makers and politicians that decisions need to be taken regarding the marine environment. Establishing the HSMPA will be an important step towards implementing the ecosystem approach towards management of the eastern Mediterranean Sea. This proposal may be beneficial and provide better management methods for sustainable fisheries as well coastal states, if they so desire. Designation of HSMPAs in the proposed areas will help to protect vulnerable habitats and threatened species, protect breeding populations which can provide recruiting stocks, restore over-exploited zones, increase fisheries productivity in the long term, reduce by-catch of seabirds, cetaceans and sea turtles, and reduce overfishing of highly migratory fish.

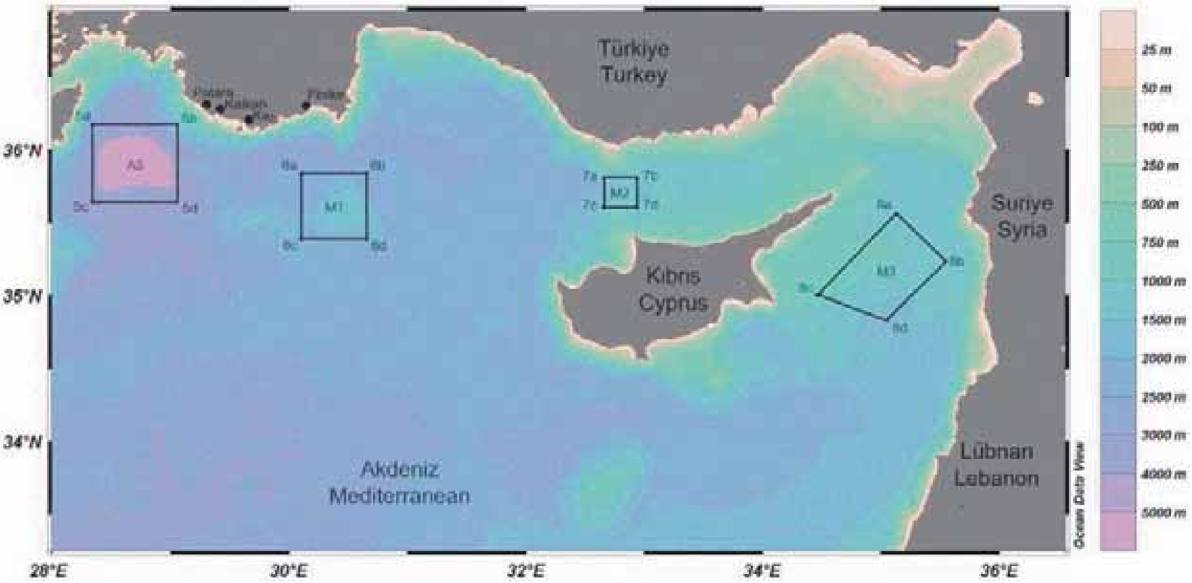

Fig. 6:

Proposed areas for high sea marine protected areas (HSMPA) in the eastern Mediterranean Sea, see explanation in the text (Öztürk, 2009).

Scovazzi (2002) stated that the Mediterranean Sea should be considered a primary heritage of concern to bordering States. This message indicated that more responsibility should be adopted by each State to protect and cooperate for the protection of the Mediterranean Sea.

Designation of HSMPAs is also one of the objectives of the Convention on Biological Diversity and the associated Jakarta Mandate. Furthermore, the IUCN Amman Resolution on High-Seas MPA's adopted in October 2000 called for national governments, NGO's and international agencies to improve integration of established multilateral agencies and existing legal mechanisms in order to identify areas of the high-seas suitable for collaborative management action, and to reach agreement by consensus on regimes for their conservation and management. Thus, collaborative management action in the Aegean Sea between Turkey and Greece could develop joint management processes. Acer (2006) suggested that a joint maritime regime and cooperation between Turkey and Greece need to be comprehensive, while Oral (2009) stated that the peaceful delimitation and establishment of uncontested maritime zones is a prerequisite to ensuring the future sustainability of the marine environment in the Aegean Sea. Equitable and reasonable solutions are needed to solve maritime disputes with the guidance of customary international law, which may then help to improve the recovery of the Aegean marine environment. In the eastern Mediterranean Sea, an area shown in Fig. 6 as M3, there may be a chance for peace and cooperation between Turkey, Syria, Lebanon and the Northern and Southern Republics of Cyprus.

There are several examples in the world ocean of particularly sensitive sea areas (PSSA), which are designated by the International Maritime Organization (IMO). The aim of the PSSA is to protect vulnerable habitats in marine areas, yet there is only one PSSA area in the Mediterranean Sea: the Strait of Bonifacio between France and Italy .

An HSMPA could substitute for this as an alternative protection instrument. Therefore, special long-term research programmes and special funds are needed for conservation of marine biological diversity resources beyond marine and coastal protected areas, with a view to establishing protected area networks. These proposals would also help to create a forum for discussion and exchange of information among scientists, marine conservationists, fisherman and decision-makers in the Mediterranean region.

Nevertheless, it is clear that there are increasing risks to biodiversity in areas beyond national jurisdiction in the eastern Mediterranean Sea, in benthic features such as seamount communities, cold seeps, hydrothermal vents and other specific habitats. For pelagic habitats, upwelling areas and gyres, such as that of Rhodes, also play important roles in fuelling ecosystems in the entire Levantine area.

Finally, there is an immediate need for taking concerted action in order to conserve high seas benthic and pelagic boundaries in the eastern Mediterranean Sea. Even these boundaries are uncertain due to a lack of detailed scientific information and simply poor knowledge.

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3.2. Central-southern Mediterranean submarine canyons and steep slopes: role played in the distribution of cetaceans, bluefin tunas, and elasmobranchs

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INTRODUCTION

Morphologically, the Strait of Sicily comprises the continental shelf and slope. However, in the area there are also banks, seamounts, irregular incised slopes forming troughs and canyons of V, U and flat-bottomed types. The latter referred to as grabens due to their origin, considered to have been produced by subsidence of the earth's crust between two faults. These canyon-like grabens are governed by a fault system that extends throughout the Sicily Channel from Southern Sicily to Tunisia and which has also been responsible for the major tectonic and geomorphological development of the Maltese islands (Illies, 1981; Galea, 2007). The Maltese islands lie in the Sicily Channel on a relatively stable plateau of the African foreland, the Pelagian Platform, about 200 km south of the convergent segment of the Europe-Africa plate boundary that runs through Sicily (Galea, 2007).

In the extension of the Sicilian continental shelf toward the Pantelleria Rift (Adventure Bank and Graham Bank plateaus), five volcanic seamounts have been recognised (Tetide, Anfitrite, Galatea, Cimotoe and Graham). Two other much larger seamounts, Bannock and Nameless Bank (Banco Senza Nome), are located between the Malta and Pantelleria basins and close to the eastern border of the Nameless Bank respectively (EC, 2011).

A strip of deeper water approximately 96 km wide (200–1700m deep, GEBCO 08, 2010) stretches in the middle of contrasting shallow Tunisian waters on one side and the banks of Sicily and Malta on the other side, in a manner that links the deeper waters of the two main western and eastern Mediterranean basins through this relatively restricted deep water passage. In turn this passage has narrower, deeper troughs and canyon-like grabens that may channel the deepest waters down to a 600-1700m depth. The deepest water passages in the Sicilian Channel appear to link to the Bizerte Canyon and the Ustica trough in the Western basin, and to the Heron Valley in the Eastern basin. The area of particular interest for this paper includes the deep Malta, Linosa and Pantelleria troughs or canyon-like grabens, that run parallel to Malta and Sicily in a north west direction and up to the volcanic islands of Linosa and Pantelleria. Also of interest are regions where steep slopes lead to deeper waters.

Submarine canyons are defined as deeply incised, steep-sided underwater valleys winding along or across the continental shelf or continental slope. Their cross sections tend to be V-shaped along the upper course and U-shaped in the lower course (Danovaro *et al.,* 2010). As submarine canyons may also be described in relation to submarine troughs, thus indicating a relationship that may be found in the Straits of Sicily, the submarine canyon-shaped parts of the troughs found in the region need to be considered as contributing to the deep canyon and steep slope formations in this Central-Southern Mediterranean region. The contrast between the shallow and deep waters found may have encouraged a greater diversity of species adapting to the variable conditions or isolating them in patchy distributions.

The review on global distribution of large submarine canyons by Harris and Whiteway (2011) is an important basis on which to build further awareness and pursue research on these marine features, especially highlighting the fact that for the Mediterranean it is valuable to consider not only the large submarine canyons but also smaller canyons which may still contribute unique habitat and conditions for unique biodiversity. Therefore, as indicated by various researchers (Harris and Baker, 2012), different seafloor geomorphologies need to be studied to provide important data and possible relationships between various seafloor features, including submarine canyons, steep slopes and regions close to seamounts, and the conditions which provide specific benthic habitats and affect the distribution of micro to mega species distribution.

In general, Mediterranean canyons are found to be more closely spaced than in other areas of the world (Harris and Whiteway, 2011) thus constituting a probable hotspot for submarine canyon species. The deep-sea submarine canyons of the Mediterranean vary in size, linking the coastal areas to the deep sea. These canyons may act as conduits of coastal detritus (organic and inorganic) to the deep-sea grounds (Gardner, 1989). Submarine troughs, canyons and valleys can also connect various deep water areas allowing for exchange of materials and deep water species horizontally as well as vertically. The seafloor geomorphology may also affect pelagic species distribution in both direct and indirect ways. Most prominently through the availability of refugia and prey in these deep water formations.

Mediterranean water circulation is considered to be highly complex with the Atlantic low-salinity waters coming into the Mediterranean as a surface layer until it turns into intermediate waters in the Eastern Meditrranean Levantine Intermediate Water (LIW, Lascaratos *et al.,* 1993). The high-salinity waters of the Mediterranean thus find their way beneath the Atlantic water, moving in the opposite direction toward the Atlantic Ocean. Apart from high salinity (38 to 39.5), the Mediterranean deep waters are reported to be highly oxygenated, oligotrophic, and highly homeothermic from 300-500m to the bottom, with the western and eastern basins' bottom temperatures ranging from 12.8°C to 13.5°C and 13.5°C to 15.5°C respectively. However, due to the slow turnover, these deep waters may be vulnerable to warming up with climate change (Danovaro *et al.,* 2010).

Depth and sea water temperature values recorded by the Minilog system during several bottom trawl surveys carried out in the Strait of Sicily (Central Mediterranean Sea) in spring (MEDIterranean Trawl Survey – MEDITS) and late summer (GRUppo Nazionale risorse Demersali – GRUND project) support an ongoing warming of the water masses in the Strait of Sicily (13.5°C, representing the asymptotic temperature between 200 and 800m), and confirm the existence of the basic three layers structure (Atlantic, Levantine and Transitional waters) (Ragonese *et al.,* 2008).

The enhanced productivity (Macquart-Moulin and Patriti, 1996; Vetter and Dayton, 1998) and the local currents related to canyons may play a role in larval drift and juvenile recruitment because of the relationship between canyons and the formation of intermediate nepheloid layers (Company and Sardà, 1997; Puig *et al.*, 2001; CIESM, 2003). The Mediterranean basin as a whole, but also the central-southern Mediterranean region, have been reported as hot spots of biodiversity (Mediterranean marine biodiversity constitues 7.5% of global biodiversity in its 0.82% of sea surface), endemism (Myers *et al.,* 2000) and spawning for various species (Camilleri *et al.,* 2002; Camilleri, 2003; Vella, 2006; 2008; 2010; Oceana, 2009; Fortibuoni *et al.*, 2010; Rais, 2010; Vella *et al.,* 2011). With an average depth of 1500m and a maximum depth of 5267m, the Mediterranean does offer deep sea habitats. The role of deep sea and submarine canyon habitats and refugia for various species and regional productivity should therefore not be underestimated. In the Sicily Channel, depth goes down to 1700m (GEBCO 08, 2010) and is therefore deeper than the Mediterranean average. A more detailed consideration of the range of depths (GEBCO 08, 2010) for the deep water region considered here is illustrated in the bar chart (Fig.1). Fig. 2 shows a map with bathymetry in the central southern Mediterranean around the Maltese Islands (Schlitzer, 2012).

Fig. 3 illustrates a map shading the region with deeper waters in the Strait of Sicily with some cross-section (C.S.) sites indicated, where depth profiles are illustrated in figures 4A to 4H for regional cross-sections C.S. 1 to C.S. 8. In particular cross-sections C.S. 1, C.S. 3, C.S. 6, C.S. 7 and C.S. 8 illustrate V, U and flat-bed graben conformations associated with submarine canyons.

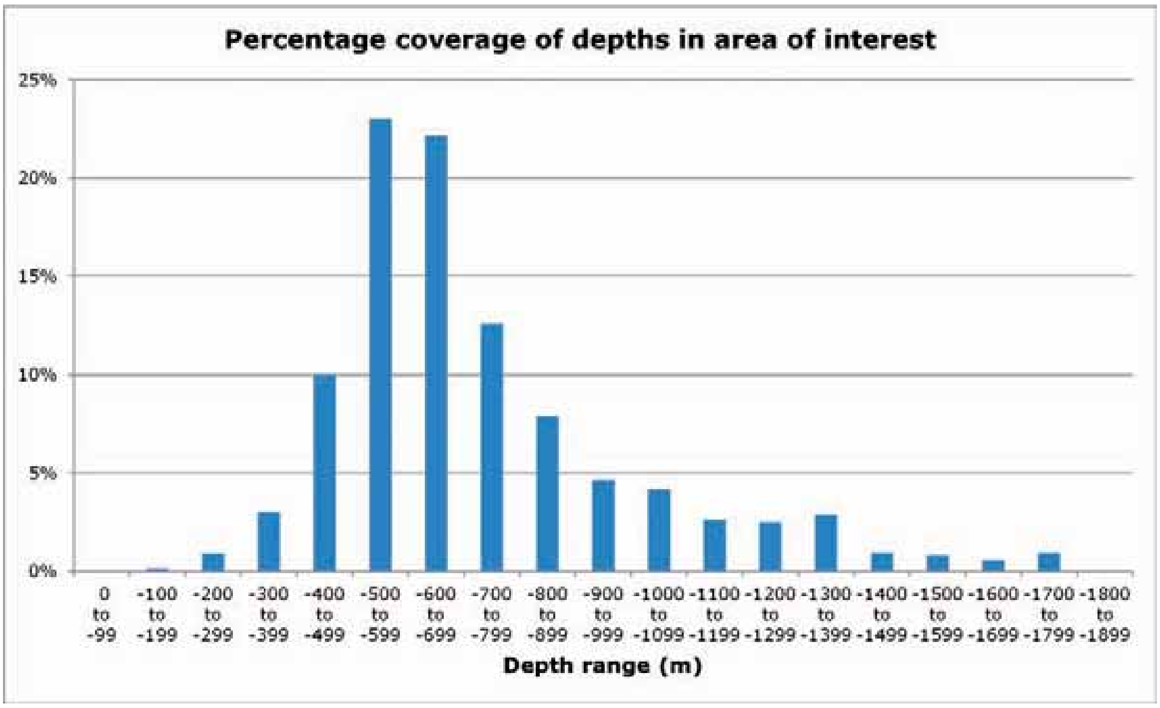


Fig. 1:

Bar graph illustrating the relative coverage of the sea depth (m) (GEBCO 08 2010) in the deep sea region of the Sicily Channel area, shaded region of the Map in figure 3.

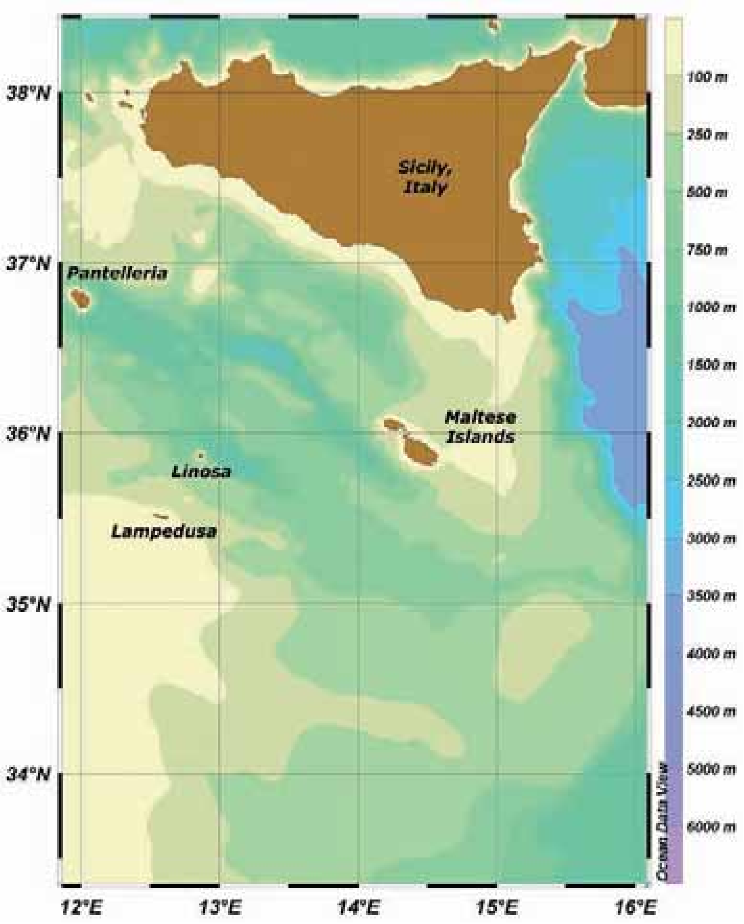


Fig. 2:

Bathymetric Map (Ocean view) of the Central-Southern Mediterranean Sea (Schlitzer, 2012).

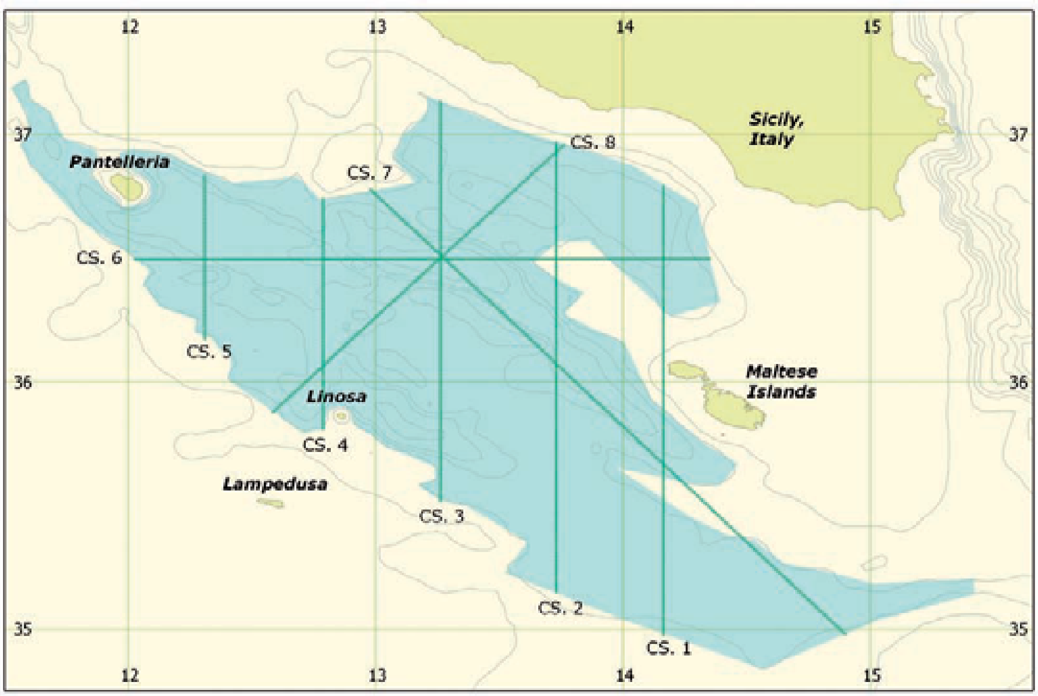
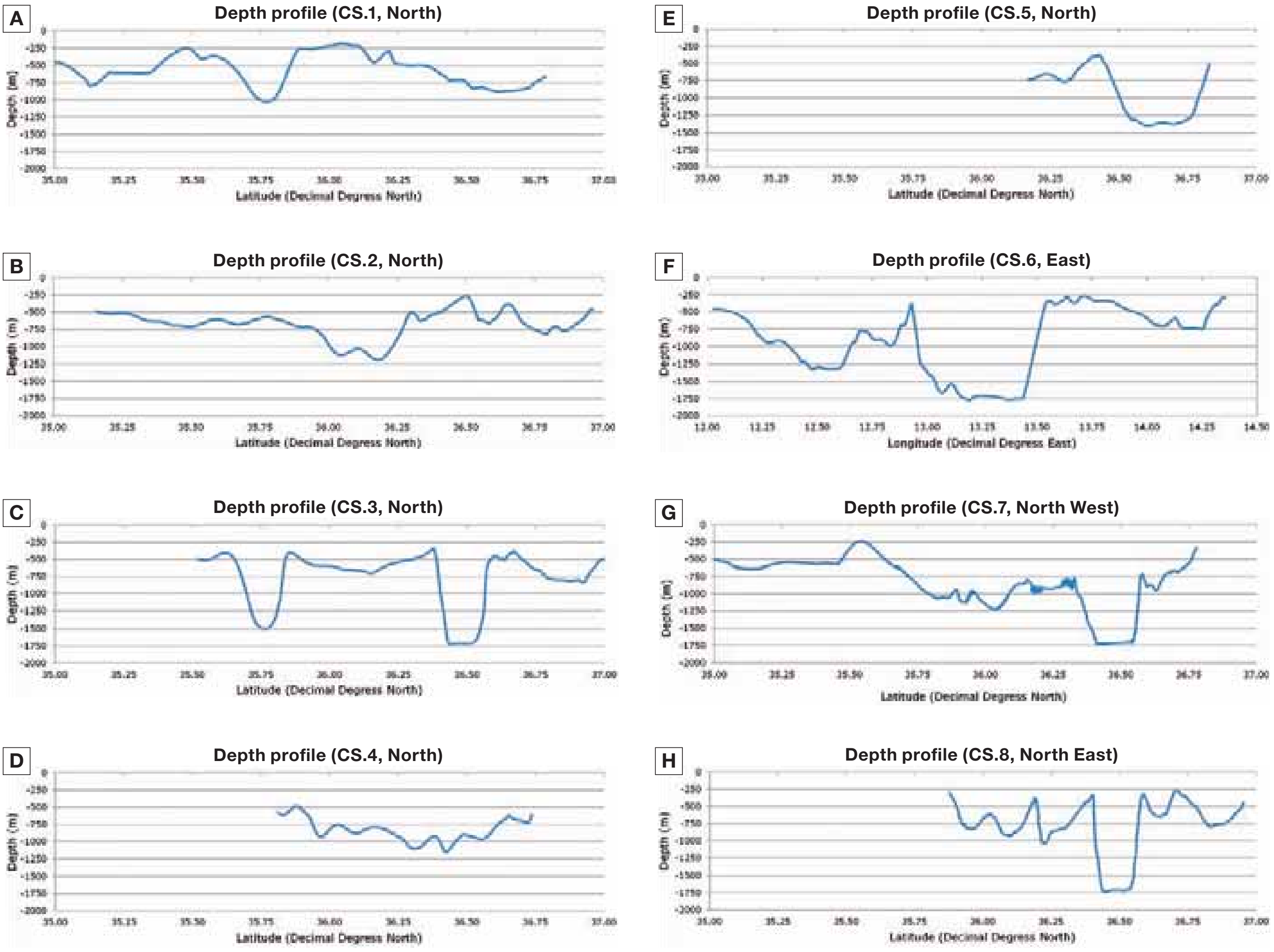


Fig. 3:

Cross-sections through the shaded deeper water region in the Strait of Sicily.



Figs. 4A; 4B; 4C; 4D; 4E; 4F; 4G; 4H:

illustrating bathymetric cross-sections from the lines C.S.1 to C.S. 8 respectively, as shown in Fig. 3.

MODISA data of annual Sea Surface Temperatures and Chlorophyll a at random stations both at the deepest (D) bathymetric regions and less deep peripheral (P) regions marked on the map in figure 5 are compared. Figs. 6A and 6B show annual variations for the SST (MODISA) for stations located in deeper waters and less deep peripheral waters respectively for the years between 2003 and 2011; Figs. 7A and 7B show annual variations in chlorophyll a (MODISA) for these same stations in deeper and less deep peripheral waters respectively for the years 2003 to 2011.

Figs. 6A and 6B show that the highest annual SST values for all stations was for the year 2003 with a second peak in 2006 for the deeper water stations, postponed to 2007 for most peripheral deep water stations. The lowest annual SST values are those for 2004 and 2011. Deep water station D1 indicates, however, a higher than average SST for 2004 and no decline since 2009.

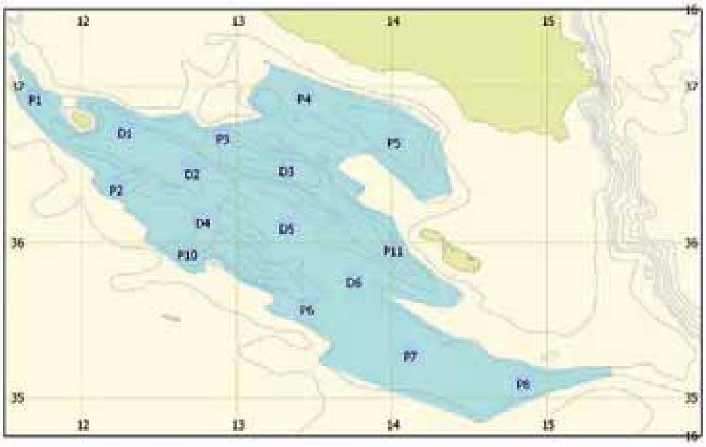
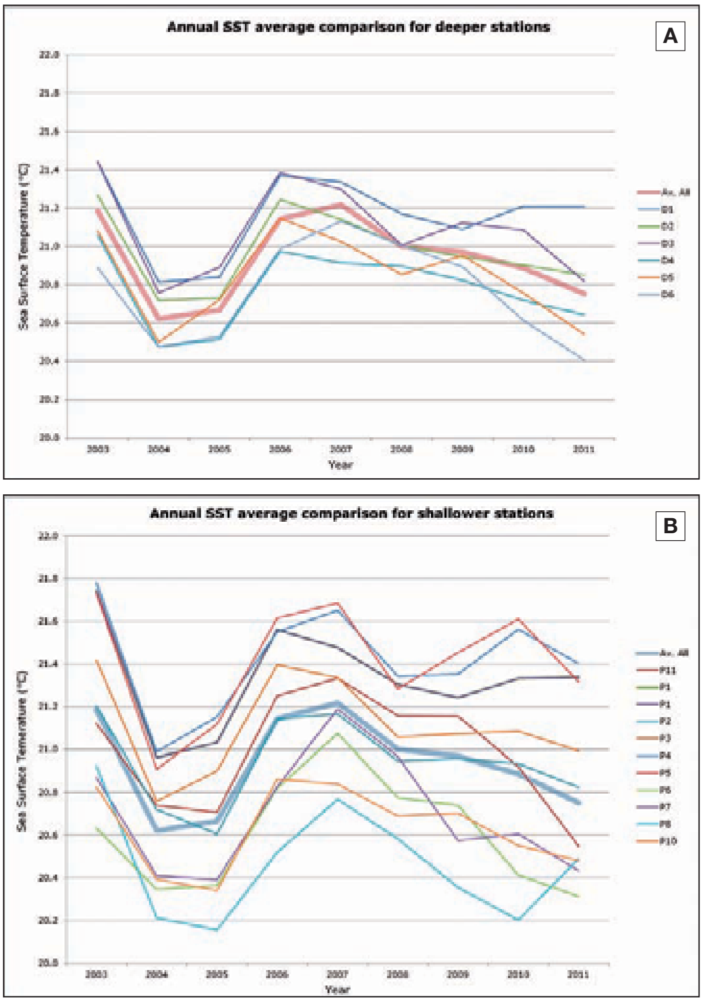


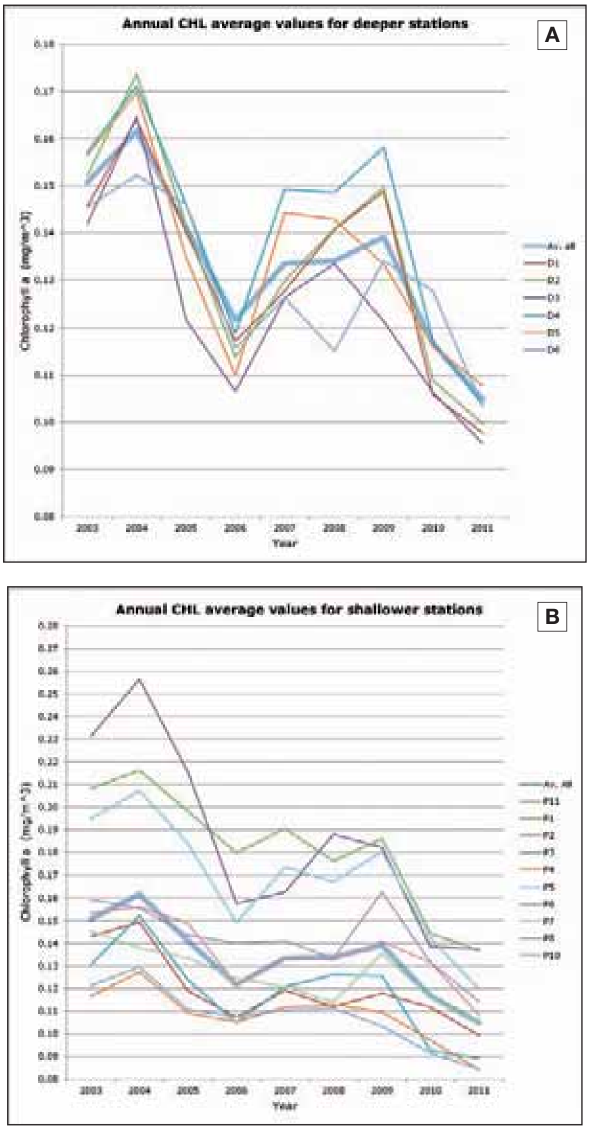
Fig. 5:

Map indicating locations of the deep water stations and peripheral deep water stations within the shaded deeper waters of the Strait of Sicily, where annual measures (MODISA) for SST (Figs. 6A and 6B) and Chl a (Figs. 7A and 7B) were compared between 2003 and 2011.



Figs. 6A and 6B:

illustrating annual variations for Sea Surface Temperatures (SST) MODISA at the deeper water stations and peripheral deep water stations respectively.



Figs. 7A and 7B:

illustrating annual variations for Chlorophyll a concentrations (CHL a) MODISA at the deeper water stations and peripheral deep water stations respectively.

Figs. 7A and 7B show that, since 2004, concentrations of Chlorophyll a have been decreasing in the region. Though this trend is reflected in all stations, deeper waters and offshore peripheral deep water regions tend to show higher values than the overall annual average for Chlorophyll a concentrations in the region considered.

CONSERVATION NEEDS FOR DEEP SEA LIFE ASSOCIATED WITH SLOPES AND CANYONS

Impacts of climate change and human activities on deep sea and submarine canyons in the Mediterranean and close to islands need special attention. According to Harris and Whiteway (2011), shelf-incising canyons above 1500m water depths are more vulnerable to destructive fishing practices, which include bottom trawling, and ocean acidification, indirectly caused by anthropogenic climate change. The importance of conservation work for submarine canyon ecosystems is stressed in particular in relation to islands.

Environmental pressure as a result of intensive maritime traffic (and corresponding collision risk/accident risk) in the area surrounding Malta is relatively high. Moreover, in recent years, pollution in the Mediterranean Sea basin has increased, with the Strait of Sicily being strongly affected by traffic and pollution (EC, 2011).

As anthropogenic activities and impacts increase in deeper reaches of the Mediterranean Sea, it is necessary to determine how changing conditions in the marine environment may affect species distributions, isolating or fragmenting their habitats, while opening access to other species. The conditions for vertical and horizontal movement by marine species need to be understood and, where necessary, management to maintain effective corridors for these movements needs to be implemented as human explorations, exploitation and developments affecting the deep sea increase. This is particularly important with migrating species which need to continue to find viable paths through which to travel with the least disturbance and impact on their survival.

Dolphin fish (*Coryphaena hippurus)* and bluefin tuna (*Thunnus thynnus)* are two fish species known to seasonally migrate in large numbers through the Straits of Sicily. The former in its juvenile stages (Vella 1999), the latter during its spawning phase (Vella, 2006; 2009a; 2010a). Sea birds including shearwater species (*Calonectris diomedea* and *Puffinus yelkouan*); Marine Turtles, such as the Loggerhead turtle, (*Caretta caretta)* and the rarer Leatherback turtle *(Dermochelys coriacea)* and large distance ranging cetaceans, such as Fin whales, (*Balaenoptera physalus),* Sperm whales (*Physeter macrocephalus), Striped dolphins* (Stenella coeruleoalba), Risso's Dolphins (*Grampus griseus*) and Common dolphins (*Delphinus delphis*) and Bottlenose dolphins (*Tursiops truncatus*) also travel or migrate across basins passing through these waters. Some species spend more time than others in these waters, while others reside in them for most of their lives (Vella, 1998; 2000; 2001; 2002; 2005; 2008; 2010a, b and c; Vella, 2011; Vella *et al.,* 2011).

DEMERSAL AND BENTHIC DEEP SEA SPECIES AND THEIR EXPLOITATION

Some of the main species targeted by deep-sea trawl fisheries in the Mediterranean include: European hake (*Merluccius merluccius)*; Blue and red shrimp (*Aristeus antennatus)*; Giant red shrimp (*Aristaeomorpha foliacea)*. European hake (*Merluccius merluccius)* are targeted by gillnet and longline fisheries. Associated deep sea species caught as by-catch from trawling include: Norway lobster (*Nephrops norvegicus*); Deep-water rose shrimp (*Parapenaeus longirostris)*; Blackbelly rosefish *(blue-mouth redfish*) *(Helicolenus dactylopterus*). Many more species are by-catch and discarded, including: Greater forkbeard (*Phycis blennoides*); Four-spot megrim (*Lepidorhombus boscii*); Golden shrimp (*Plesionika martia*); Horned octopus (curled octopus) (*Eledone cirrhosa*); European conger (*Conger conger*); Blue whiting (*Micromesistius poutassou*) (GFCM SCSA, 2003; D'Onghia *et al*., 2003; Sardà *et al*., 2004; EC, 2002).

In the Mediterranean, trawling is illegal in deep waters; in fact, in 2005, the first step to regularise the prevention of further damage came into effect with new regulations to safeguard deep-sea habitats and ban towed trawl nets and dredges at depths beyond 1000m (REC-GFCM/29/2005/1 in GFCM-COC, 2007). Since 2005, Mediterranean countries have required trawlers to use a minimum mesh-size opening of 40mm in the "cod end" section of their nets in order to allow smaller, juvenile fish to escape, thereby conserving breeding stocks. Yet human activities, including research and exploration, still continue to make use of similar destructive methods causing further deleterous impact on vulnerable and legally protected benthic and demersal species in deep waters. Repeated MEDITS trawl surveys that began in 1994 have continued with activities well after 2005 using experimental otter trawl net with a cod end stretched mesh-size 20mm (Ragonese *et al.,* 2005; 2006; Dimech *et al.,* 2007). When in line with what the FAO calls "the precautionary approach" to fisheries management, the 2005 ban aims to protect fragile deep-sea habitats and slow-growing fish which live there and constitute an integral part of the marine ecoystem and food chains.

From MEDITS trawl surveys in the Straits of Sicily, including trawling grounds off the Maltese islands within the GFCM geographical sub-unit 15, Otter trawl samples were collected in the summers of 2003, 2004 and 2005 from 45 stations located at different depths between 80 and 800 m. A total of 552,963 live individuals (22,887 kg) consisting of 189 different species (26 elasmobranchs, 111 teleosts, 26 decapods and 26 molluscs) were identified, of which teleosts were the largest component in terms of both abundance and biomass (Dimech *et al.,* 2007).

For megafaunal organisms, various types of trawls and nets can provide quantitative, though not absolute, estimates of species abundance. Submersibles (e.g. Uzmann *et al*., 1977) and towed still and video camera systems (e.g. Russel *et al*., 1986; Freiwald *et al.,* 2009) have been used for ground truthing. These approaches are particularly useful in rugged or fragile habitats where trawling is not possible, and due to the increasing vulnerability of deep sea life (e.g. Kreiger *et al*., 2002; CIESM, 2003).

In a recent review of the knowledge on fisheries by-catches and discards in the GFCM area, it is stated that certain fishing activities undertaken in deep sea regions have high ecosystem impacts (Vassilopoulou, 2012). Shrimp trawl fishery undertaken in deep sea is such a source of high generation of discards in various parts of the Mediterranean with up to 49% of by-catch in the Straits of Sicily (Castriota *et al.,* 2001). In the latter, for 1 kg of shrimps, 9.6 kg of by-catch were produced, of which 5.2 kg were discarded (Castriota *et al.,* 2001). Furthermore, a Mediterranean-wide estimate of discards of the deepwater trawl fishery for shrimps is 39.2% of total catch, with this ratio reaching 56.5% when targeting shrimps and Norvegian lobster (*Nephrops norvegicus*) (Kelleher, 2005). Such fisheries also present substantial by-catches of sharks and rays (CIESM, 2003; Tudela, 2004; Kelleher, 2005; Bensch *et al., FAO. 2009*). Lack of adequate knowledge of the various species being impacted by increasing exploitation may jeopardise their long-term survival. These gaps need to be filled in to manage sustainable fisheries while conserving deep sea species (Company *et al.,* 2003; Vella *et al.,* 2007; Vella, 2009b).

SOME FISH AND ELASMOBRANCH SPECIES REQUIRING SPECIAL ATTENTION

Apart from the economically important Dolphin fish (*Coryphaena hippurus*) caught up to 400m depths (Macias *et al.,* 2011) and the European hake Mediterranean subspecies *(Merluccius merluccius smiridus)* found till depths of up to 800m, Bluefin tuna (*Thunnus thynnus*) is by far one of the most economically important fisheries resources in the central Mediterranean region. Electronic tagging has provided insights into the seasonal movements and environmental preferences of the Atlantic bluefin tuna, which has been found to dive to depths of more than 1000m and maintain a warm body temperature (Block *et al.,* 2001). Seasonal migration of the Blue fin tuna for spawning between May and June sees the region off the Maltese Islands become one of the species' main spawning grounds in the Mediterranean.

Among the various species of elasmobranchs caught by trawl fisheries off the Maltese islands, the following are known to inhabit deep waters: *Centrophorus granulosus* (50-1300m); *Centroscymnus coelolepis* (500-1800m max >3000m) *Chimaera monstrosa* (300 – 500m max 1000m); *Dalatias licha (200 – 600 max 1800m); Etmopterus spinax* (300-2000m); *Galeus melastomus* (150-1400m); *Heptranchias perlo* from shallow (50m-600m); *Hexanchus griseus* (30m to max of 1800m); *Mustelus asterias* (shallow to 350m); *Oxynotus centrina* (50-700m); *Raja circularis* (100-660m); *Raja clavata* (30m-700m); *Raja melitensi* (30-550m); *Raja miraletus* (17m-462m); *Raja oxyrinchus* (15-900m); *Raja radula* (40m to 300m); *Scyliorhinus canicula* (50-500m); *Scyliorhinus stellaris* (1-400m); *Squalus blainvillei* (300-500m); *Torpedo marmorata* (10-30 max 100m).

The Velvet belly shark *(Etmopterus spinax)* is well-adapted to deep sea life. It is reported to feed on small animals such as deep-sea krill *(Euphausiidae),* shrimps *(Pasiphaeidae),* cuttlefishes *(Sepiolidae),* squids *(Ommastrephidae and others),* and a wide range of small teleosts including shads *(Sternoptychidae),* barracudinas *(Paralepidididae),* lanternfishes *(Myctophidae)* and pouts *(Gadidae).* Its diet changes with age and size.

The Velvet belly shark, Portuguese Dogfish (*Centroscymnus coelolepis*) and Black-Mouthed Catshark (*Galeus melastomus*) have been found to share deep sea habitats in other parts of the Mediterranean. In 2004, detailed scientific research at the Maltese fish landing site led to the discovery of new elasmobranch species caught by Maltese fishermen; the Portuguese Dogfish was one such new recorded species never reported before (Dalli, 2004; Dalli and Vella, 2006).

While the diet of the Black-Mouthed Catshark is quite diverse and does not overlap that of the other two sharks, the diets of large Velvet bellies and the Portuguese Dogfish are both very squid-intensive. Competition between these two species may be reduced by depth selection, whereby the Portuguese Dogfish feeds at greater depths than the Velvet belly shark with the possible additional benefit of being missed by trawl fishermen too.

Unfortunately, it has been noted that most large long-lived shark species are decreasing in Maltese fisheries landings. One such species is the Six-gilled shark (*Hexanchus griseus*), which is targeted by artisanal fishermen in the Strait of Sicily and has been part of ongoing elasmobranch conservation research (Vella and Vella 2010; 2011). *Hexanchus griseus* is mainly a deep water shark, rarely found at depths of less than 100 m. The species usually seems to stay close to the bottom, near rocky reefs or soft sediments. The deepest one was found at about 2500 m. These sharks are diel vertical migrators, coming up to the surface nocturnally. *H. griseus* also seasonally migrates to shallower coastal waters (Martin, 2000; Musick and McMillan, 2002).

A rare, endemic and critically endangered deep water species in the area includes the Maltese ray, (*Leucoraja melitensis),* with a usual depth range of between 400 and 600m (Vella *et al.,* 2010).

Another three important elasmobranch species found in deep waters of the Strait of Sicily are the legally protected (by Maltese Law) basking shark (*Cetorhinus maximus*) which may be found from close to the sea surface to 900 m depth; the white shark (*Carcharodon carcharias*), which can also be found at the sea surface but may go deeper to 1800m and more; and the giant devil ray (*Mobula mobular*), whose sea depth range extends to 700m depth. These three deep diving elasmobranchs are included in Annex II of the Barcelona Convention.

DEEP SEA CORAL HABITATS

Cold-water coral reefs in the Mediterranean are subfossil and date back to the last glacial age, a time of cooler seawater and better food availability. One healthy and well-developed deep-sea coral mound (consisting primarily of *Lophelia pertusa* and *Madrepora oculata*) is known to exist in the Ionian Sea (Cartes *et al*., 2004). In 2003, a second living and healthy deepwater coral bank, also consisting of *Lophelia* and *Madrepora*, was found at a depth of 390–617 m, some 20–40 km off the southern coast of Malta (Schembri *et al*., 2007; GFCM SAC, 2007; Bensch *et al*., 2009).

A total of 51 benthic species, among them porifera, cnidarians, brachiopods, mollusks, polychaetes, crustaceans and echinoderms, have been recorded in the Strait of Sicily, where the deep-water corals are located in three main areas (Zibrowius and Taviani, 2005; Schembri *et al.,* 2007; Freiwald *et al.,* 2009). Not all the fauna reported by Zibrowius and Taviani (2005) were found alive. Recent observations by ROV off Malta revealed thick fossil coral frameworks with overgrowing coral assemblages, mainly consisting of *M. oculata* and *L. pertusa* associated with *Corallium rubrum* and *gorgonians* (Freiwald *et al.,* 2009). The colony bases were generally inhabited by the symbiotic polychaete *Eunice norvegica,* and in some dives *Dendrophyllia cornigera* was detected. Observations from ROV dives in the Linosa Trough showed the fossil and modern coral communities thriving under overhangs and in large caves, and they were particularly common in volcanic bedrock sequences. In the Urania Bank, the colonies of *M. oculata* measured up to 70 cm high and 50 cm wide, while those of L. pertusa rarely exceed 10 cm in size (Freiwald *et al.,* 2009). Recently acquired data indicates that Mediterranean deep-water corals habitats are rich in species diversity. Cephalopods, crustaceans and fish can be attracted by the structural complexity of deep-water coral reefs, which may act as essential habitats for feeding and spawning. Deep-water coral habitats can act as spawning areas for some species and nursery areas for others, as suggested by the higher catches of benthopelagic species (such as the shrimp *Aristeus antennatus* and *Aristaeomorpha foliacea*), as well as sharks, hakes, rockfish, greater fork beard, gurnards and blackspot seabream caught by long-line in these areas (D'Onghia *et al.,* 2010). Studies on prokaryotic assemblages associated with the deep-sea coral *Lophelia pertusa* in the Central Mediterranean Sea revealed specific and unique microbial assemblage (Yakimov *et al.,* 2005; Danovaro *et al*., 2010).

Vulnerable deep coral assemblages, cold seep assemblages, benthic communities and pelagic species affected by over-exploitation and habitat degradation are found in the central-southern Mediterranean region (Vella *et al.,* 2011). Overall marine biodiversity impoverishment is due to change caused by increasing human activities including oil exploration, aquaculture, maritime and fisheries activities, climate change and alien species from both sides of the Gibraltar and Suez Channel openings (Vella *et al.,* 2011).

INTEGRATING SPATIAL DISTRIBUTION STUDIES TO VERTICAL DEPTH FEATURES.

Cetacean, turtle, elasmobranchs and large pelagic migratory predators, such as the bluefin tuna, are studied in the 120,000 km^2 area around the Maltese Islands (Vella, 1998; 2011), taking care to use methods that are environmentally friendly as well as scientifically sound. Thanks to dedicated long-term field research, as well as fishermen's surveys and fish market research, important data relating to elusive or economically important species in the region has been collected over the years. Apart from teleosts, elasmobranchs and sea-birds mentioned above, different cetacean species and turtles are studied including: common dolphins (*Delphinus delphis*) and various other cetacean species including bottlenose, striped, Risso's dolphins, sperm and fin whales (Vella, 1998; 2000; 2001; 2002; 2005; 2008; 2009; 2010a, b and c; Vella and Vella, 2010; Vella *et al.,* 2010; Vella, 2011).

CETACEANS FOUND IN THE DEEPER WATERS OF THE STRAIT OF SICILY

Various cetaceans found in the central-southern Mediterranean region are found to associate with deep waters and also to prey on species found in deep waters.

The sperm whale (*Physeter macrocephalus*), long-finned pilot whale (*Globicephala melas*), Risso's dolphin (*Grampus griseus*) and Cuvier's beaked whale (*Ziphius cavirostris*) are teuthophageous, i.e. they prey exclusively or preferentially on cephalopods (Astruc and Beaubrun, 2005). The stomach contents of stranded animals in the Mediterranean show an overlap of the diet of sperm whales, pilot whales and Risso's dolphins. Their principal prey are a few species of bathypelagic cephalopods from the Histioteuthidae and Ommastrephidae families (Astruc and Beaubrun, 2005).

Altogether, *H. bonnellii*, *H. reversa* and *T. sagittatus* may represent 60 to 100% of the diet of the three predators studied. These species of cephalopods principally occur at the same depths, between 200 and 800 m (Quetglas *et al.*, 2000; Praca and Gannier, 2007). *H. bonnellii* and *T. sagittatus* are two of the many cephalopod species by-caught by deep sea trawl fisheries off the Maltese Islands.

Sperm whales *(Physeter macrocephalus)*

Diving to 400 – 1000 m (max 3000 m), the sperm whale may remain underwater for up to 90 minutes (Whitehead, 2002). This species is present in the Sicily channel, especially in deeper waters (Vella, 2012, *in prep.*).

The sperm whale, the most studied species, seems to be opportunistic in its habitat use, exploiting areas with steep slopes, as well as offshore waters featuring SST fronts (Gannier and Praca, 2007; Gannier *et al.,* 2002).

The species sperm whales prey on include cephalopods, such as *Histioteuthis bonnellii* (Roberts, 2003). Astruc and Beaubrun (2005) used the Index of Relative Importance (IRI) to compare the importance of prey species in the diet of Mediterranean cetaceans (Cortes, 1997), from stomach contents of stranded animals. The sperm whale presents an IRI>90% for *Histioteuthis bonnellii*.

Long finned Pilot whales *(Globicephala melas)*

This species has been found to dive to a depth of over 600m in the deep waters of the Ligurian sea (Braid *et al.,* 2002). Pilot whales have been reported to prefer waters deeper than 1000 m (Gannier, 1998b). The diet of the pilot whale has an IRI between 40 and 50% for *Todarodes sagittatus,* between 10 and 20% for *H. bonnellii* and *H. reversa*, and the remaining 10% consist of several other species, including some Gadidae (Astruc and Beaubrun, 2005). In Spitz *et al.* (2011), the main characteristic of the long-finned pilot whale diet was found to be the unique combination of mesopelagic prey and of prey living on, or close to, the bottom in neritic waters, suggesting some dietary plasticity, as found in striped dolphins (*Stenella coeruleoalba)*.

Cuvier's beaked whale *(Ziphius cavirostris)*

This species is a pelagic, deep-diving cephalopod predator. Stranding records of this species in Sicily and Malta also confirm the presence of this elusive species in the Sicily channel.

Risso's dolphins *(Grampus griseus)*

Risso's dolphin seems to prefer waters with steep slopes from 500 to 2000m (Gannier, 1998b). Risso's dolphin has the most diverse diet composed of *H. reversa* (IRI>30%), *H. bonnellii* and *T. sagittatus* (10<IRI<30%) and several other species with an IRI<10% (Astruc and Beaubrun, 2005). Cephalopod remains from the stomachs of a Risso's dolphin (Grampus griseus Cuvier, 1812, Cetacea) entangled in a fishing net off the Ligurian coast (central Mediterranean Sea) included squids *Ancistroteuthis lichtensteini*, *H. bonnellii*, *H. reversa* and *Todarodes sagittatus* and the sepiolid *Heteroteuthis dispar.* All these cephalopods live in oceanic water, including water over the steep continental slope where Risso's dolphin is frequently sighted. *H. reversa* contributed 78% of the cephalopods by number, 81% of the wet weight and 73% of the dry weight and calorific value. One stomach of Risso's dolphin contained the remains of six cuttlefish (mainly *Sepia officinalis*) and one large benthic octopod. A small quantity of salps was recovered from a second specimen (Spitz *et al.,* 2011).

This cetacean species is found in the Sicily Channel especially in deeper waters, at times also sharing the area with striped dolphins (Vella, 1998; 2012, *in prep.*).

Striped dolphins *(Stenella coeruleoalba)*

Striped dolphins in the western Mediterranean Sea are primarily oceanic top predators, but they also routinely exploit coastal areas characterised by submarine canyons, which create spatially defined patterns in food availability (Gannier, 1999). In the Sicily strait, these dolphins are encountered in large numbers especially in deeper waters (Vella, 1998; 2012, *in prep.*). These small cetaceans are found to distribute themselves close to submarine slopes, escarpments, valleys such as the Heron valley, and the various canyon-grabens, such as the Malta and Linosa canyon-grabens (Vella, 2012, *in prep.*).

In studies on the food and feeding ecology of the striped dolphin in the oceanic waters of the north-east Atlantic, the most significant fish family identified was the lanternfish (24% M) with *Notoscopelus kroeyeri* and *Lobianchia gemellarii* being predominant. Among squid, the oceanic *Teuthowenia megalops* and *Histioteuthis spp.* were the most significant. The pelagic shrimps *Sergestes arcticus* and *Pasiphaea multidentata* were the most prevalent crustaceans. Prey composition and size-range differed slightly with sex and age or body size of the dolphins (Ringelstein, 2006).

The striped dolphin is an oceanic species that occasionally occurs in neritic habitats; in the Bay of Biscay it is abundant offshore and erratic in occurrence over the shelf. Given that prey assemblages differ widely among these habitats in terms of both taxonomic composition and ecology, this would suggest that striped dolphins are able to shift from vertically migrating meso-pelagic prey to neritic or coastal prey types. Fish accounted for 91% of the diet by number and 61% by mass; the rest was mostly cephalopods, crustaceans being present as trace. Specific composition included both oceanic (myctophid and sternoptychid fish; histioteuthid, gonatid and brachioteuthid cephalopods), neritic (gadids and anchovy; loliginid, sepiolid and sepiid cephalopods) and even coastal (atherinid fish) prey types, showing that these animals had changed their diet as they moved over the shelf (Spitz, 2006).

Cephalopods, however, have also been found to dominate the stomach contents of other stranded striped dolphins in other study areas; 88% of the prey ingested (60% of the species) were pelagic or bathypelagic and 99% were either partially or completely oceanic during the life cycle (73% of the species) (Blanco *et al.*, 1995; Würtz and Marrale, 1993).

Striped dolphin distribution was significantly related only to depth (Gomez *et al*., 2008). In this study, striped dolphins show a preference for waters between 700 and 1900 m deep. A study of delphinids in the entire Mediterranean indicated a preference on the part of striped dolphin for open waters (2000 m deep), although a high percentage of sightings also occurred in waters between 1000 and 2000 m (Gannier, 2005). A smaller scale study in the Ligurian sea showed similar habitat use results (Gannier, 1998). However, in other Mediterranean areas (Italian waters, Notarbartolo di Sciara *et al*., 1993; Alboran Sea, Canadas *et al.,* 2002), dolphins did not prefer such deep waters, as also seen in our study area. In the Ligurian Sea a diurnal offshore–inshore movement was observed, indicating that dolphin depth preferences changed depending on the hour of the day (Gannier, 1999).

Common dolphins *(Delphinus delphis)*

The Mediterranean sub-population of common dolphins is reported to be endangered (IUCN, 2011). The species' subpopulation is also present in the Sicily Channel, with larger groups observed around Malta, where from combined data recorded from ship and aerial surveys conducted between 1997-2002, density estimates were reported of 0.135 dolphins per km² (CV=0.28; 95% CI=0.066-0.290) in the area around the Maltese islands (Vella, 1998; 2002; Bearzi *et al.,* 2003; IUCN 2011/Bearzi, 2003).

This species is found to distribute itself widely and seasonally in different areas around the Maltese islands and offshore in the Central-Southern Mediterranean Region. Both shallow and deeper water habitats (at least 280 m, Kinze, 2002) are utilised where it may be observed in association with Bottlenose dolphins or Striped dolphins (Vella, 2005; 2008; 2012; *in prep.*). In the Mediterranean, Common dolphins have in fact been reported in both pelagic and neritic environments, occasionally sharing the former with Striped Dolphins and the latter with Bottlenose Dolphins (Bearzi *et al.,* 2003).

Off southern California, Common dolphins mainly eat anchovies and squids during the winter, but in spring and summer deep-sea smelt and lanternfish are preferred (Reyes, 1991). Based on radio-telemetric studies and analysis of stomach contents, short-beaked common dolphins off southern California start feeding at dusk and continue to feed throughout the night. They feed primarily on organisms in the migrating deep scattering layer, especially myctophids and bathylagids (Evans, 1994; Culik, 2010). They have also been reported to feed on fishes of the Clupeidae and Carangidae families and cephalopods such as Southern Calamari, Arrow Squid and octopus species in southern Australian waters (Kemper and Gibbs, 2001).

Bottlenose dolphins *(Tursiops truncatus)*

Though the bottlenose dolphin is one of the cetacean species mostly adapted to, and associated with shallow waters, its offshore relatives can spend most of their time in deeper waters and dive to over 400 m for their prey (Klatsky *et al.*, 2007). In the Central-southern Mediterranean, offshore bottlenose dolphins are also found to travel extensively in deeper waters where steep slopes and seamounts or banks are close by (Vella, 2012; *in prep.*). In terms of prevalence of species in the Bottlenose diet in the Mediterranean, fish has been reported as the most important prey consumed (96.6%), whereas cephalopods represented the remaining 3.4%. Diet is mainly based on two fish species: blue whiting (*Micromesistius poutassou)* and hake (*Merluccius merluccius)*. Blue whiting was the most common prey, representing 84.9% by number and 50% by mass of the fresh fraction. Hake constituted 9% by number and 39.3% by mass of the fresh fraction. On the other hand, the oceanic cephalopod (*Todarodes sagittatus)* is the most important cephalopod prey (4.8% by mass of the fresh fraction) (Arronte, 2009).

Leatherback and Loggerhead Turtles

Leatherback turtles (*Dermochelys coriacea*) may dive very deep on occasion (one descended to a maximum depth of 1,230 m, which represents the deepest dive ever recorded for a reptile). They generally restrict their diving to less than 250 metres, which increases the likelihood that they will encounter longline hooks (Hays *et al.,* 2004).

Loggerhead turtles (*Caretta caretta*) do not usually exceed 100m in their dives. Some research results show a highly opportunistic foraging behavior by the turtles on both live and dead material in the epipelagic zone, as well as on all types of seafloors (Casale *et al.*, 2008).

CONSERVATION MANAGEMENT MEASURES THAT NEED IMPLEMENTATION TO SAFEGUARD VULNERABLE DEEP SEA ECOSYSTEMS

Appropriately Watling *et al.* (2010) ask the question: can ecosystem-based deep sea fishing be sustained? In general, there is still much implementation and sustainable fishing targets to be reached for shallower water activities. As fish stocks are being depleted and we are fishing down the foodweb, the next target seems to be exploiting deeper levels of our seas.

As the rush to discover new marine species, their distribution and potential exploitation continues to descend deeper in our seas, it is necessary to set conservation goals and monitoring methods to fill the knowledge gaps. This needs to be achieved without leaving species gaps behind or by negatively affecting these vulnerable and unique sites with aggressive sample collection methods. As technology comes to the aid of deep sea exploration and research, it will be easier to achieve conservation through low-impact research and management methods.

Target stocks: various recommendations that are relevant to the target stocks of deep-sea high seas fisheries have been adopted by GFCM Members, in addition to IUU measures. These include the previously mentioned REC-GFCM/29/2005/1 on the management of certain fisheries exploiting demersal and deep-water pelagic species, and more recent resolutions have been added such as:

- *Resolution GFCM/31/2007/3 – through this resolution GFCM Members agreed on voluntary implementation of at least the 40 mm square mesh size codend of trawl nets exploiting demersal resources.*
- *REC-GFCM/31/2007/1 on the mesh size of trawl nets exploiting demersal resources – Members may continue authorizing, until 31 May 2010 only, the use of codend mesh size smaller than 40 mm to operate in certain local and seasonal demersal trawl fisheries exploiting not-shared demersal stocks. However, this derogation applies only to fishing activities already formally authorized by the GFCM Members and shall not involve any future increase in the fishing effort provided.* (GFCM, 2007)

To date, there has been almost no response to UNGA Resolution 61/105 in terms of impact assessments of deep-sea fisheries in the Mediterranean on benthic ecosystems. Indeed, there is very little data on many of the important vulnerable marine ecosystems (VMEs) in the Mediterranean, and their current and past distributions are not understood (Bensch *et al.,* 2009).

Many of these habitats are vital to commercial species, both juveniles and adults. It is widely acknowledged that several of these important VMEs have been largely destroyed across wide areas of the Mediterranean as a result of bottom fishing, especially trawling (Rogers and Gianni, 2010).

The GFCM has recently established criteria for identification of sensitive habitats of relevance for the management of priority species, including VMEs formed by corals, crinoids and other species, as well as seamounts, canyons and cold seeps (GFCM SAC, 2008).

A report has also been made to the European Commission on Sensitive and Essential Fish Habitats in the Mediterranean Sea (EC, 2006). This report also identifies many of the significant deep-sea VMEs in the Mediterranean area and describes their relevance to fisheries and the impacts on them from fishing activities. As yet, there is no indication of the development of a systematic approach to identification of VMEs or the management of deep-sea fisheries to protect such habitats.

The setting up of conservation areas with implemented monitoring and enforcement for effective management will be challenging but necessary, even in this region of the Mediterranean where the shallow embraces the deep, and nature depends on man embracing sustainable development. Developing knowledge shows that deep water marine life in canyon-like features and slopes of varying steepness contribute to ideal spawning sites, refugia and feeding banquets for predators which have adapted to make use of these unique resources in different ways and according to the time of day, year or developmental stage.

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3.3. The case study of the marine canyon of Cuma (Tyrrhenian sea, Italy): implication for cetacean conservation off Ischia island

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STUDY AREA

Ischia, a large volcanic island near the Gulf of Naples, is located at 40° 44' N, 13° 55' E, in the southern Tyrrhenian Sea (Italy). Prior to 1990, there was very little known about the cetaceans inhabiting the water off Ischia Island. To address this, the "Ischia Dolphin Project" was set up in 1991, and a long-term research program on cetacean species was established. Since 1997, the research effort was mainly focussed on an area situated north of Ischia Island, a particular zone characterised by a rich diversity of marine life and a concentration of pelagic fauna. This region with a complex and varied topography corresponds to the submarine canyon of Cuma, a large deep submarine valley, which reaches a maximum depth of 800 m between the islands of Ischia and Ventotene (Fig. 1). This canyon represents a great sedimentary basin for materials which are carried along the coast by the Volturno and Garigliano rivers (Gulf of Gaeta); the canyon increases the upwelling speed and also acts as a conveying duct to the waters of the deep basin (Pennetta *et al.*, 1998). The shelf area of Ischia Island in front of the canyon is characterised by seagrass meadows (*Posidonia oceanica*), rocky banks and rocky cliffs with coralligenous formations.

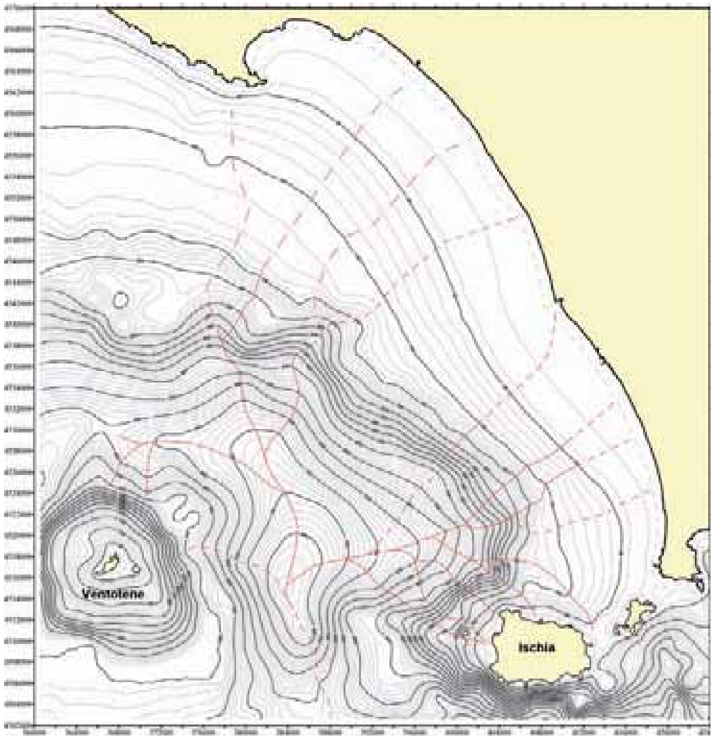

Fig. 1:
The study area (Pennetta *et al.*, 1998).

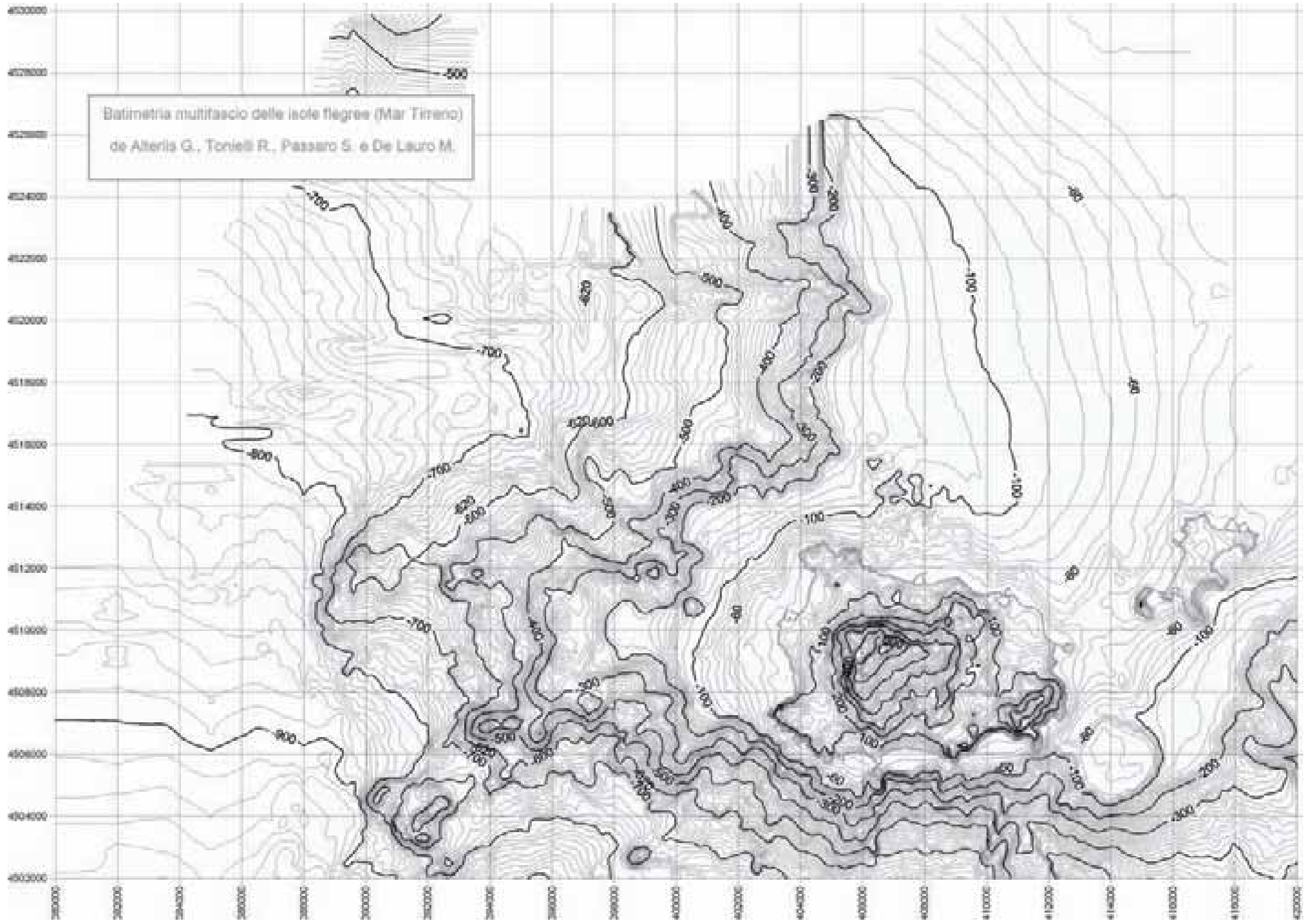

Fig. 2:
Morpho-bathymetry map of the coastal water of Ischia (de Alteriis and Toscano, 2003).

Submarine geological and geomorphological studies in the area started in 1998 thanks to the Geology Department of the University of Naples "Federico II" (Pennetta *et al*., 1998). They produced the first detailed description of the region, naming the entire area "Canyon of Cuma", intending with this definition to pool together a complex topographical system including the northern part of Ischia as far as the large submarine valley between the Islands of Ischia and Ventotene (Fig. 1; red lines represent the axes of the canyons and broken red lines mark out the same axes submerged by the sand; see Pennetta *et al*., 1998). The principal axis of the Canyon has a southwest-northeast orientation, with several minor tributary channels departing from it.

Using high-resolution geophysical instrumentation (Multibeam and Side Scan Sonar), the CNR Geo Mare Sud Institute in Naples conducted new detailed geological surveys alongside Ischia coastal waters in 2003, producing a novel morpho-bathymetry map of the island (Fig. 2; de Alteriis and Toscano, 2003).

The authors distinguished several small systems rather than combining different regions in a whole complex system, identifying canyons (Cuma, Punta Cornacchia and Punta Imperatore) and erosional channels (Forio) along the island's edge from north to west, to south (Fig. 3; red boxes delimitate the canyons' and channels' heads).

The study area is well-known for its high biodiversity and for the presence of large pelagic predators such as whales and dolphins (Mussi and Miragliuolo, 2003), as well as key species in the pelagic trophic web such as the euphasiacean *Meganyctiphanes norvegica* (Mussi *et al*., 1999). Seven cetacean species have been regularly observed, as it is a feeding site for fin whales (*Balaenoptera physalus*) (Mussi *et al*., 1999), a feeding and breeding ground for striped dolphins (*Stenella coeruleoalba*), Risso's dolphins (*Grampus griseus*) (Mussi and Miragliuolo, 2003) and sperm whales (*Physeter macrocephalus*) (Mussi *et al*., 2005). Furthermore, the area has been listed in the last IUCN Cetacean Action Plan (Reeves *et al*., 2003) as a critical habitat for the endangered short-beaked common dolphin, *Delphinus delphis*. Bottlenose dolphins (*Tursiops truncatus)* and pilot whales (*Globicephala melas*) are also present in the area (Mussi *et al*., 1998), as well as pelagic fish such as *Mobula mobular*, *Thunnus* sp., *Xiphias gladius* and sea birds such as *Calonectris diomedea*, *Puffinus puffinus* and *Larus ridibundus*.

The entire area is affected by several human activities that may detrimentally influence its ecosystems. Among these, tourism and fisheries are the most evident factors during the summer season, when the frequency of both maritime (mostly ferries and fast ferries) and recreational boat traffic, as well as the intensity of the fishing effort, usually increase.

Ischia, together with the Procida and Vivara Islands, was designed as a Marine Protected Area (MPA) (called "Regno di Nettuno"). The MPA includes the coastal regions between the above-mentioned

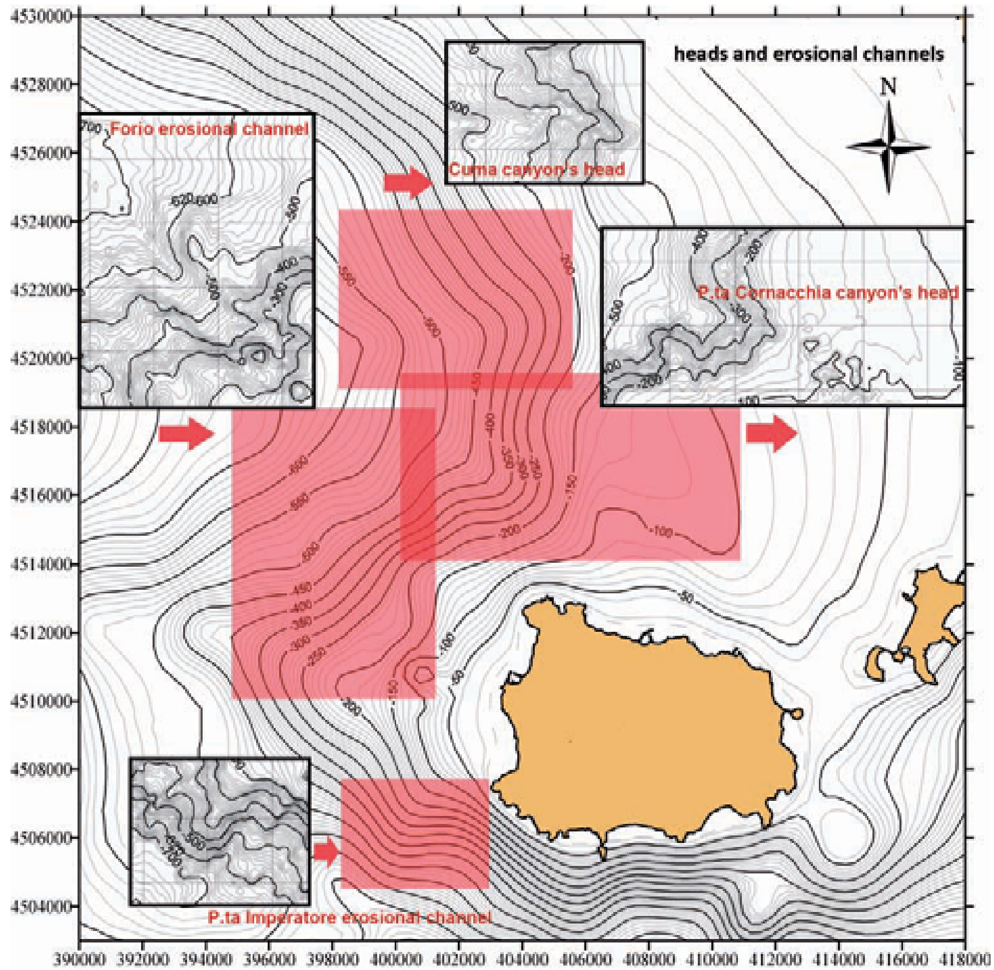

Fig. 3:

Canyons and erosional channels in the coastal waters of Ischia.

islands and the mainland, and a more pelagic area located north of Ischia specifically intended as an important site for cetaceans' diversity and a critical habitat for the short-beaked common dolphin.

Two of the physical conditions that may affect cetaceans' occurrence, distribution and behaviour include complex variations in bottom topography and bathymetry, both influencing oceanographic processes that concentrate prey and structure prey availability vertically in the water column, thus producing a number of effects that are exploited by cetaceans. Therefore, the main objective of this case study is to present an overview of the available data around Ischia and Ventotene Islands over nine years (2000-2008), showing how the geomorphology of the submarine canyon of Cuma has an influence on such cetacean species. Furthermore, since an increasing number of recent studies have recognized that both fixed spatial and variable oceanographic features, and their functional relationships with cetaceans, can be of great importance for conservation, a description on how and why animals use specific oceanographic phenomena can help to identify critical habitats (Hyrenbach *et al.*, 2000; Hooker *et al.*, 1999; Cañadas *et al.*, 2002; Hooker and Gerber, 2004; Yen *et al.*, 2004).

SURVEYS

The study area was approximately 60X74 km. The size of the area was limited by distances that could be covered by the research vessel within a single day before returning to port. Data was collected by two to four trained observers during daily standardized boat-based, photo-identification and acoustic surveys within the study area. Regular survey trips throughout June, July, August, September and October each year (2000-2008) have been conducted using a 17.7 m. sailing vessel (*Jean Gab*) at a sea state of zero to 4 on the Beaufort scale during good light conditions, at a steady speed of 2-4 knots. The position of the research vessel was automatically recorded every 3 minutes using a GPS receiver. A detailed trip log of the routes covered was noted down using Logger, the IFAW Data Logging Software.

Data including start and end times of boat trips, weather and sea state, location, species, start and end times of each group observation, best estimate of the group size and composition (number and sex of adults, juveniles, calves and newborns), behavioural categories, sounds and other complementary information were recorded.

A total number of 536 boat surveys were conducted on 928 days during the nine-year study period (from June 2000 to October 2008). The survey effort totalized 31,160.11 nautical miles and 5,269 hours, of which 545 were spent observing and photographing animals (Tab. 1).

YEAR	N. OF SURVEYS	TOTAL EFFORT (KM)	TOTAL EFFORT (HOURS)	TOTAL DAYS AT SEA
2000	51	1900,47	348	95
2001	57	3279,79	399	91
2002	71	3814,28	566	131
2003	68	3527,31	629	120
2004	75	3427,62	757	117
2005	69	3144,95	599	114
2006	73	3937,99	652	122
2007	72	3865,34	614	138
2008	78	4262,36	705	142
TOT	**614**	**31160,11**	**5269**	**1070**

Tab. 1:
Total and yearly effort (in terms of surveying time in hours, covered distance in km and days at sea).

CETACEANS

A total number of 625 sightings of seven cetacean species were recorded in the study area (397 visual, 228 acoustic) (Tab. 2).

Striped dolphin was the most frequently sighted species over the years (n=251). Also remarkable is the constant presence of sperm whales (n=81) and short-beaked common dolphins (n=45), although the first became more common in the area as from 2004 while the occurrence of the latter decreased in the last four years. However, it must be taken into account that the increased number of sightings of sperm whales was facilitated by the use of acoustic equipment since 2004. Risso's dolphin (n=18) was quite common in 2000, not sighted from 2001 to 2003 and sighted again since 2004. Pilot whales (n=16) were sighted from 2000 to 2003 and, after that, only in 2006. Fin whales (n=15) were irregularly located over the years, with an increasing number of sightings in 2008. The detection of bottlenose dolphins (n=16) appeared to be quite limited due to a minor research effort in coastal waters.

The area appears to be diverse in terms of species distribution (Fig. 4). With the only exception of pilot whale, all species seem to be influenced by the presence of the canyon system, exploiting the environment at different depths, but concentrating near the canyon's heads.

SPECIES	YEARS																		TOT		TOT
	2000		2001		2002		2003		2004		2005		2006		2007		2008				
	V	A	V	A	V	A	V	A	V	A	V	A	V	A	V	A	V	A	V	A	
Striped dolphin *Stenella coeruleoalba*	15	0	13	1	27	6	15	0	28	2	17	4	30	0	36	4	51	2	232	19	**251**
Common dolphin *Delphinus delphis*	6	0	7	0	2	0	7	0	9	0	4	0	5	0	1	0	4	0	45	0	**45**
Bottlenose dolphin *Tursiops truncatus*	1	0	0	0	1	0	4	0	2	0	3	0	0	0	3	0	2	0	16	0	**16**
Risso's dolphin *Grampus griseus*	4	0	0	0	0	0	0	0	1	0	3	1	1	0	1	0	6	1	16	2	**18**
Pilot whale *Globicephala melas*	2	0	1	0	3	0	4	1	0	0	0	1	2	0	0	1	0	1	12	4	**16**
Sperm whale *Physeter macrocephalus*	1	0	0	2	2	3	3	1	5	9	10	8	9	3	6	3	15	1	51	30	**81**
Fin whale *Balaenoptera physalus*	0	0	0	0	3	0	0	0	1	0	1	0	0	0	2	0	8	0	15	0	**15**
Unidentified species	0	0	0	5	0	7	0	22	0	25	2	38	2	24	3	28	3	24	10	173	**183**
TOTAL	29	0	21	8	38	16	33	24	46	36	40	52	49	27	52	36	89	29	397	228	**625**

Tab. 2:
Total number of visual cetacean sightings (V) and acoustic detection (A) during the period 2000-2008.

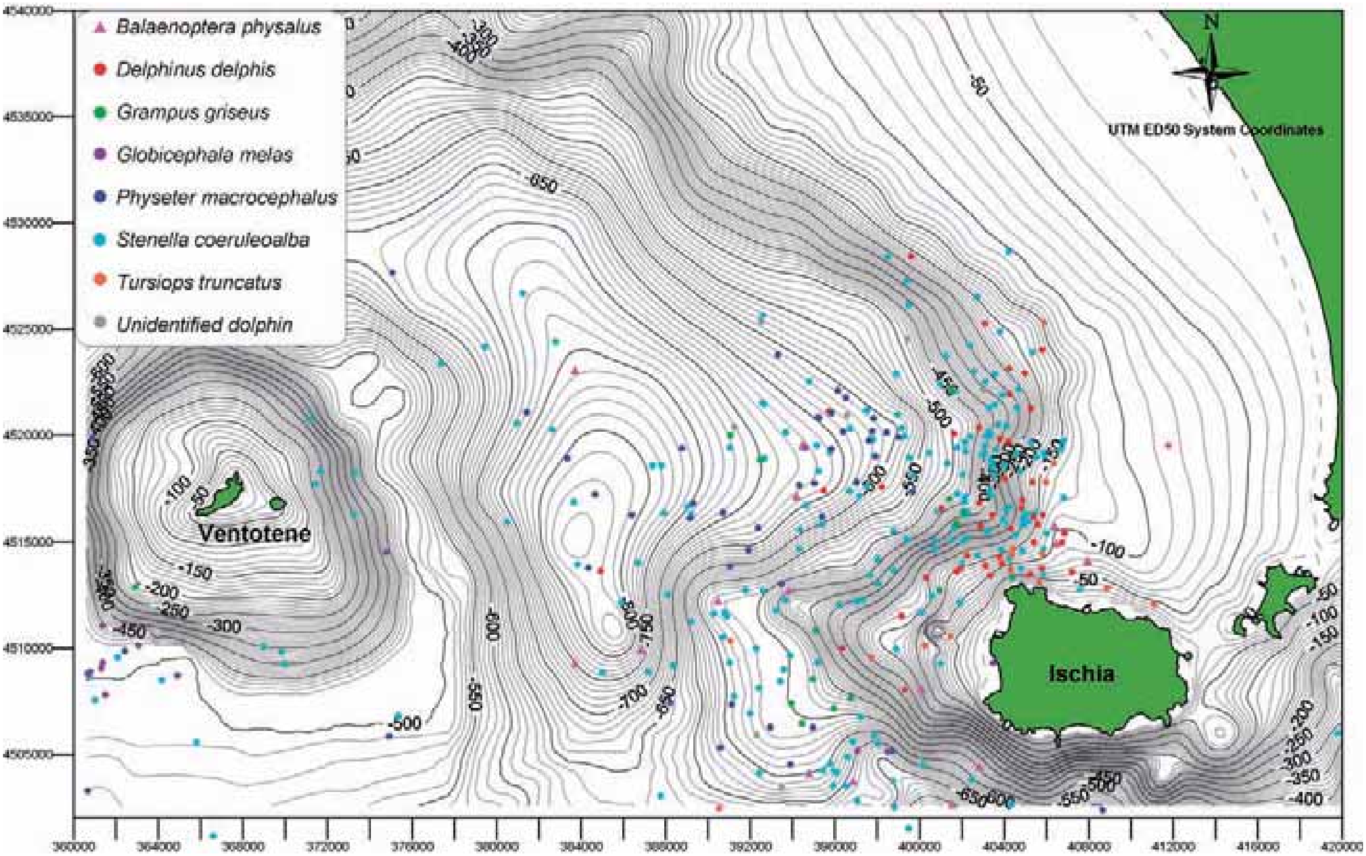

Fig. 4:
Cetacean visual sightings during the period 2000-2008.

Striped dolphin was spread over a wide region and used both neritic and pelagic environments (Fig. 5). Despite this opportunistic range, *Stenella coeruleoalba* seems to converge and concentrate in the same area as *Delphinus delphis* (Fig. 6), with a relevant overlap in their distribution. However, both species tended to prefer high slopes.

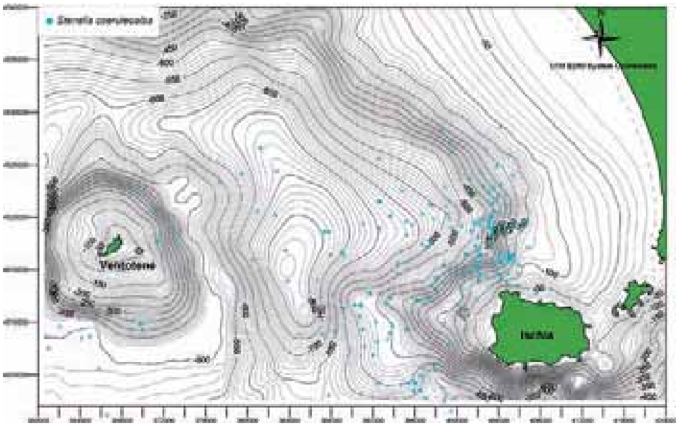

Fig. 5:
Striped dolphin encounters during the period 2000-2008.

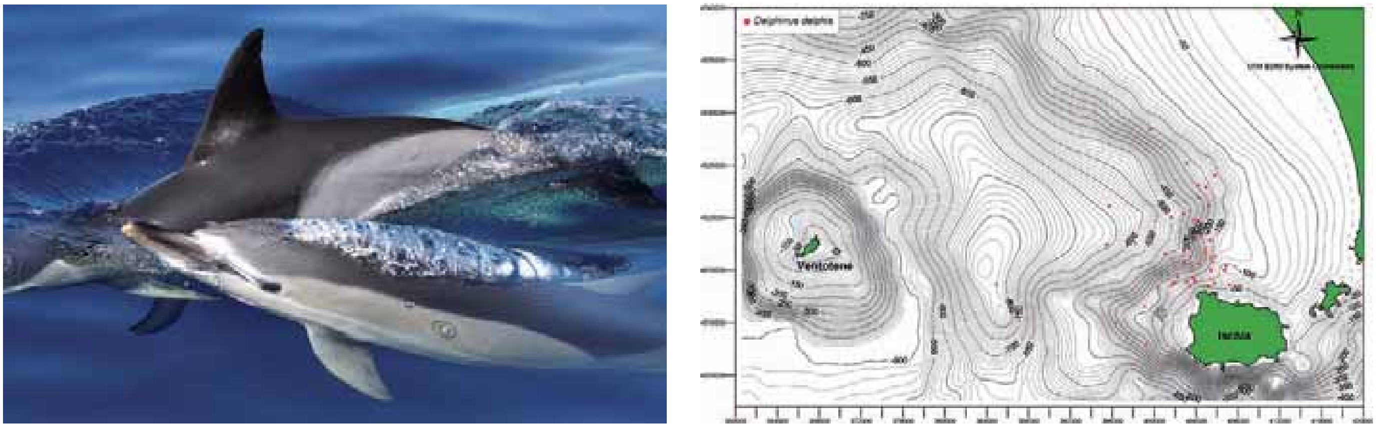

Fig. 6:
Common dolphin encounters during the period 2000-2008.

Common dolphins were principally located north of Ischia Island (Fig. 6), in the region corresponding to the heads of Cuma's and Punta Cornacchia's canyon, within a wide range of depth (55-450 m), preferring to spend most of their time where the bottom is irregular and with middle-high slope.

Bottlenose dolphins (Fig. 7) were mostly sighted in coastal waters, at a depth of less than 100 m; however, there were few observations of the species in deeper waters, far from shore sites, clearly related to the canyons system.

Apart from one peculiar sighting, Risso's dolphins were observed within a range of 300-750 m in depth, alongside two preferential areas located north-west (corresponding to the canyons' head) and west of Ischia Island (Fig. 8).

Pilot whale was the only species found outside the Cuma's canyon system (Fig. 9). Its favourite region was located south-west of Ventotene Island, at a depth of over 400 m.

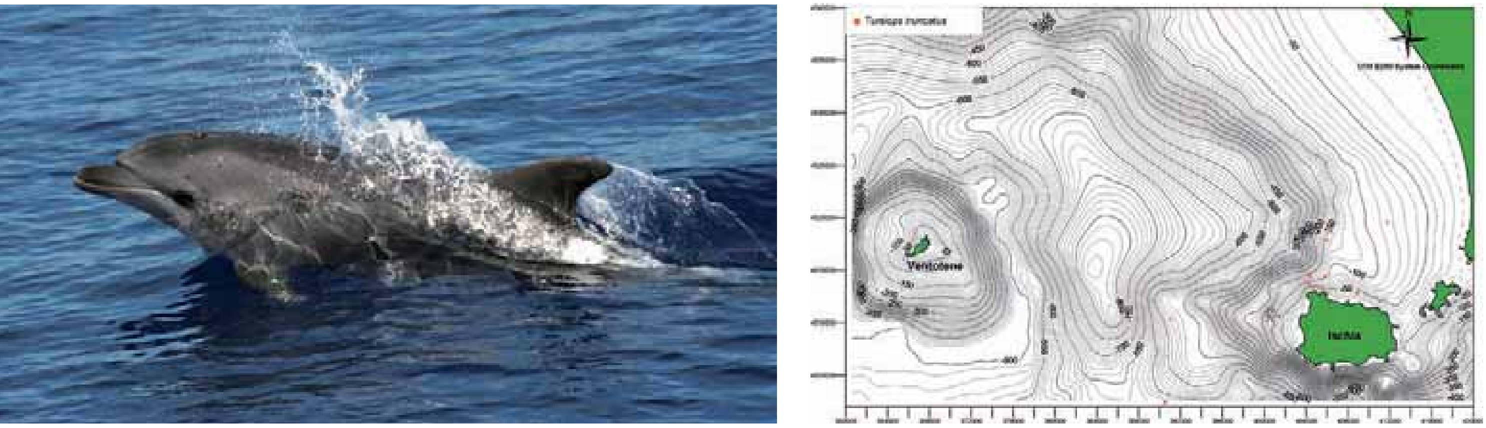

Fig. 7:
Bottlenose dolphin encounters during the period 2000-2008.

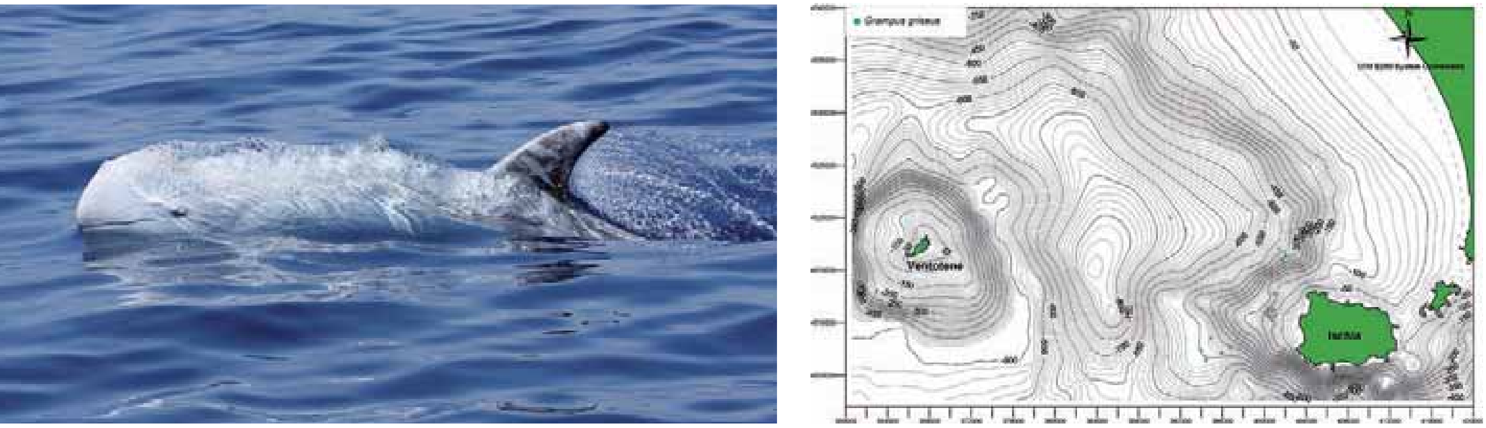

Fig. 8:
Risso's dolphin encounters during the period 2000-2008.

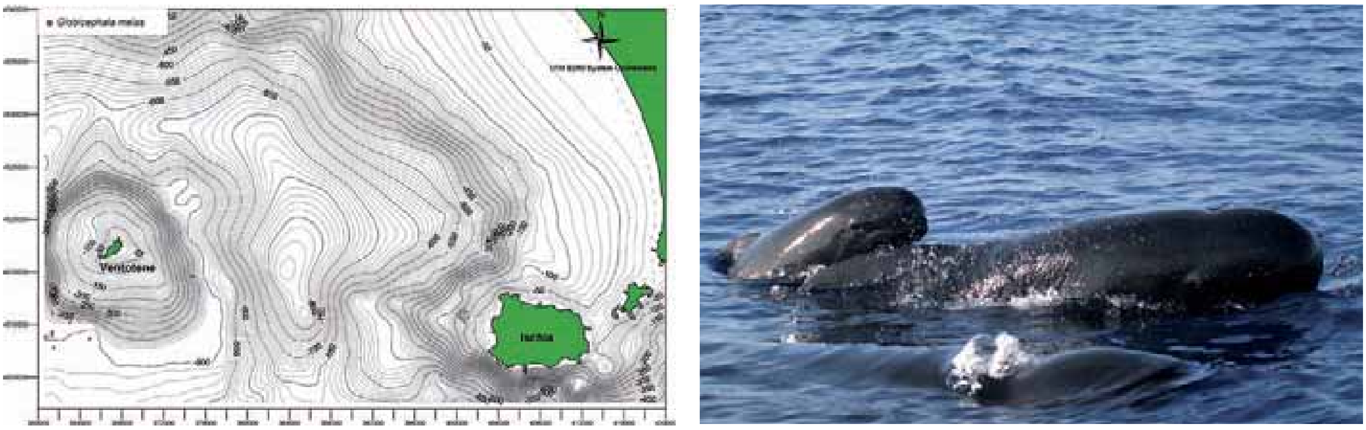

Fig. 9:
Pilot whale encounters during the period 2000-2008.

Sperm whales were principally observed north-west of Ischia Island, in the region corresponding to the deepest parts of Cuma's and Punta Cornacchia's canyons, between 500-800 bathymetric lines (Fig. 10). However, the species was also sighted in the western part of the island and in the large deep valley between Ventotene and Ischia.

Finally, fin whales were located in a wider area, alongside both coastal (within 100 m in depth) and pelagic sites (between 500 and 750 bathymetric lines) (Fig. 11). The relationship with the canyons system seems to be less strong than for other species; however, a certain degree of association is recognizable in the north-west and south-west sighting areas.

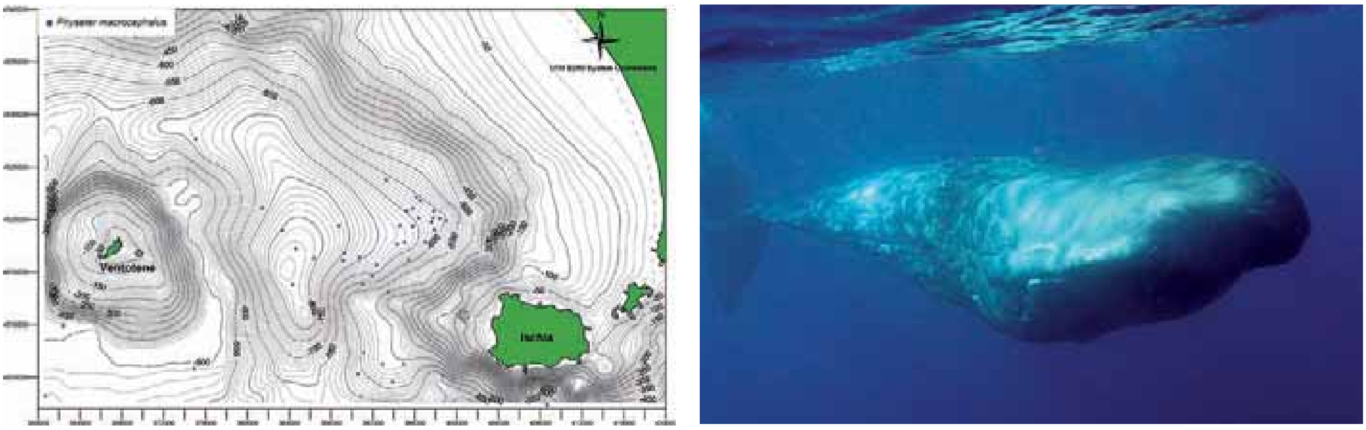

Fig. 10:
Sperm whale encounters during the period 2000-2008.

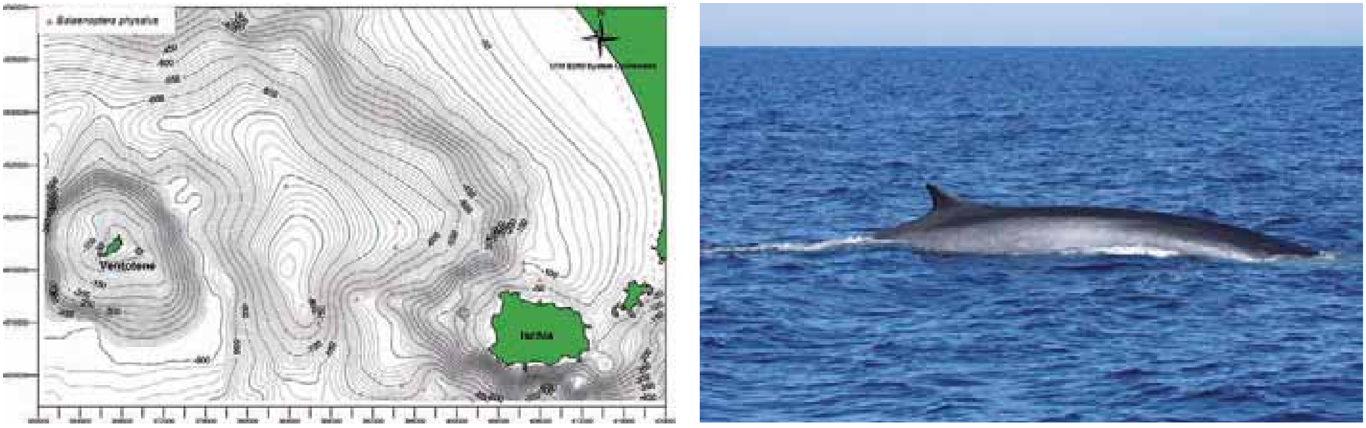

Fig. 11:
Fin whale encounters during the period 2000-2008.

Stenella coeruleoalba: mother and calf pair.

GENERAL COMMENTS

The continental shelf in the study area is characterized by complex bathymetries, including a submarine canyons system, a deep basin between Ischia and Ventotene, and some shallow banks. It is well-known that any environmental, oceanographic and anthropogenic factors play key roles influencing the occurrence and distribution of cetacean species in a complex way. Here, the topography of the Cuma's submarine canyon system seems to induce phenomena that support elevated cetacean diversity and abundance compared to surrounding waters, as observed in "The Gully" (eastern Canada; Hooker *et al.* 1999).

Furthermore, in this case study we have shown how bathymetric characteristics may be useful in understanding the distribution of cetaceans. In theory, bathymetric features may provide a means of predicting important foraging habitats for upper trophic-level marine predators like cetaceans. This study and many others have demonstrated that submarine canyons, and complex and steep topographies are important to cetaceans, possibly as centres of trophic transfer. While we have yet to investigate the mechanisms of predator aggregation, these habitats are likely to be associated with elevated marine productivity and prey retention, thereby making dense prey patches available to predators.

Cetacean distribution in the study area seems to be stratified according to environmental characteristics; bottlenose dolphins concentrate in relatively shallow waters, whereas the others mainly stay close to the canyon heads where upwelling is maximized, or further offshore. Furthermore, the different species display relatively persistent bathymetric associations with the Cuma's canyon system through time. While this static bathymetric characteristic does not change temporally, the distribution of top-predators and their prey may vary seasonally and interannually, due to the influence of hydrographic processes linked or unlinked to bathymetry. Therefore, assessing species distributions in relation to both bathymetric and hydrographic habitats is essential to obtain a more complete understanding of the dispersion of upper-trophic marine predators and the nature and location of habitat ''hotspots''. Nonetheless, the wildlife–habitat associations documented in this study have important implications for conservation and management.

Providing the local Authorities with the information deriving from research and monitoring activities, we were able to intervene on the design of the perimeter of the coastal Marine Protected Area "Regno di Nettuno", so as to include a pelagic Zone D specifically devoted to the protection of the critical habitat of common dolphin. Furthermore, in order to protect the whole canyon system within a SCI (Site of Community Importance) and also cover the critical habitat of the sperm whale, we are promoting a coordinated effort with the Italian Ministry of Environment and the Italian Marine Biology Society.

Stenella coeruleoalba: porpoising event near the coast of Ischia.

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3.4. Mediterranean submarine canyons as stepping stones for pelagic top predators: the case of sperm whale

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INTRODUCTION

Submarine canyons have long been considered important areas for marine life supporting abundant and unique communities of megafauna, sometimes including species not observed in other environments. These emerged valleys are becoming increasingly recognised as recurrent sources of enhanced productivity (Allen *et al.*, 2001; Genin, 2004) and habitat heterogeneity. Indeed, they provide an important habitat for various life stages of benthic and demersal fishes and invertebrates along continental margins (Demestre and Martìn, 1993; Stefanescu *et al.*, 1994). These physiographic features may also serve as "keystone structures" and aggregation areas for top predators like tuna, sharks and marine mammals.

The bottom topography of the north-western Mediterranean Sea is not a uniform flat environment. It is characterized by the presence of certain geomorphologic features such as seamounts, and is incised for the most part by several submarine canyons. These deep incised valleys occupy nearly 50% of the continental slope (Gili *et al.*, 2000). This area constitutes one of the pools of the greatest diversity and highest production (Franqueville, 1971; Andersen *et al.*, 2001), stimulating the regular presence of eight cetacean species (Notabartolo di Sciara, 2002). The aggregation of various teutophageous, planktophageous and ichtyophageous cetaceans may reveal the high productivity of this area.

SPERM WHALE DISTRIBUTION RELATED TO SEA BOTTOM MORPHOLOGY WITHIN THE PELAGOS SANCTUARY

Several studies have attempted to correlate cetacean distribution to geomorphologic features in the Mediterranean Sea (Gannier, 1998; Cañadas *et al.*, 2002; Azzellino *et al.*, 2008; Aïssi *et al.*, 2008; Moulins *et al.*, 2008). It seems that as well as depth and slope, submarine canyons exert an important influence on cetacean distribution, even if the degree of this correlation largely depends on hydrological, topographical and biological contexts at local scale. For example, in the Ligurian sea, it has been confirmed that habitat selection by Cuvier's beaked whale strongly depends on the presence of a trough surrounded by steep slopes at the mouth of submarine canyons (Moulins *et al.*, 2007) and the Genoa canyons are described as specific attractive areas and overlap hotspot ecosystems for striped dolphin, Risso's dolphin and sperm whales (Moulins *et al.*, 2008).

Recent studies have been conducted in the Pelagos Sanctuary using a wide range of spatial and temporal scales to try to elucidate the relationship between preferred habitats of sperm whales and specific physiographic features. This area encompasses an aggregation of seamounts located in the south-eastern part and successive submarine canyons. This part of the Mediterranean is considered as the most densely canyoned margin segment in the entire basin. Of the most important and prominent canyons considered, we refer to the Genoa and Imperia canyons in the northern part of the Ligurian Sea. The others were relatively smaller and located north and west of the Island of Corsica, such as the Saint Florent, Porto, Sagone and Ajaccio canyons (Fig. 2).

Visual and acoustic surveys were carried out over three consecutive years (2009-2011) focusing on this largest toothed whale in the Pelagos Sanctuary. Observations have been reported throughout the area. However, the target species does not appear to be homogeneously distributed. Sightings occurred over a large bottom depth range, with a tendency to increase on the continental slope and the abyssal plain. The distribution of the depth data appeared to be bimodal, with one marked peak of sightings in waters around 1000 ±250 m deep, and a majority of sightings in waters around 2000 ±250 m deep. (Fig. 3).

Fig. 1:
Diving sperm whale. Imperia canyon, 18th May 2011. ISHMAEL Project. © Maurizio Würtz – Artescienza s.a.s.

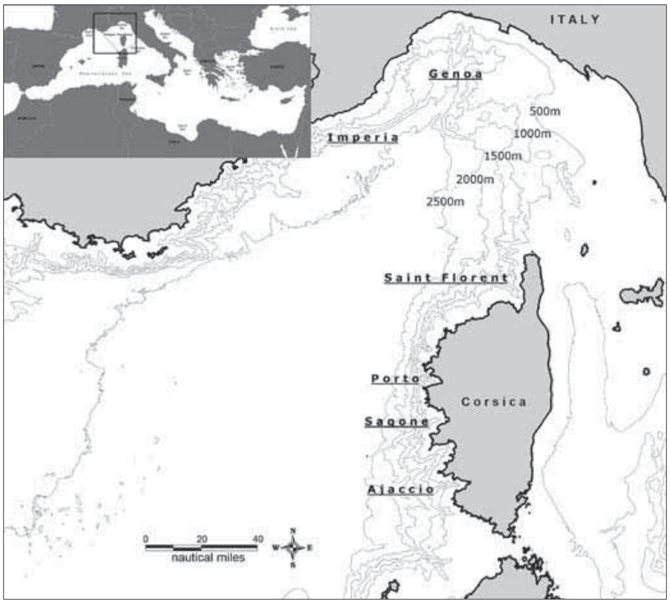

Fig. 2:
Map of the Mediterranean Sea and approximate position of submarine canyons monitored during sperm whale surveys (mentioned in the text) inside the Pelagos Sanctuary with gradual increasing of bathymetry each 500m.

The spatial distribution of sperm whales was reflected in three dissimilar morphological regions: submarine canyons (region 1), inter-canyons (region 2) and seamount areas (region 3). In the survey effort spread along the whole study area, the survey division within the three regions was relatively homogeneous. A relevant distinction of encounter rates was registered between these three zones characterized by different topography. Sightings were greater in region 1 (n=63/113), to a lesser extent in region 2 (n=41/113), and even lower in region 3 (n=9/113). Thus, a marked preference for the canyon area has been evidenced by sighting frequency (56%). Sperm whales seemed to favour in particular the submarine canyon habitat, which appeared in ranked order as the major influent, rather than inter-canyons (36%) or seamounts (8%) (Fig. 4).

This tendency was supported by several dedicated observations and the frequent use of submarine canyons has been previously reported in the Mediterranean Sea (Gannier and Praca, 2007; David, 2000). Preferential use of submarine canyons has also been suggested in other regions of the globe: in the Gully region off the Nova Scotia shelf (Whitehead *et al.*, 1992), in the Mississippi Canyon in the Gulf of Mexico (Davis *et al.*, 1998), the Kaikoura Canyon on the east coast of New Zealand (Larivière, 2001) and in the north-east United States (Waring *et al.*, 2001).

The canyons generally open on the continental shelf, at around 100 to 200 m depth and extend down to the abyssal plain, over 2000 m deep. The head of the canyon was delimited by the 200 m contours and the canyon mouth by the 2000m isobaths. In order to evaluate the variability of distribution of sperm whales and to investigate their affinity within the canyon structure, this area was split initially into three classes: head (200-500m deep), middle (500-1000m deep) and mouth (more than 1000m deep). Sightings were located for the most part at the opening of submarine canyons and

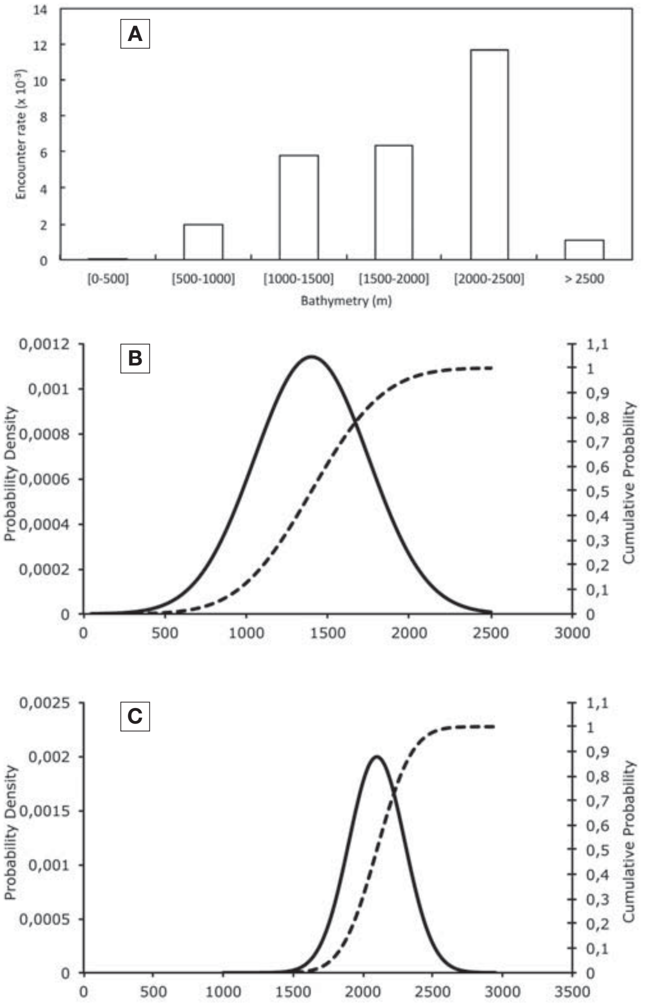

Fig. 3: Sperm whale occurrences inside the Pelagos Sanctuary related to depth parameter (A), revealing the bimodal distribution in waters of 1400 m (B) and 2000 m deep (C), fitted as Gaussian curves (continuous line) resulting from the Bhattacharya test and their cumulative probability (dotted line).

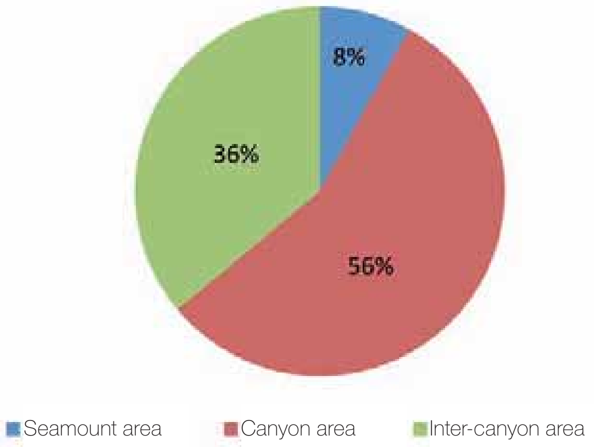

Fig. 4:

Cumulative percentage of sperm whale occurrence in areas with different physiographic features (canyon, inter-canyon and seamount areas).

their opposite extremity. The encounter rate was assessed in each class, and appeared to increase particularly in the outer canyon. Thus, the spatial distribution of sperm whales highlights habitat suitability in the deep area of submarine canyons.

To delineate the characteristics and spatial distributions in relation to canyon morphology, a new split related to the middle axe of the canyon was applied leading to segregation in the eastern and western parts of canyons. The spatial distribution of sperm whales appears to concentrate mainly in the western part of canyons. In particular, the pattern of distribution of this species is associated with the steep and complex topography of these emerged valleys. Indeed, submarine canyons studied in this area are characterised by a relatively gentle slope (mean slope 80 m/Km) in their upper heads located close to the shore. However, a steep slope (mean slope 180 m/Km) extends far over the abyssal plain of these valleys on the sea floor.

CONCLUDING REMARKS

Sperm whale distribution in the Pelagos Sanctuary seems to be influenced mainly by the structure of submarine canyons which affects hydrological and biological phenomena. Certainly, the steep topography of submarine canyons induces upwelling that supports elevated cetacean diversity and abundance compared to surrounding waters (e.g. The Gully in eastern Canada; Hooker *et al.* 1999). The bottom relief modifies currents, leading to the concentration of organisms. Hydrological features, including eddies and topographically-induced upwellings, generate fronts and bring nutrients, which in turn increase primary productivity and the aggregation of zooplankton from enhanced secondary production. Internal waves, which are produced by complex and steep topography, can also lead to the concentration of prey species.

Submarine canyons can strongly modify flow, shelf-slope exchanges of water and material (Hickey, 1995; Perenne *et al.*, 2001) and this coupling can aid the transport of particulate organic matter that influences productivity. Submarine canyons can also act as funnels for water upwelling from deeper oceanic levels to shallower shelf regions, providing nutrient inputs to the marine ecosystem (Flaherty, 1999) and enhancing productivity.

The sperm whale diet includes a large variety of food items, but consists primarily of mesopelagic and bathypelagic cephalopods (Clarke, 1980; Kawakami, 1980). It has therefore been impossible to directly relate sperm whale distribution to the distribution of their prey because methods of effectively sampling these deep-living squid have not yet been developed (Clarke, 1987). Many papers report evidence that cetaceans occupy the continental slope, especially the part of submarine canyons that cut into the slope. Steep slopes and submarine canyons play an important role in influencing the water patterns in and around the surrounding area because of their size and the area they occupy (Hickey, 1995).

Physical processes in submarine canyons have received much attention (Shepard *et al.*, 1974; Freeland and Denman, 1982; Noble and Butman, 1989; Breaker and Broenkow, 1994; Alvarez and Tintore, 1996), but studies on the ecological processes of canyons are still limited. The refuge role of submarine canyons may be especially important for protecting top predators in general, and cetacean populations in particular, from extirpation in ecological cul-de-sacs.

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3.5. Canyon heads in the French Mediterranean Overview of results from the MEDSEACAN and CORSEACAN campaigns (2008-2010)

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France

INTRODUCTION

Sporadic observations made almost fifty years ago by small submarines “*diving saucers*”, and more recently by ROV, provide only very limited enlightenment on the *a priori* important biodiversity and vulnerability of canyon heads lying off the French coasts in the Mediterranean. A study of available data on these zones has so far demonstrated a crucial lack of reliable and sufficiently extensive information between depths of 50 and 600 m, especially with a view to implementing international conventions to which France adheres (the Barcelona convention, for example), European regulations with extension of the off-shore Natura 2000 sites, and to defining the perimeters of new marine protected areas and developing their management plans.

The MEDSEACAN and CORSEACAN data acquisition campaigns were organized between 2008 and 2010 from the Spanish border to the frontier with Monaco, and off the western coast of Corsica, to remedy this lack of information and obtain a reference record of the ecosystems concerned and the pressures to which they may be subjected.

At the time of this publication, their results are still being processed. They do, however, already reveal contrasting ecosystemic situations on the one hand and, on the other hand, while Corsican canyons seem to be relatively spared, a clearly visible anthropogenic impact on "continental" sites.

ROLE OF THE GULF OF LION CANYONS IN THE WESTERN MEDITERRANEAN DEEP WATER FORMATION

The shelf and slope of the Gulf of Lion in the north-western Mediterranean Sea are deeply incised by all three submarine canyon types identified by Harris and Whiteway (2011), spaced less than 10 km apart: these canyons extend from 100-150 m depth to 1500-2000 bottoms and make the Gulf of Lion one of the most dense “canyoned” zones in the world oceans (Fig. 1).

From the French-Spanish border to Cassis, at least 16 main canyons can be identified: Lacaze-Duthiers, Pruvot, Bourcart (Aude), L’Hérault, Sète, Catherine-Laurence, Marti, Montpellier, Aigues-mortes, Petit Rhône, Grand Rhône, Estaque, Marseille, Couronne, Planier and Cassidaigne. These canyons are mainly located far from the coast due to the offshore extension of the Gulf of Lion shelf (up to 70 km from the coast); with this particular feature, they form part of a larger canyon functional system, which is also constituted by canyons off the Catalan coast to the west and Liguria-Provence canyons to the east, both characterized by very reduced shelves and steep slopes.

The deep western Mediterranean has long been viewed as a steady system. The constant trend towards higher salinity and temperature, observed since the ‘50s, and its recent acceleration has shown that the system's variability is not simply confined to

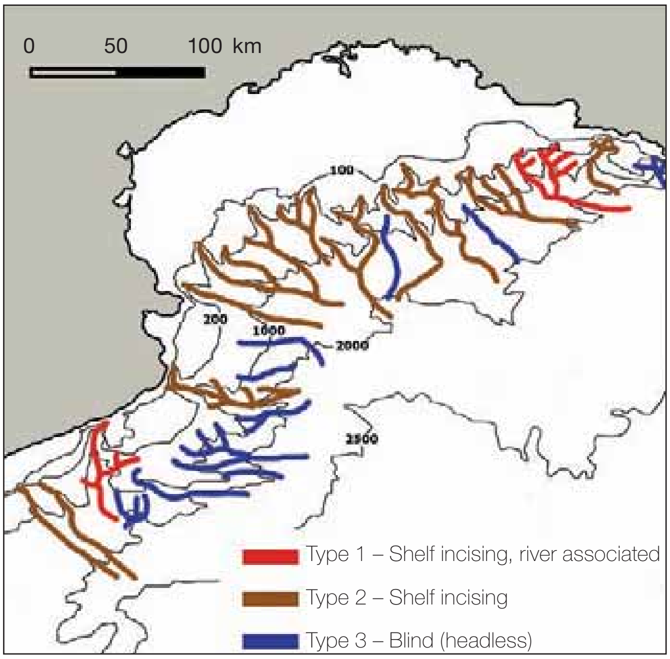

Fig. 1:
Types of submarine canyons in the Gulf of Lion (modified from Harris and Whiteway, 2011).

the upper layers, but also involves deep waters (Schroeder *et al.*, 2009). Massive convection events are responsible for new deep water formation occurring in restricted regions of the World Ocean: the Gulf of Lion is one of these regions where this very peculiar phenomenon irregularly takes places, due to the cooling and evaporation of offshore surface waters by cold north-westerly winds (Tramontane and Mistral) during winter (Gascard, 2009).

While Ligurian Sea and eastern Catalan sub-basins are shallow deepening water areas, deep convection occurs in the south-central zone of the Gulf of Lion at depths under 500 m, within a quasi-circular area of about 234 km in diameter. Thus, convection is much deeper in the Gulf of Lion and its location, maximum depth, duration and formation rate of convection vary inter-annually and can reach the sea bottom (as in the winter of 2005) or constitute intermediate layers (as in the winters of 1999, 2006, 2008 and 2010), whereas no deep waters were formed from 2000 to 2004, in 2007 or 2009 (Bryden, 2009; Gascard, 2009).

From the Gulf of Lion, deep water flow spreads following a cyclonic circulation pattern, firstly southward along the eastern coast of the island of Menorca, then splitting into two veins, the first flowing towards Gibraltar along the southern Balearic shelf, the second turning north-eastward, interacting with Levantine Intermediate Water (LIW) and creating mesoscale eddies and gyres, which re-circulate the flow towards the Gulf of Lion and the northern periphery of the western Algerian Gyre. The deep water spreading from the Gulf of Lion in the western Mediterranean has been estimated to take about one or two years and is mainly driven by the mesoscale dynamic similar to Algerian and Sardinian eddies (Béranger *et al.*, 2009).

Even if the deep water formation in the western Mediterranean sub-basin has always been assumed to be more efficiently achieved by offshore convection than concurrent cascading (van Haren and Millot, 2009), recent research has led to a re-evaluation of the effects of cooling and evaporation on the coastal surface waters over the wide shelf of the Gulf of Lion, which become denser and cascade downslope, carrying large quantities of particles in suspension.

As a climate-driven phenomenon, the dense shelf water cascades in the Gulf of Lion have major effects during severe winters and a direct impact on the thermohaline properties of the western Mediterranean deep water: they spread a thick and persistent bottom layer containing significant amounts of suspended sediment throughout the entire western basin (Fig. 2), called the *nepheloid layer* (Puig *et al.*, 2009). The Rhône River is the major source of freshwater and sediment to the Gulf of Lion and accounts for 3-14% of overall organic carbon and 10-12% of total inorganic carbon river inputs to the Mediterranean Sea (Stemmann and Pujo-Pay, 2010). Sediment transported from the shelf to the deeper bottoms is then funnelled and accelerated by the high number of submarine canyons, which characterizes the Gulf of Lion margin (Canals *et al.*, 2009).

Vertical and horizontal transport of organic-carbon rich water-masses also fuel deep nanoplankton and microplankton respiration. At the same depths, metabolic rates have been found to be higher in the western Mediterranean than in the Atlantic and equatorial Pacific Oceans: these higher rates are not consistent with organic matter supply via rapid sinking, but are explained by dissolved organic carbon (DOC) being transported to the depths by eddies, deepwater convection and cold-water cascading during winter. Respiration in the deep-sea is an important factor affecting food chains and variations in fisheries yield; moreover, it helps to sequester the CO2 in the deep water by converting DOC and particulate organic carbon (POC), originally produced in the surface waters. Since the Mediterranean Deep Water residence time is about 22 years, this injected CO_2 is effectively removed from the atmosphere for this time period (Packard *et al.*, 2009).

Thus, thanks to the combined effect of circulation, transport, convection and cascades mediated and enhanced by canyons, the Gulf of Lion is one of the most productive zones in the entire Mediterranean Sea.

MEDSEACAN CAMPAIGNS

MEDSEASCAN is a data acquisition campaign launched by the Agency for marine protected areas between autumn 2008 and spring 2010, carried out by several scientific teams (Ifremer, EPHE, CNRS, Marine Science Institution of Barcelona, Universities of Perpignan, Marseille and Nice, Oceanological Observatories of Villefranche-sur-Mer and Banyuls/Mer – Paris VI University).

For the first time, Mediterranean canyons off the French coast became the subject of a systematic reconnaissance campaign. In order to compare the canyon heads, the exploration effort was shared out homogeneously, with about ten days' work on each of the 13 boxes within a pre-defined sampling grid (Fig. 3). In each of these boxes and during the successive phases of the campaign, exploration of the sides of the canyons was carried out using the same method, the same technical resources, implemented by the same scientific and technical teams. Description of the sites was primarily based on data acquisition in the form of images (photos, video) taken from underwater veicles, either manned or remote-controlled (ROV).

Species of megafauna were identified visually, relying where possible on samples taken throughout the campaign.

From the Spanish border to the frontier with Monaco, about 20 sites were thus explored on this mission totalling almost 100 days, with 200 dives to depths of 50 to 800 m undertaken either by submarine or ROV. Almost 14,800 photos, 390 hours of video and dozens of samples were taken in real time by observations made by the scientists on board (Fig. 4).

Sites explored in the Gulf of Lion, from west to east:

Box 1 : Lacaze-Duthiers, Pruvost and Bourcart.

Box 2 : Marti and Sète.

Box 3 : Montpellier, Petit Rhône, Grand Rhône.

Box 4 : Planier and Couronne.

Box 5 : Cassidaigne and (unnamed, off the Embiez islands).

Canyons explored off the Liguro-Provence coast between Cassidaigne and the Italian border, also from west to east) :

Box 6 : Sicié, Toulon, Porquerolles.

Box 7 : Pampelonne.

Box 8 : Saint-Tropez, Drammont, Cannes.

Box 9 : Nice (Var).

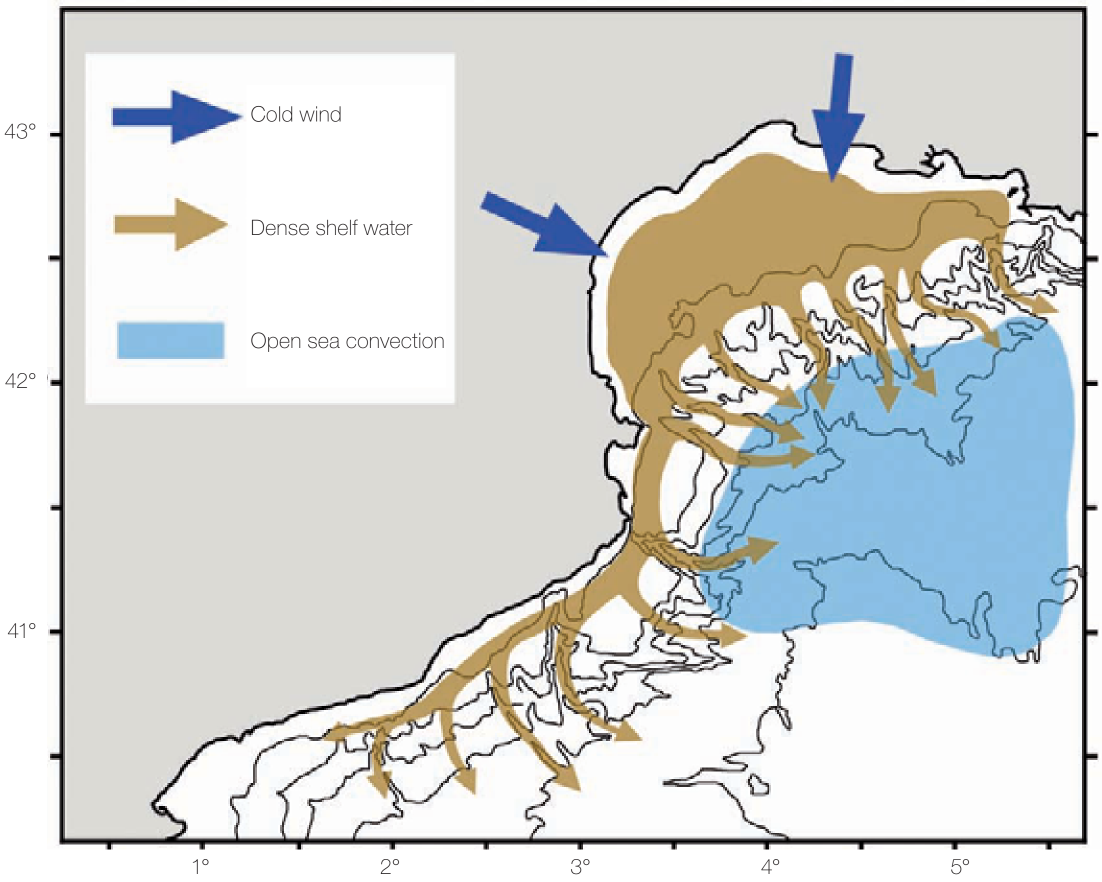

Fig. 2:

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 (modified from Puig *et al.*, 2009).

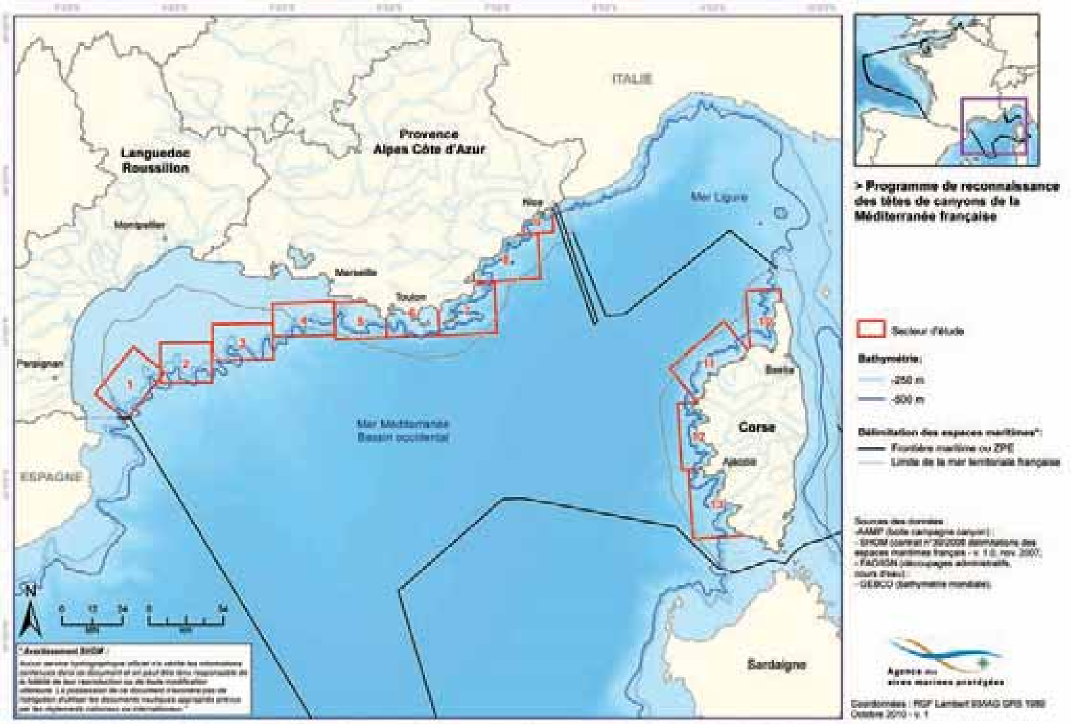

Fig. 3:

Subdivision of the zone covered by the MEDSEACAN and CORSEACAN data acquisition campaigns, in 13 boxes: 9 for the continental area, 4 for the western coast of Corsica.

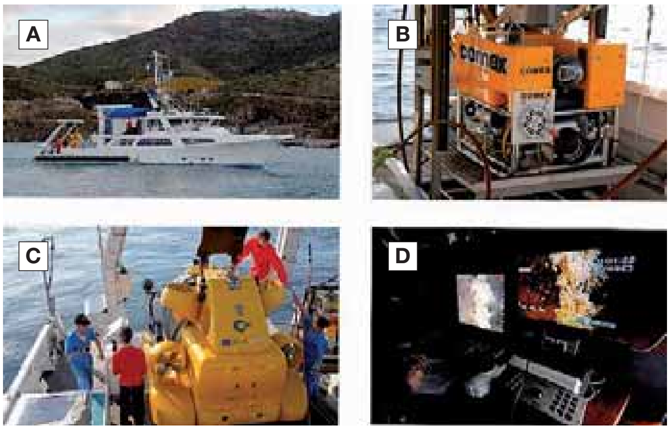

Fig. 4:

Technical resources used:
(a) 30 m oceanographic MINIBEX vessel, (b) Achille ROV,
(c) REMMOA submersible,
(d) scientific PC for direct study of the images received.

Fig. 5:

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

Lacaze-Duthiers canyons

The Lacaze-Duthiers canyon (Fig. 3, box 1) contains exceptional biodiversity and thus differs from canyons to the east, very silted up and exhibiting a gentler morphology.

In these canyons, one finds a vagile biodiversity typical of muddy bottoms (shrimp, Norway lobster *(Nephrops norvegicus),* hake *(Merluccius merluccius)*, grenadier (Macruridae), greater forkbeard *(Phycis blennoides),* blackmouth catshark *(Galeus melastomus),* small-spotted catshark *(Scyliorhinus canicula),* octopus, cuttlefish, anemone, comatula), with few sessile species. Chimaera (*Chimaera monstrosa*, considered as a quasi-threatened species by the IUCN in the Mediterranean) were more frequently observed in the Petit Rhône canyon (Fig. 3, box 3) than in the others. This canyon also contains hake of a larger size than elsewhere, a large number of bivalves and an interesting succession of facies. Few blocks of rock, but debris of *Dendrophyllia cornigera*, sometimes in considerable quantities, drawing varied sponges, hydroids and small sea fans.

Off Banyuls-sur-Mer, narrow and sinuous, with sides often steep with many rocky cliffs, this canyon lies at the far west of the Gulf of Lion.

About 50 years ago, thanks to the first dives performed with Cousteau's SP 300 diving saucer, cold coral colonies were observed on a cliff at a depth of 230 m (Petit and Lazubier, 1962 ; Reyss, 1964). They consisted of *Madrepora oculata* combined with yellow coral (*Dendrophyllia cornigera*). Fragments of *Lophelia pertusa* had been dragged to deeper levels. In 2008-2009, several campaigns revealed other locations of *Madrepora oculata* and the presence of living colonies of *Lophelia pertusa*. The MEDSEACAN campaign notably furnished evidence of large colonies of this white coral (of metric size), never before observed in the Mediterranean.

The Lacaze-Duthiers canyon can claim exceptional biodiversity for this type of deep water environment. Its coral reefs are associated with the development of a fauna rich in sessile invertebrates, including in particular other species of cold corals (*Dendrophyllia cornigera*, *Desmophyllum cristagalli*), brachiopods (*Gryphus vitreus*) and deep sea oysters (*Neopycnodonte cochlear*).

The corals found in this canyon (*Desmophyllum cristagalli*, *Madrepora oculata*, *Lophelia pertusa* and *Dendrophyllia cornigera*) are remarkable species (Fig. 5), which are protected in France. *Lophelia pertusa* is listed in the CITES convention (Appendix II).

Of the 50 or so species observed, 13 are either on the lists or in the appendices of European directives. Fourteen others are designated as species of commercial interest.

Compared to other canyons in the western Mediterranean, this richness seems to be closely related to the existence of multi-year phenomena of dense coastal cascading, responsible for massive replenishment of fresh organic matter to this deep-sea environment.

The richness of this environment is also demonstrated by the presence of top predators, birds and marine mammals observed on the surface. Among them, two species of cetaceans come under the European Habitats directive and the Barcelona convention. For the eleven species of birds observed, three come under the Habitats directive and nine are on the list of protected species in France.

Observations made during MEDSEACAN in the Lacaze-Duthiers canyon and its two neighbouring canyons (to the east) led to their being included in the perimeter of the Marine Nature Park of the Gulf of Lion (Fig. 6). The decree to that effect was signed on October 11, 2011.

Planier and Couronne canyons

While the silted Couronne canyon (Fig. 3, box 4) offers no particular interest, that of Le Planier (idem) seems more heterogeneous, with a left side consisting of silt and a right side presenting silted rock with cliffs, overhangs and grottoes. It contains large oysters (possibly *Neopycnodonte zibrowii*, to be confirmed), rare in the Mediterranean, several species of antipatharia, large *Callogorgia verticillata* and numerous sponges. Also worth noting, an encounter with a six-gill shark (*Hexanchus griseus*, a species considered as quasi-threatened by the IUCN) over 3 m long, and an Atlantic wreckfish (*Polyprion americanus*), a species whose biology is still poorly understood.

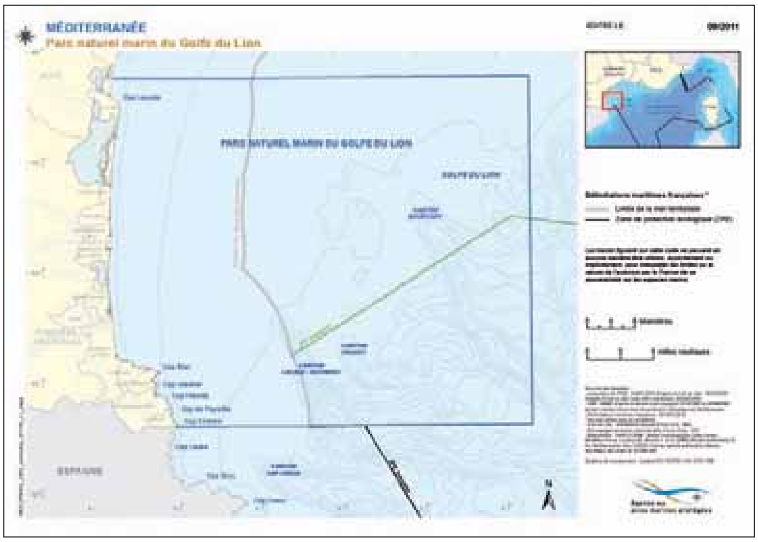

Fig. 6:
Perimeter of the Marine Nature Park of the Gulf of Lion.

Cassidaigne canyon

The Cassidaigne canyon (Fig. 3, box 5) has steep sides with numerous vertical cliffs. It descends very rapidly to a depth of 1000 m. Its biodiversity is largely heterogeneous, though exploration of a promontory on its right side, to a depth of 220 m, revealed exuberant sessile fauna with numerous anthozoarians and spongarians. Such diversity of anthozoans (*Madrepora oculata*, *Corallum rubrum*, *Dendrophyllia cornigera*, *Paramuricea calvata*, *Eunicella cavolini*, and several antipatharians) (Figs. 7 and 8) was never observed in any other canyon throughout the entire campaign. Also worth noting, the existence of a bed of the gorgonian *Callogorgia verticillata*, in another site.

This narrow canyon, cut out of the limestone, is located east of the creeks of Marseille, offshore from Cassis. It rapidly attains a depth of 2000 m, high cliffs and numerous overhangs characterize its morphology.

The Cassidaigne canyon has long been the subject of many scientific studies: the first dives were undertaken by Cousteau in the 1950's. Cold corals of the type *Madrepora oculata* were observed in the early 70's. A German research team made deep dives in the spring of 2009 as part of the European HERMES programme. The discarding of residue from bauxite refining (known as "red mud") at a depth of 310 m was the starting-point for studies (particularly observations) to assess its impact on the marine environment. Since 1995, a follow-up procedure, placed under the responsibility of a scientific advisory board, has been in place.

The observations, mostly *ad hoc*, reported since the 70's describe a rich environment with red, white and yellow corals adhering to rocky cliffs in the upper part of the canyon, at depths not exceeding 300 m.

Depending on the zones observed, biodiversity in the Cassidaigne canyon is heterogeneous. On a rocky promontory jutting out on its right side near the canyon head, a considerable number of anthozoarians and spongarians have been observed. Such diversity among anthozoarians in one and the same site was not observed anywhere else during this campaign: white coral (*Madrepora oculata*), red coral (*Corallium rubrum*), gorgonia (*Paramuricea clavata, Eunicella cavolini*), yellow coral (*Dendrophyllia cornigera*), black coral (several species of Antipatharia). A bed of *Callogorgia verticillata* gorgonia, including large specimens, was also observed at the exit from the canyon. Elsewhere, however, biodiversity appears to be much weaker.

The biodiversity observed led to the Cassidaigne canyon head being included within the permimeter of the future "Parc National des Calanques".

Fig. 7:
Madrepora oculata and *Corallium rubrum*, Cassidaigne canyon, 200 m depth.

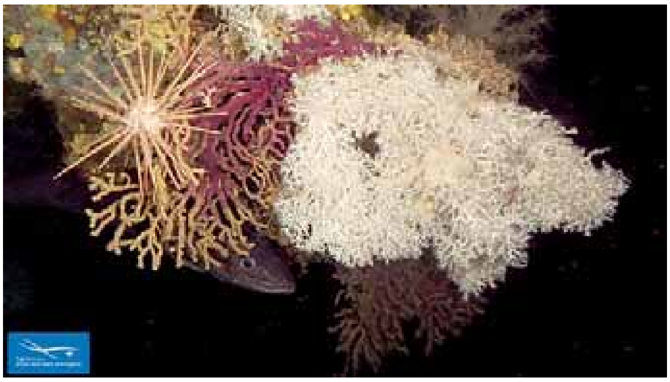

Fig. 8:
Paramuricea clavata, Madrepora oculata and *Conger conger,* Cassidaigne canyon, 200 m depth.

Canyons off the Liguro-Provence coast

Unlike the Gulf of Lion, the continental shelf off the Liguro-Provence coast is very narrow: significant depths are attained very rapidly. The highest density of canyon heads lies between the Saint-Tropez peninsula and Cap d'Antibes (Fig. 3, box 8).

Biodiversity observed in the Sicié canyon (Fig. 3, box 6) is much greater than that in the canyons off Saint-Tropez and the Var where silt clearly predominates, sometimes forming vast undulations. Numerous species of anthozoarians were observed, together with gorgonia such as *Viminella flagellum* and *Bebryce mollis*, red coral *(Corallium rubrum),* yellow coral (*Dendrophyllia cornigera)*, antipatharians and a single occurrence of white coral (*Madrepora oculata*). Average biodiversity was noted for vagile species, with squid, hake *(Merluccius merluccius),* cutlassfish *(Lepidopus caudatus)* and grenadiers (Macruridae). Also worth noting, the presence of large *Neopycnodonte* sp oysters.

Sampling box 7 (Fig. 3) groups together the Pampelonne canyons and the canyon of Les Stoechades. The sea bottoms appear to be very heterogeneous with the presence of silt, sand, boulders and rock in place. The Pampelonne canyon is rather poor between depths of 600 and 200 m. Beyond 200 m, biodiversity is much more prevalent (with fixed communities of invertebrates installed on rock boulders).

Accumulations of posidonia leaves, sometimes forming a thick mat, were observed in the canyons of Porquerolles, Les Stoechades, but above all in that of Toulon. Also worth noting, the existence, in these last two cases, of thanatocoenosis of deep corals (not yet identified) with large-size skeletons

The canyon of Nice (Fig. 3, box 9) presents a wide diversity of substrata and diverse benthic communities (silt, biogenous detritus, deep rock communities...). But overall specific diversity remains poor. Only a few locations manifest wider biodiversity. A very small colony of *Madrepora oculata* was found there.

OBSERVED FISHING AND ANTHROPOGENIC IMPACTS

Many traces of human activities were observed during the dives: accumulations of long lines and all kinds of waste material (plastic, scrap metal, trawling debris...). As Daniel Reyss (1964) has noted, this detritus was not visible on dives he undertook in the Lacaze-Duthiers canyon. They furnish proof of the vulnerability of canyons and the pressures (pollution and overfishing) brought to bear on them by human activities (Lacaze-Duthiers).

Fisheries activity has left many visible traces. Fragments of long lines and nets can be found hanging on rocks in the Cassidaigne and Lacaze-Duthiers canyons. Their dragging movements caused by currents can be a threat for fixed fauna, and for cold corals in particular. The other canyons, wider and silted up, bear many traces of trawling (Fig. 9), attesting to the importance of their halieutic resources and their exploitation. This trawling activity can destroy rare and fragile fauna.

There is much more waste material on the sea bottom in the case of canyons whose heads are near the coast (Lacaze-Duthiers) or large towns (Planier canyon off Marseille). The quantity of detritus is quite low for canyons in the central part of the Gulf of Lion, very far from the coast.

In canyons off the Liguro-Provence coast, detritus (Fig. 10) is extensive and heterogeneous, though plastic is predominant. A considerable amount of diverse war-related material was observed in the Saint-Tropez and Toulon canyons.

Often narrow, these canyons are not subjected to trawling, though numerous examples of debris such as long lines and nets have been observed.

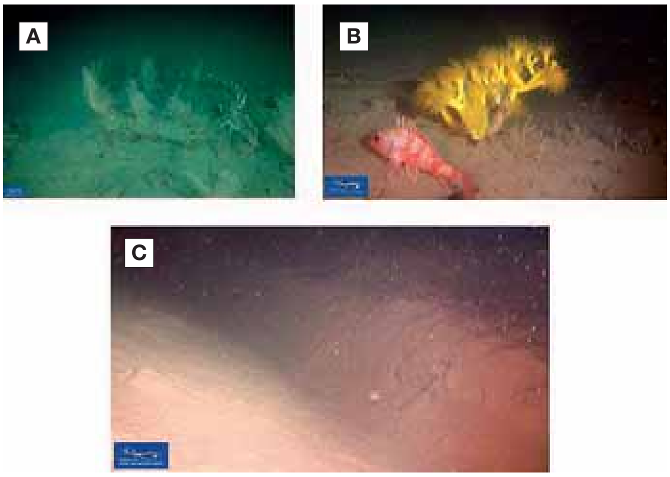

Fig. 9:

Richness in the Bourcart canyon (350 m depth) threatened by trawling gear.

a) bed of *Callogorgia verticillata* gorgonia and spiny lobster,

b) yellow coral *Dendrophyllia cornigera,*

c) traces of trawling activity.

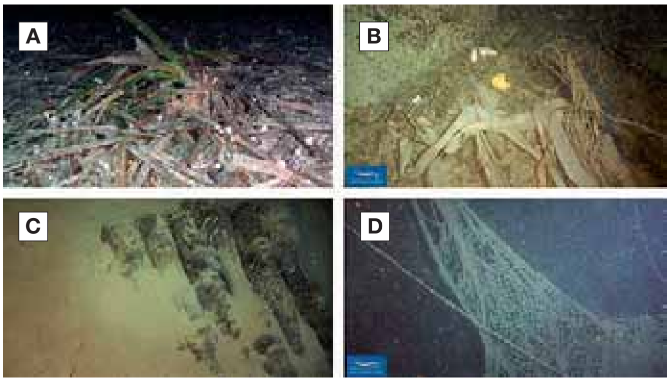

Fig. 10:

Debris in canyons located east of Cassidaigne.

a) accumulation of posidonia leaves in the Toulon canyon at 230 m depth,

b) unauthorized dumping west of the National Park of Port-Cros at 300 m depth,

c) mortar shell in the Saint-Tropez canyon,

d) debris of fishing nets in the canyon of Nice at 350 m depth.

CANYONS OFF THE WEST COAST OF CORSICA

The narrow continental shelf around the Island of Corsica is incised by at least 16 canyons: Centuri*, Saint-Florent, Île-Rousse, Calvi, La Revellata*, Galéria, Porto, Peru*, Sagone, Lava*, Ajaccio, Valinco, Les Moines, Porto-Vecchio*, Aléria* and Cervione*.

By 2011, the CORSEACAN data had still not been processed but already by the end of the reconnaissance campaign, it was possible to state that the sea depths and communities observed are clearly distinct from those observed during the MEDSEACAN campaign.

The boundaries of species distribution and assemblages of fauna are different. While no white coral was discovered, other very rare species were observed. Some of them (currently to be confirmed) even appear to be totally new.

A low amount of waste material and few traces of fisheries activities allow us to conclude that the communities are in a good state of preservation, which is not the case for the continental canyons.

CONCLUSION

Systematic reconnaissance of canyon heads in the French Mediterranean was undertaken during the MEDSEACAN and CORSEACAN campaigns, conducted by the Agency for marine protected areas in partnership with various scientific organizations, both French and foreign. It provided additional knowledge about environments little known until then. While waiting for a real reference record, being prepared in 2011 and 2012, the observation reports (currently in publication) nevertheless provide a global synthesis allowing us to sketch out remarks of a very general nature:

a) A very high level of heterogeneity between the canyons was observed in terms of their morphology, geology and distance from the coast. A rapid examination of biodiversity also reveals significant differences between rocky canyons: those to the east demonstrate that the presence of hard substrata does not necessarily imply the presence of a high level of fixed fauna. On the other hand, numerous sessile and vagile species were observed in certain canyons that are silted up.

b) From an initial examination, it does not appear that unknown species were observed. However, some of the species are very rare in the Mediterranean and have only been spotted on very rare occasions. New sites of cold corals were discovered.

Several of these species are considered to be endangered by the IUCN, and the production of a guide to macrofauna in Mediterranean canyons would seem to be a priority.

c) The Lacaze-Duthiers and Cassidaigne canyons are exceptional biodiversity hotspots. In the Lacaze-Duthiers canyon, exuberant colonies of *Madrepora oculata* and *Lophelia pertusa* were observed, together with numerous vagile and sessile species. The colonies of *Lophelia* are the largest ever observed in the Mediterranean. Biodiversity in the Cassidaigne canyon is heterogeneous, although a highly varied fauna was found in one localized sector - with a diversity of anthozoans observed nowhere else in a single site.

Compared with those obtained in the other canyons, these observations fully justify the sites being awarded particular protection. The canyon heads of Lacaze-Duthiers and the two canyons further east have thus been incorporated into the perimeter of the marine nature park of the Gulf of Lion, with a part of the Cassidaigne canyon becoming part of the project for the national park of Les Calanques.

e) An anthropogenic impact is plainly visible with a clear accumulation of waste material when the continental shelf is narrow and the canyons are close to large towns such as Marseille or Nice. This material consists of all kinds, though plastic predominates. Numerous war-related items (mostly ammunition) were found in canyons lying east of Toulon.

f) In the silted canyons in the Gulf of Lion, the impact of fisheries is visible with numerous examples of trawl towing gear in a muddy environment, sometimes containing rare and endangered species. These traces confirm the existence of halieutic resources.

In canyons with rocky sides where trawling is impossible, debris from long lines and nets was observed. Inert, occasionally colonized by a few species, they nevertheless present a risk for the remarkable species attached to the cliffs (being swept away by currents).

The heterogeneity of the canyons, the wide variety of the species and the very localized character of observations of significant biodiversity call for a predictive approach to these environments and fully justify the pursuit of a reconnaissance programme.

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3.6. Role and importance of submarine canyons for cetaceans and seabirds in the north-western Mediterranean sea

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INTRODUCTION

We know that cetaceans and seabirds are not randomly widespread at sea. A lot of physical and biological factors influence their distribution directly or indirectly. Most of the time, as they are at the top of the trophic chain, they will reflect the distributions of their prey (Burger, 1988; Cotté *et al.,* 2009; Daroven *et al.,* 2003; Murase *et al.*, 2002; O'Donoghue *et al.,* 2010). These animals can hence be perceived as bio-indicators, and provide rough information on the trophic richness of a given area. In fact, a recent multidisciplinary campaign at sea in the head of canyons at the edge of the continental shelf highlighted the richness of some canyons: the MEDSEACAN campaign undertaken by the French Agency for Marine Protected Areas (AAMP).

But canyons cannot be viewed separately from the system linking the shelf to the abyssal plane; moreover, they should be taken into consideration within the continental slope. When canyons have to be considered, the whole margin should also be taken into account as it acts as a favourable channel for exchange between the three bathymetric areas. This is especially true for animals like cetaceans and seabirds which are extremely mobile and able to travel rapidly from one area to another. Furthermore, these animals are not directly linked to the bathymetric limit usually used to define a canyon, i.e. the 200 m contour isobaths for the head, but they are influenced by the currents occurring in canyons, because they concentrate biomass. The effect of canyons on mobile top predators should therefore be measured beyond their near "borders", integrating in particular eddies occurring over canyons.

Since 1994, we have collected data at sea over the different bathymetric areas: the continental shelf, slope and abyssal plane. Analyses are still going on to test our hypothesis concerning canyons in the north-western Mediterranean Sea:

— canyons could be a principal feeding area for some species of cetaceans,

— and they could be a secondary feeding area for other species of cetaceans and seabirds when the period (season) or the year (exceptionally low richness in the principal usual feeding areas) is less productive.

— For seabirds, canyon heads could constitute one of the principal feeding areas during the reproduction season.

Many articles from around the world show that cetaceans preferentially frequent the continental slope, especially its upper part, and also in particular submarine canyons (Kenney and Winn 1987; Mullin *et al.* 1994; Hooker *et al*., 1999). But studies dealing with the use of a canyon by cetaceans or seabirds are so far scarce. What is the importance and on which time and space scales do canyon systems play a role in the distribution of different cetacean and seabird species?

This review is based on studies that we carried out in the north-western Mediterranean Sea (Fig. 1) with data collected from 1994 to 2010, from May to June, with our partners (see acknowledgements). We studied among other things the importance and role of submarine canyons on the continental margin in three regions: 1) Gulf of Lion with large and long canyons, far from land and not much edged by the continental shelf, and with a lack of inter-canyon areas; 2) Provence, where canyons are relatively narrow with steep heads, and in the vicinity of the Northern Mediterranean Current (NMC), separated by small inter-canyon areas, and 3) Corsica, where canyons are short and narrow, hence small, and notably incise the shelf, with extended inter-canyon areas.

This article is also based on data collected during the MEDSEACAN campaigns lead by the French Agency for Marine Protected Areas, above the heads of French Mediterranean canyons (*EcoOcean Institut* unpublished data) from October to June. Lastly, this review is based on scientific literature presenting results of studies completed in this part of the Mediterranean Sea.

Canyons are theoretically defined from the 200 to 2000 m depth contour. But we define their limits to take into account hydrological processes which mostly occur over the heads and edges of canyons beyond these topographical limits (see map 1). To compare abundances between canyon and inter-canyon areas, we only analyzed both sectors of Provence and Corsica, the inter-canyon entity missing in the third one, the Gulf of Lion.

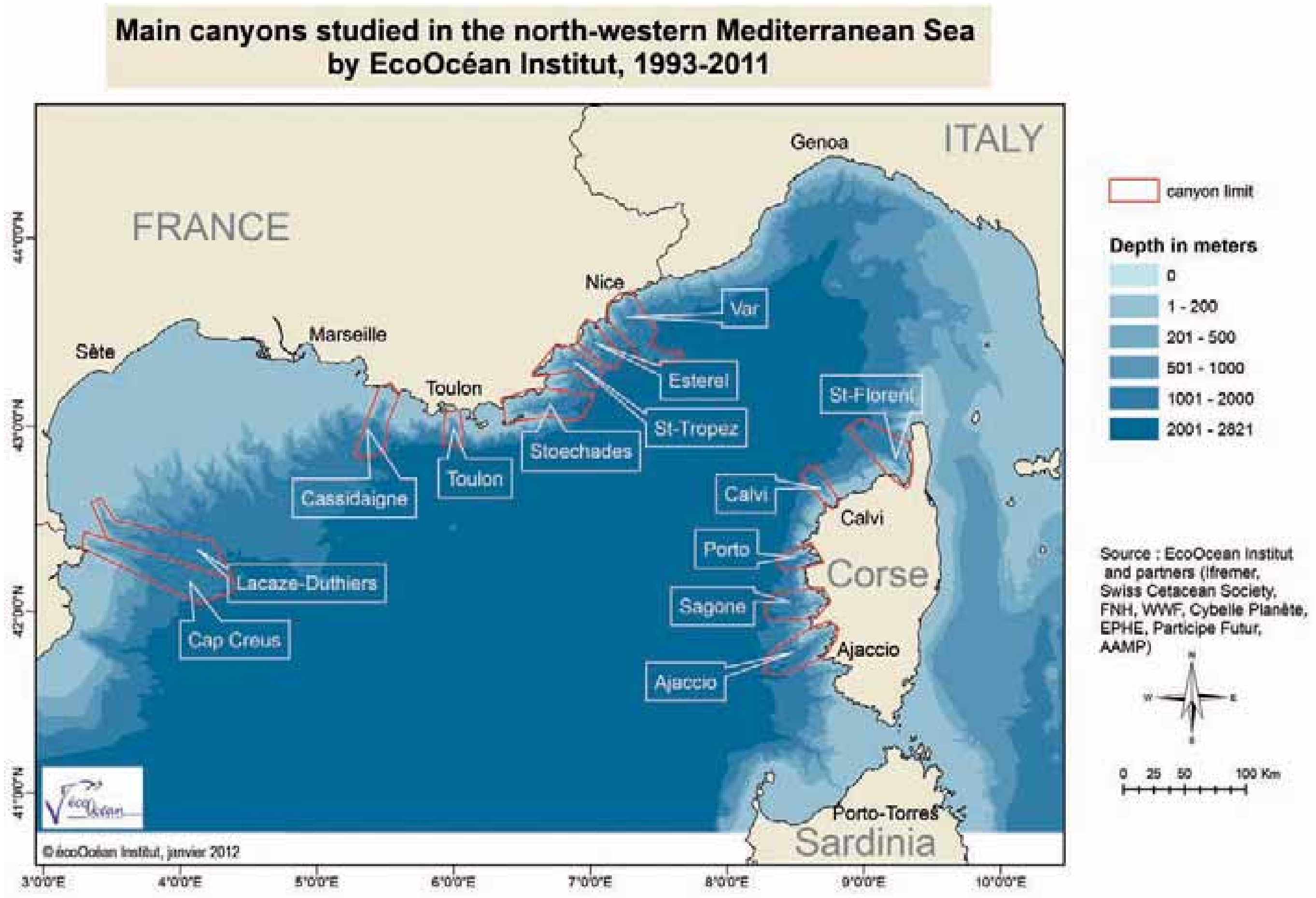

Fig. 1:

Area and canyons studied in the north-western Mediterranean Sea.

The indicators used to highlight the importance of canyons are:

- Frequentation: number of species and their relative abundance, number of individuals per unit effort, here Nautical Mile (NM), spatial distribution and movements,
- Utilisation: type of behaviour, site fidelity, temporal variation (scale of a day, a season or a year), relations to environmental parameters,
- The convergence of several top predators with different types of diet and their inter-actions.

IMPORTANCE OF THE CONTINENTAL MARGIN

Very few cetaceans are to be found over the continental shelf (0.2 ind./NM). They are far more abundant over the continental slope, mainly in its upper part from 200 to 1000 m depth contour (1.02 ind./NM). They are also numerous over the lower part, up to 2000 m (0.86 ind./NM). In comparison, the relative abundance of cetaceans offshore, over areas beyond the 2000 m depth contour, reaches a maximum of 1.42 ind./NM (David 2000).

Species preferring the continental slope include Risso's dolphin (*Grampus griseus*), the sperm whale (*Physeter macrocephalus*) and Cuvier's beaked whale (*Ziphius cavoristris*), as several authors have already pointed out (Bompar, 1997; Di-Méglio, 1999; Praca and Gannier, 2008; Azzelino *et al*., 2008; Moulins *et al*., 2008). However, all species, from coastal to pelagic, have been sighted more or less frequently over this bathymetric entity: bottlenosed dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), pilot whale (*Globicephala melas*) and also the fin whale (*Balaenoptera physalus*) (David, 2000; Di-Méglio, 1999; Delacourtie *et al*., 2009; Moulins *et al.,* 2008).

Concerning seabirds, we studied these animals mostly in summer (June to September), so most of the species studied were linked to their colonies at that time. But during the MEDSEACAN campaigns we also collected data in winter and spring. We observed at least 8 species: Cory's shearwater (*Calonectris diomedea)* and Yelkouan shearwater (*Puffinus yelkouan yelkouan*), the Yellow-legged gull *(Larus cachinnans micahellis)*, Black-headed gull (*Larus ridibundus),* Mediterranean gull (*Larus melanocephalus),* Common tern (*Sterna Hirundo),* Northern Gannet (*Sula bassana*) and Atlantic puffin (*Fratercula arctica*).

It appears that seabirds are more frequently encountered over the continental shelf (0-200 m) and the upper continental slope from 200 to 1000 m depth than over the lower part of the continental slope from 1000 to 2000 m or offshore > 2000 m depth (Table 1 from Di-Méglio, 1999).

Conéjéro and Beaubrun (1998) found Cory's and Yelkouan shearwater over the continental shelf and the continental upper part of the slope of the Gulf of Lion respectively 0.6 ind/NM and 2.7 ind./NM for the two species of shearwaters. It seems that two

	Cory's shearwater	Yelkouan shearwater	Yellow legged gull	Atlantic puffin	Northern Gannet	Black-headed gull	Mediterra-nean gull	Common tern
0-200 m	1.24	0.71	2.69	0.02	0.03	0.10	0.02	0.27
200-1000 m	0.43	0.22	0.76	0.01	0.01	0.29	0.01	0.11
1000-2000 m	0.19	0.27	0.05	0.01	0.01	$0.06.10^{-2}$	$0.06\ .10^{-2}$	$0.06.10^{-2}$
> 2000 m	0.11	0.03	0.03	$0.02\ .10^{-1}$	$0.06.10^{-2}$	$0.02.10^{-2}$	$0.01.10^{-2}$	$0.03.10^{-2}$

Tab. 1:

Seabird abundance (in individual/NM) over different depth stratum.

categories can be defined: coastal semi-pelagic ones, like *Laridea* and *Sternidae*, and more pelagic ones, like the Shearwaters. The first stay closer to the coast, 2 to 3 NM for some small gulls and for terns (Black-headed gull, Mediterranean gull, Common tern) and up to 10 or 12 NM for the bigger ones (Yellow-legged gull). Thus, in the Gulf of Lion, where the slope's break is sometimes as far as 40 NM from the coast, few of these birds ever reach it. But near the Var river on the French Riviera coast, where lots of colonies of these birds exist and where the continental shelf is nearly inexistent and the slope very steep, these birds can reach the upper part of the continental slope. Other semi-pelagic species were also mostly sighted over the continental shelf and slope: the Northern Gannet and Atlantic puffin.

For seabirds, very few studies exist on the distribution of these animals at sea in this part of the Mediterranean. Nevertheless, most of them show that the continental shelf and upper part of the slope is a preferential range for seabirds (Abello and Oro, 1998; Carboneras and Requena, 2010; Conéjéro and Beaubrun, 1998; Di-Méglio, 1999; Zotier *et al*., 1999).

CANYONS AND INTER-CANYON AREAS

According to our data, the relative abundance of cetaceans proves to be higher in canyons than in inter-canyon areas (Wilcoxon paired test, with data for the four best years of the prospecting effort, 1994 to 1997, p=0.06 accepted as significant) (David, 2000). First of all, Odontoceti (toothed whales) frequent in particular canyons compared to other parts of the continental margin, mainly Risso's dolphins and sperm whales, but also pilot whales and Cuvier's beaked whales. These four species are exclusively or preferentially teutophageous (squid eaters). Canyons are also important areas for the striped dolphin, which is an ichtyo-teutophageous species (fish and squid eater). Finally, the difference is less pronounced for the fin whale, the only Mysticeti (baleen whales) and planctonophageous species sighted. The study made by Moulins *et al.,* (2008) in the Ligurian Sea also found that four species frequently inhabit the Genoa Canyon area: striped dolphins, Cuvier's beaked whales, sperm whales and Risso's dolphins. Other studies on the Sperm whale in this part of the Mediterranean Sea have also highlighted their preference for canyons (Gannier and Praca 2007; Moulins and Würtz, 2005), while maps of preferred habitats show favourable areas in cells including canyons for Risso's dolphin and even pilot whales (Praca and Gannier, 2008; Delacourtie *et al.,* 2009).

This interest in canyons has also been described for cetaceans in Tyrrhenian (Mussi *et al.,* 2001), Ligurian (D'Amico *et al.,* 2001; Moulins *et al*., 2008) or Greek canyons (Frantzis *et al*., 1999). All authors mention high abundances of cetaceans, mainly Risso's dolphins, fin whales, sperm whales and Cuvier's beaked whales within canyons, and highlight the trophic role of these areas. A similar phenomenon has been observed in the Atlantic Bay of Biscay, where some species, such as Cuvier's beaked whales and Sperm whales, are more often found in the vicinity of the Santander canyon (Kizska *et al*., 2007). A well-studied site is the Gully, the largest submarine canyon off the coast of eastern Canada. Here too, the abundance of cetaceans is higher in the canyon than in other parts of the Scotian shelf and slope (Hoocker *et al.,* 1999). The most interesting feature is that a population of 230 northern bottlenose whales use the Gully throughout the year, and approximately 57% of this population reside in a 20x8 km core area at the entrance to the canyon at any given time (Whithead *et al.,* 1997). This species partitions the Gully with sperm whales into largely separate habitats. Other species appear to partition the Gully temporally but not geographically.

Even if most of our campaigns at sea take place in summer, other more sporadic missions in spring have encountered cetaceans in canyons, particularly in Corsica: fin whales have been seen feeding in Saint-Florent canyon (Cesarini, *pers. comm.*), and Di-Méglio (2005, unpublished data) reported that three-quarters of fin whale sightings during a continent-to-Corsica mission were seen feeding in the Valinco and Bonifacio canyons in April. In addition, during the MEDSEACAN campaigns undertaken in spring, autumn and winter in "shallow" waters (200 to 600 m), our preliminary results show that 5 cetacean species have been observed there, even "pelagic" ones (fin whales and pilot whales) (Table 2), some of them feeding.

Concerning the use of canyons by cetaceans during the summer, nearly 67% of the fin whales sighted during feeding activities were distributed in canyons rather than inter-canyon areas. During fixed point observation, no less than eight fin whales at a time were observed during the entire day feeding in the head of a canyon in early spring. For other species seen during transect in summer, the proportion of individuals sighted in feeding activities distributed in canyons compared to inter-canyon areas was 88% for striped dolphins and attained 92% for Risso's dolphins. On the other hand, only 33% of feeding sperm whales were found in canyons, and no pilot whales were seen hunting there, but they are night feeders and frequently rest during the day in canyons. Between 80 and 100% of socialising animals were localised in canyons, whatever the species. When the number of individuals is grouped by trophic categories and weighted by the prospecting effort (Table 3), the trends are the same except for the striped dolphins which socialise and rest more outside canyons.

It is interesting to note that, in summer at least, canyons are particularly attractive for groups of cetaceans with new-borns and calves. Actually, the percentage of new-borns in the groups of striped dolphins observed was slightly higher in canyons (2.8%)

Species	Lacaze-Duthiers (November)	Lacaze-Duthiers (June)	Cassidaigne (October)	Toulon (April)	Stoechades (May)	St-Tropez (April)	Var (April)
Bottlenosed dolphin	X		X		X		
Striped dolphin	X				X		
Fin whale		X					
Pilot whale			X				
Sperm whale							X

Tab. 2:

Cetacean species sighted in the heads of several canyons studied during the MEDSEACAN campaigns (2008-2010) (*EcoOcean Institut* unpublished data).

Ind./MN	Feeding	Socialising	Resting	Travelling	Unknow
Fin whale, canyon	0.003	0.001	0.001	0.004	0.006
Fin whale, inter-canyon	0	0	0.001	0.009	0.006
Striped dolphin, canyon	0.270	0.013	0.026	0.231	0.186
Striped dolphin, inter-canyon	0.144	0.048	0.041	0.143	0.261
Teutophageous, canyon	0.020	0.032	0.002	0.022	0.014
Teutophageous, inter-canyon	0.007	0	0	0.009	0.015

Tab. 3:

Comparison of the relative abundances (ind./NM) of animals engaged in four behaviours and sighted in canyons and inter-canyon areas in summer (David, 2000).

than in inter-canyon areas (1.5%). For Risso's dolphins and pilot whales, new-borns were only seen in groups located over canyons, reaching 4.3 and 4.5% respectively. Moulins and Würtz (2007) also reported the unusual sighting of a social pod of sperm whale in the Var canyon.

Apart from this "summer" use of canyons, the use of canyons also seems to be sporadic for some "pelagic" cetacean species, as in the case of eight fin whales seen in early June feeding the whole day in the head of the Lacaze-Duthiers (MEDSEACAN (*EcoOcean Institut* unpublished data) or in Corsican canyons (St-Florent, Valinco and Bonifacio) (Di-Méglio, 2005, data unpublished, Cesarini, *pers. comm.*). These and other canyons could be used as transient places when animals are probably on their way to reach the productive waters of the Liguro-Provençal basin (David *et al.*, 2001; Castellote *et al.,* 2010), or be small secondary hotspots: Cuma canyon system (Mussi *et al.,* 2001) and the canyons around Lampedusa (Guisti *et al.,* 2005).

Concerning seabirds, they are really mobile and can travel fast from one entity to another. Nevertheless, our results show that canyons are places regularly frequented by sea birds, mostly their heads which incise the continental slope. Conéjéro and Beaubrun (1998) as well as Beaubrun *et al.,* (1998) also pointed out the importance of canyon heads for seabirds. During MEDSEACAN campaigns in canyon heads, we encountered 17 species of seabirds, some of them regularly (Table 4). Furthermore, it is also over canyon heads and the shelf break that feeding seabirds are more often seen (shearwaters as well as small gulls and terns) (Di-Méglio 1999; Conéjéro and Beaubrun, 1998). Very few studies analyse the role of canyons in the distribution of birds in this part of the world. Only Conéjéro and Beaubrun (1998) as well as Beaubrun *et al.,* (1998) in the Gulf of Lion, show similar results as ours: in the north-western Mediterranean Sea, canyons and in particular their heads are places regularly frequented by sea birds.

EACH CANYON IS DIFFERENT

Some canyons seem more attractive than others for the whole cetacean community (Friedman test, p=0.03), namely Cassidaigne in Provence, St-Florent in Corsica and finally Lacaze-Duthiers in the Gulf of Lion (David, 2000). The three trophic categories reached their highest abundance in the canyon of Cassidaigne. Teutophageous species are more frequent in Stoechades and Lacaze-Duthiers, whereas abundance of ichtyo-teutophageous species is higher in Saint-Florent (David, 2000). Fin whales were encountered more frequently in the Cassidaigne and Ajaccio canyons.

An example of monthly evolution: the canyon of Stoechades is barely visited during June and July, but during August and September it becomes a principal occupancy site for large groups of Risso's dolphins and pilot whales, with numerous new-borns.

We obtained the same results during recent MEDSEACAN campaigns, with Lacaze-Duthiers being the most attractive canyon for cetacean species, with Cassidaigne and Stoechades in second position (Table 2).

Concerning seabirds, our results (Di-Méglio, 1999 and MEDSEACAN, see Table 4) highlighted four canyons and their surroundings: Lacaze-Duthiers and Cassidaigne in the Gulf of Lion, Var in Provence and Ajaccio in Corsica. The first one seems to be attractive for most of the species, particularly shearwaters (Di-Méglio, 1999; Conéjéro and Beaubrun, 1998). Cassidaigne is frequented by semi-pelagic species such as the Mediterranean shearwater, Northern Gannet and also diverse gulls. The Var delta

Canyons Species	Lacaze-Duthiers (November)	Lacaze-Duthiers (June)	Cassidaigne (October)	Toulon (April)	Stoechades (May)	St-Tropez (April)	Var (April)
Yelkouan shearwaters	X	X	X	X	X	X	X
Cory’s shearwaters		X	X	X	X		
European storm-petrel	X						
Northern gannet	X	X		X	X	x	X
Great cormorant	X		X				
European shag					X		
Great skua	X						
Yellow-legged gull	X	X	X	X	X	X	X
Kittiwake	X						X
Mediterranean gull	X						X
Black-headed gull	X		X			X	X
Lesser blacck-backed gull	X						
Audouin’s gull		X					
Sandwich tern			X				X
Common tern							X
Razorbill	X						
Atlantic puffin		X			X		

Tab. 4:

Seabird species sighted in the heads of several canyons studied during the MEDSEACAN campaigns (2008-2010).

is a place largely frequented by most of the gull and tern colonies, so they are abundant in that nearby canyon. In Corsica, Ajaccio is a canyon frequently used by at least Cory’s shearwaters and other more coastal and semi-pelagic birds, together with the Bonifacio canyon and Strait.

The distribution of seabirds is influenced by the localisation of their colony (central place forager), the status of reproduction and their associated energy needs, and also their capacity to exploit their environment (Fasola and Bogliani, 1990). Di-Méglio (1999) showed that for a pelagic seabird like Cory’s shearwater, the great majority of seabirds are seen in the neighbourhood of their colonies during the period of laying and the incubation of their eggs, whereas outside this period, birds are regularly encountered in the entire Mediterranean basin. In our results, we show that Cory’s shearwater and Yelkouan shearwater are able to search for food far from their French continental colonies (Marseille and Hyères archipelago), at least as far as the Lacaze-Duthiers canyon some 127 to 170 NM away. On the other hand, Laridae and Sternidae generally stay closer to the coast and their colonies during all stages of the reproduction period.

Globally, it is interesting to note that the main preferential canyons for cetaceans and seabirds are almost the same. This attraction for top predators to a certain site indicates its probable richness in prey. It seems that the Gulf of Lion system, including the canyons and particularly Lacaze-Duthiers and Cassidaigne, is particularly important for cetaceans and seabirds (present study). This is supported by the findings of Beaubrun *et al.* (1998) during a campaign at sea from Barcelona to Rome over the continental shelf and slope, which noted that the main abundance of Cory’s shearwater was located in the region of the Gulf of Lion and its canyons. Similarly David (2000) also found a greater abundance of cetaceans in the canyons of the Gulf of Lion than off the Provençal canyons. In Provence, some canyons are also important for both groups which were frequently found in the Stoechades canyon, whereas the Var canyon (and delta) is mainly attractive for birds. Finally in Corsica, the Ajaccio canyon seems important for both cetacean and seabird species, at least in summer.

The attraction of Mediterranean canyons for these vertebrates can be explained by several factors. It is generally well-known that the distribution of cetaceans and seabirds at sea is directly or indirectly influenced by different environmental parameters and by the distribution of their prey. In the Mediterranean Sea, it has been demonstrated that seabirds and cetaceans are associated to thermic fronts (Di-Méglio *et al.*, 2005; Cotté *et al.*, 2009), in particular fronts of a 1 to 2°C range, which are mainly found over the continental slope and in canyons of the Provence and Corsica region, and also fronts of more than 2°C of magnitude which are usually found over the margin and canyons of the Gulf of Lion (Di-Méglio, 1999). On the Iberian coast, Louzao *et al.* (2006) showed that the foraging range of the Balearic shearwater comprised the frontal systems along the eastern Iberian continental shelf waters (depth <200 m) and areas close to the breeding colonies in the Balearic Islands. They also showed that shearwaters aggregate in productive shelf areas with elevated chlorophyll *a* concentrations. Praca and Gannier (2008) found that in the Provence and Balearic zones, the most important factor explaining the abundance of sperm whale was the shelf break and the canyons. In the Gulf of Lion and the Central Zone, the presence of frontal zones appeared as the most influential factor for the presence of sperm whales.

Based on the literature (Bethoux *et al.*, 1988; Millot, 1987), we know that in our Mediterranean study area, the continental margin is influenced successively either by continental water (Rhône and Var rivers), upwellings created by wind gusts, or the North Mediterranean Current (or Ligurian Current) and its associated thermo-haline front. These hydrological processes bring nutriments that allow or enhance productivity at the surface and concentrate or attract all the elements in the trophic chain (Frontier, 1986). This enrichment may attract buoyant prey such as squids in deep water (Smith and Whitehead, 1993; Hamazaki, 2002; Whitehead, 2003; Gregr and Trites, 2001). Particularly near the shelf break and in heads of canyons, the currents are deflected by the topographic variation and form upwellings and eddies (Durrieu de Madron *et al.,* 1990; Maso *et al.*, 1990, Rojas *et al.,* 1995). Furthermore, steep topography is found in continental slope areas, canyons or sea-mounts, and appears to be favourable to cephalopod biomass (Childerhouse *et al.*, 1995; Jaquet, 1996; Waring *et al.*, 2001; Jaquet and Gendron, 2002). This may explain why teutophageous species are more linked to the continental slope and canyon system. Most marine organisms (euphausiids, squids and fishes) are swept away during their vertical nycthemeral migrations and trapped in canyons (Maqcart-Moulin and Patriti, 1993, 1996). Several of these animals spawn in canyons where they gather and school during the summer. Canyons are then productive places in terms of zooplancton, micronecton (Champalbert *et al.*, 1992; Macquart-Moulin and Patriti, 1993; 1996; Patriti and Macquart-Moulin, 1996) and also fishes: Campillo (1992) found a high density of adult anchovies beneath thermo-haline fronts at the shelf break and particularly in canyons. Canyons are thus areas of important concentration, abundance and species diversity, and consequently attractive for cetaceans and seabirds. Conéjéro and Beaubrun (1998) linked the distribution of Cory's shearwater to the distribution of Anchovies and Sardines and also to the main area for the eggs of these fish species (Garcia *et al.,* 1994; Beaubrun *et al.*, 1998).

Moreover, the trophic web of the western region, the Gulf of Lion, may benefit from the general current flowing west along the continental slope of Provence and the Gulf of Lion, explaining its attractiveness for top predators.

Not only does the abundance of prey play an important role, but certainly also the type of prey, their availability, reachability, patches of concentration and the frequency of occurrence of these patches. Since canyons are topographically fixed, hydrological processes occurring locally should be regular and canyons could then be a regular source of "predictive" food. Moreover, it appears that canyons more frequented by cetaceans seem to be those where meanders and eddies of the NMC occur, forced by the topography of the coast, and thus canyons which are provided regularly and permanently with biomass.

The frequency of canyons cutting the slope could also be an important factor. In our study, the Gulf of Lion and Corsica have similar abundances of cetaceans (0,78 to 0,81 ind./NM), with animals scattered over numerous canyons in the first sector, and more concentrated in some canyons in the second.

DIFFERENCES INSIDE A CANYON

Looking from offshore to land, we separated each canyon into four quarters based on the head, which comprised depths from]0 to 1000 m], and the Base from]1000 to 2000 m], and the Left and Right side.

We can see that a kind of spatial partition appears between cetacean species in the canyons. For example, in the canyons studied, feeding fin whales were more often located over bases and left sides, as in the case of long-finned pilot whales, whereas Risso's dolphins were more often seen over heads and also left sides (Table 5; David, 2000). Sperm whales prefer heads, regardless of the side. Striped dolphins feed everywhere, but slightly more over right sides and heads of canyons. Altogether, teutophageous species seem to prefer to exploit left sides, regardless of depth.

One kind of partition has also been reported by Moulins *et al.* (2008) in the Genoa canyon, where four species were seen: striped dolphins were mainly present on the north-western border, the Cuvier's beaked whale species shares the upper part of the canyon with dolphins, also frequent in the deep part of the canyon, and sperm whales were observed in the middle of the canyon where both striped dolphins and Cuvier's beaked whales were absent. Finally, Risso's dolphins was frequently observed at the opening of the canyon where the Cuvier's beaked whale was absent, but shared the area with striped dolphins.

A temporal partition also exists during the day in the canyon. On a daily basis, striped and Risso's dolphins present a similar pattern (David, 2000; Di-Méglio, 1998; Gannier and David, 1997): at dawn they are mainly feeding in small groups or scattered over shallow water. In the middle of the day, they travel to areas at greater depths, and gather in bigger groups, mostly socialising and resting. In the evening they return to more shallow water, dispersing and beginning feeding activities. These species seem to be nocturnal feeders, hunting in canyon heads some prey, which concentrate and come up at night then go down again during the day. Meissner *et al.* (2008), have also showed that in the Riviera canyons (around Nice) striped dolphins occur more inside the canyon in the morning with a largely dominant feeding activity.

Ind. Alim/NM	Left side	Right side	Head	Base
Fin whale	0.004	0.001	0.001	0.005
Striped dolphin	0.22	0.40	0.34	0.26
Teutophageous	0.027	0.001	0.015	0.012

Tab. 5:

Comparison of relative abundances (ind./NM) of feeding animals in half-canyons : left and right sides, and head and base.

From dawn to dusk, the abundance of striped dolphins is higher in one quarter of a canyon, then in another quarter, and it seems that they follow a kind of circuit, clockwise or anti-clockwise, through the entire canyon. Commonly, individuals found over canyon heads at dawn are feeding, and we discerned movements from head to base in the morning, and base to head in the second part of the day (David, 2000).

In the case of seabirds, it seems that most of feeding seabirds are localised on the left side or middle part of the northern canyons, for shearwaters at least (Di-Méglio, 1999). But we have not found more literature in our study area on that particular point. Nevertheless, in general we observed a higher percentage of shearwaters at sea at dawn and/or dusk rather than in the middle of the day: around 0.23 ind/km at dawn and dusk for Cory's shearwater versus 0.12ind./km in the morning or afternoon, and 0.09 ind./km in the evening versus 0.04 at dusk and 0.06 in the afternoon for Mediterranean shearwater. This global pattern would probably be the same in canyons.

To conclude, we can say that this study and review show the importance of submarine canyons in the summer period at least for cetaceans and seabirds in the north-western Mediterranean Sea ecosystem. Cetaceans exploit them differently according to the month (David *et al.,* 2001) or the period of the day, certainly reflecting the movements of their prey. Mobile birds such as Cory's shearwater or Yelkouan shearwater exploit rich canyons even far from their colonies, and many species of birds (shearwater, gull, gannet, puffin…) frequent preferentially the shelf break and canyon heads in this part of the Mediterranean Sea. Our results and the literature thus support the hypothesis presented in the introduction. In this part of the Mediterranean Sea at least:

- the continental slope and the canyons constitute a **principal feeding area** for Risso's dolphin, sperm whale and Cuviers beaked whale in the case of cetaceans, as well as for Cory's shearwater and, when near colonies, Yelkouan shearwaters, gulls and terns in the case of seabirds,
- for striped dolphin and pilot whales, canyons can also be a **secondary feeding place** among others, mostly used at night, and lots of seabirds use canyons when they are near their colonies,
- for fin whales, canyons could be **punctual feeding places** to search for food during spring or winter, or when the usual pelagic biomass is missing (exceptionally low productive year).

It seems that the influence and importance of canyons are similar throughout the world, even if modalities and intensities depend on hydrological, topographical and biological contexts. We could also work on scale with regard to canyons, and imagine looking at the Ligurian Sea as a huge canyon within the Mediterranean Sea.

Although canyons are attractive sites for predators, some of them are more frequented than others. Factors explaining this would include the size of the canyon, its distance from a River or the coast, and its position regarding the main geostrophic currents generating upwelling and eddies which enhance the biomass and productivity. These parameters influence physical oceanography and the availability of potential resources for predators.

Cetaceans and seabirds therefore participate in the ecosystems of canyons, from the point of view of material and energy transfers and biodiversity.

By identifying principal foraging areas where top predators concentrate, we could envision those areas as core regions of Marine Protected Areas (MPAs), where high protection measures could be established. More diffuse protective measures would be applied within a larger buffer region, delineated by the foraging range of each threatened species. Marine protected areas, even on the high sea, with different levels of protection could greatly benefit the conservation of far-ranging seabirds by extending protective measures beyond their breeding colonies during both the breeding and non-breeding seasons (Louzao *et al*., 2006). The shelf break, upper continental slope and heads of canyons should therefore be integrated into a huge MPA or a network of Marine Protected Areas to ensure ecological continuity and the efficient monitoring of populations.

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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).

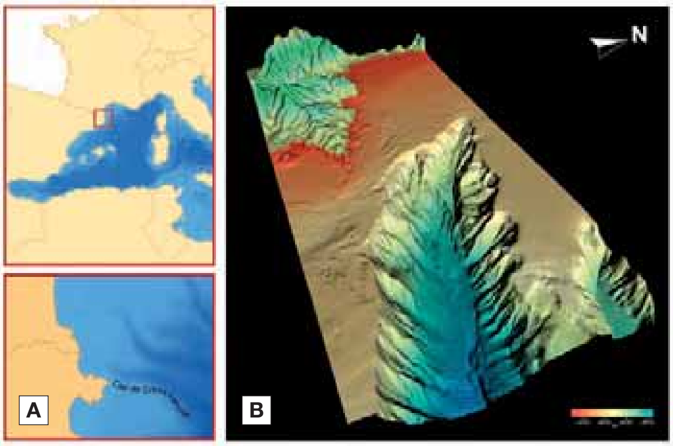

Fig. 1:
A) Cap de Creus canyon in the North Western Mediterranean context and B) its digital elevation model (DEM).

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).

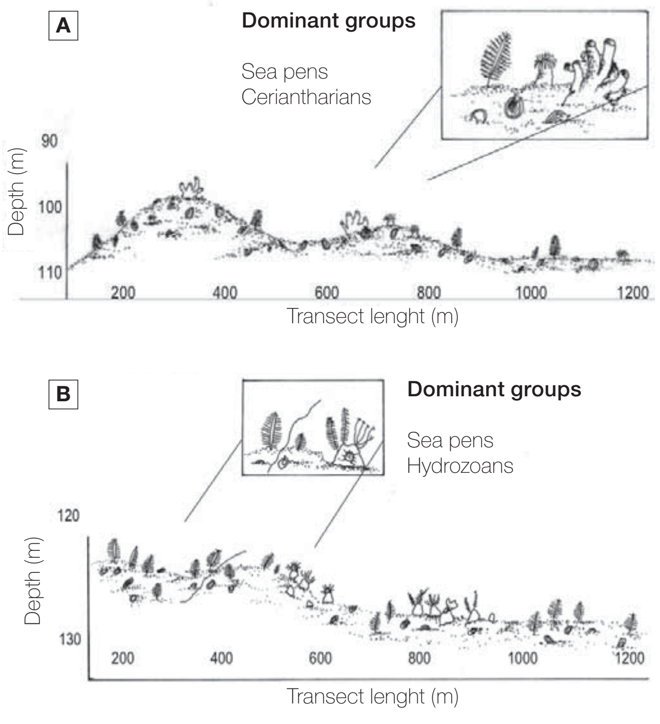

Fig. 2:

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.

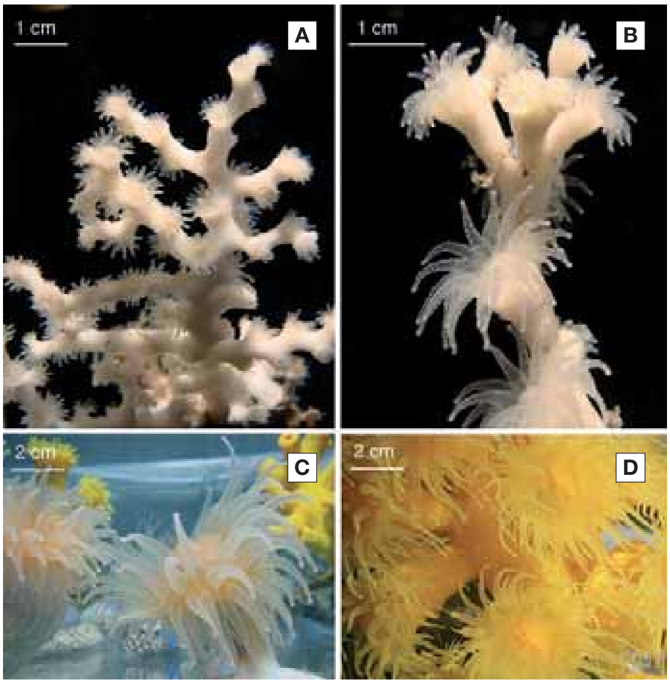

Fig. 5:

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.

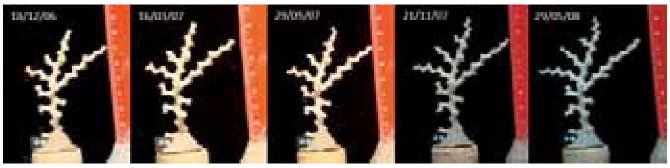

Fig. 6:

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

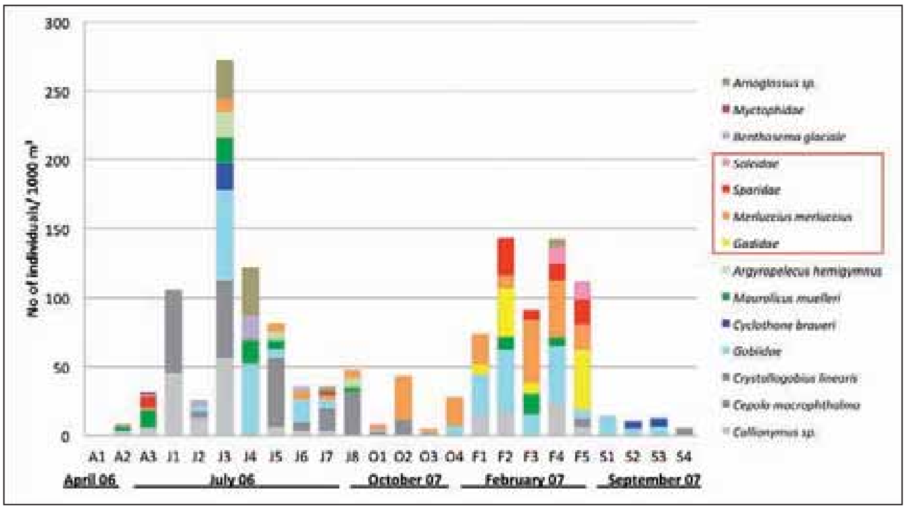

Fig. 8:
Fish larvae in zooplankton samples collected inside the Cap de Creus canyon. Commercial species are highlighted.

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.

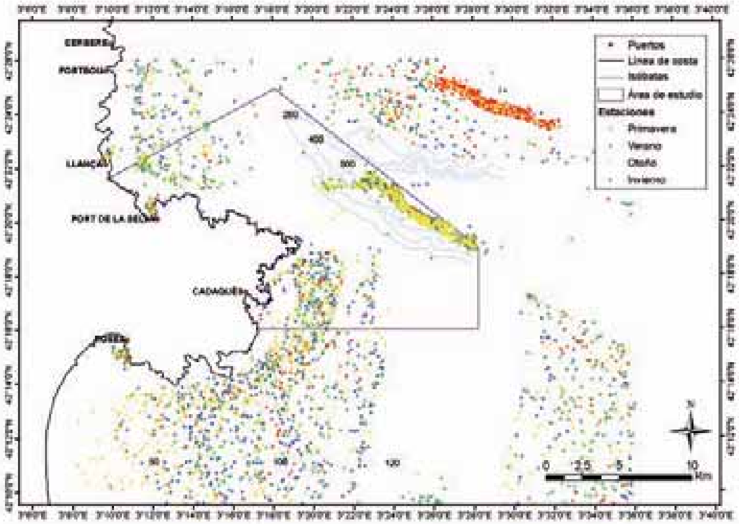

Fig. 9:

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

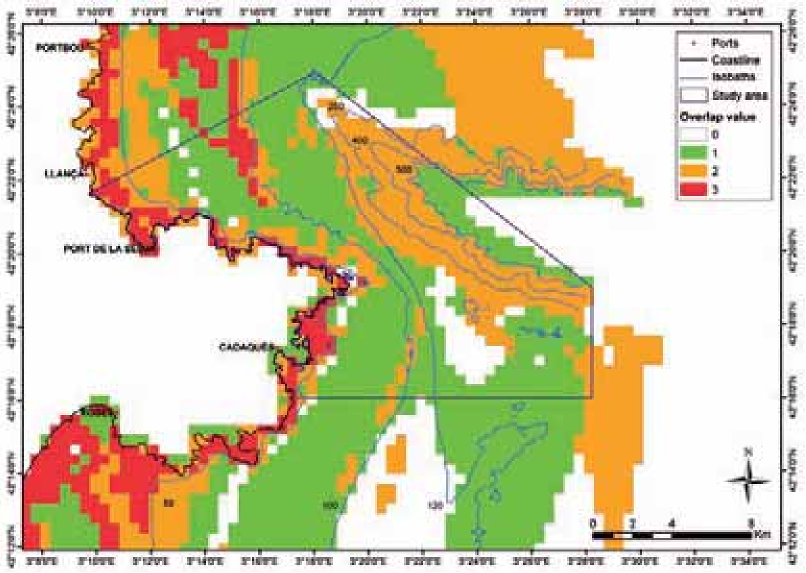

Fig. 10:
Overlap value in the study area of Cap de Creus. Minimum value of overlap is 0 when no fishing gear is present, and maximum value is 3 when 3 different gears coexist.

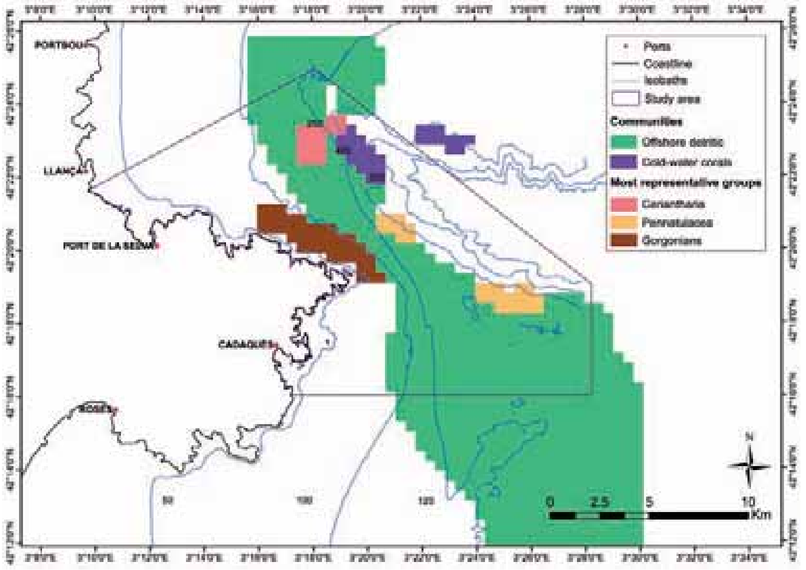

Fig. 11:
Delimitation of communities and the most representative groups in the study area.

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.

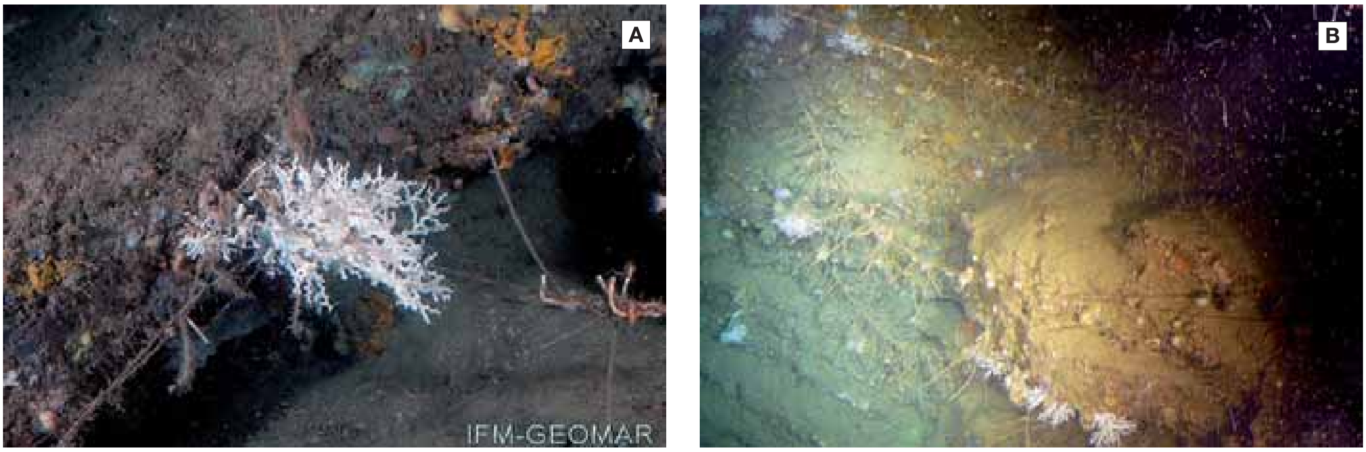

Fig. 12:

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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3.8. Submarine canyons in the Catalan Sea (NW Mediterranean): megafaunal biodiversity patterns and anthropogenic threats

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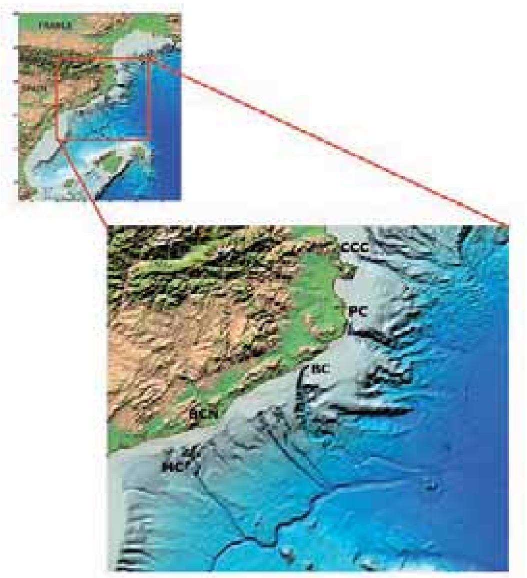

Fig. 1:

Shaded relief general bathymetry map of the northwestern Mediterranean Sea. The insert provides a detail of the central and north Catalan margin showing the canyons considered in this case study. BCN, Barcelona; BC, Blanes canyon; CCC, Cap de Creus canyon; MC, Merenguera canyon; PC, La Fonera or Palamós canyon. Catalano-Balearic Sea map modified from: 2005, Catalano-Balearic Sea – Bathymetric chart, http://www.icm.csic.es/geo/gma/MCB/index.htm. Bathymetric data from Canals *et al.*, 2004b.

INTRODUCTION: GEOMORPHOLOGY AND PHYSICAL OCEANOGRAPHY

The continental margin of the Catalonia is crossed by several submarine canyons of different evolutionary history (Fig. 1) (Canals *et al.*, 2004a). The main characteristic of the circulation pattern on the Catalan coast is a slope current referred to as the Northern current, which is associated with a shelf–slope density front that in this area flows mainly towards the southwest (Font *et al.*, 1988). This baroclinic current separates the low-salinity shelf waters from the denser open-sea saline waters.

The hydrodynamics in submarine canyons basically depend upon several forcing conditions in the region such as general circulation, bottom morphology and atmospheric regime. Forcing conditions differ among canyons and can give different responses. Most of the particulate matter transferred from the shelf through submarine canyons comes from continental runoff and/or resuspension (e.g., during storms or cascading events) and coastal biological productivity. Such transfers are conditioned by particulate matter inputs, topography and hydrodynamics outside and inside the canyon. Within the canyon, the hydrodynamic pattern may lead to the retention and/or resuspension of particulate matter, which can be affected by several sedimentation and erosion cycles before reaching a final fate (Puig and Palanques, 1998; Palanques *et al.*, 2006a; Puig *et al.*, 2008). Besides the natural processes, fishing activity carried out within their confines at the present time can play an important role in the dynamics of the canyon systems.

In this chapter we describe some of the outcomes of Spanish national and European research projects in relation to the life history, distribution, biomass and composition (i.e. biodiversity) of benthic (i.e. bottom living) vertebrate and invertebrate species in different Catalan Sea canyons and open slope areas (western Mediterranean). These biological characterizations have been carried out in relation to bathymetric, geomorphologic and seasonal changes in habitat conditions within the northwestern Mediterranean Sea (Company and Sardà, 1997, 1998, 2000; Company *et al*. 2001; Aguzzi *et al.,* 2010).

The main objective of this case study is to present a global and updated overview on the majority of available data in the Catalan area showing how the geomorphology of submarine canyons and the adjacent open slopes have an influence on the life-cycles of several bathyal species, which in some cases represent important fishery resources. Also, we will show how recruitment (i.e. the incorporation of juveniles into adult populations) of these species takes place in canyon heads. The presentation of up-to-date available data responds to the need to support initiatives of preservation and devoted management of the habitats present in these submarine canyons, mainly regarding commercial fisheries, a goal which has been pursued for several decades.

BIODIVERSITY PATTERNS

The rough topography of canyons has affected our ability to sample and study megafaunal communities until recently. Our knowledge is therefore limited. However, in the past decade, a number of studies have been conducted in the NW Mediterranean canyons, using both traditional gear such as otter and Agassiz trawls and new technologies such as ROVs (Remote Operated Vehicles). We present here data on deep-water (400-1500 m depth) megafaunal diversity from two canyons: the Merenguera canyon, just south of Barcelona, and the Blanes canyon, 60 km north of Barcelona (Fig. 1).

Merenguera canyon

The megafaunal communities in the upper part of the Merenguera canyon (450 m depth) were investigated and compared to those from the adjacent middle (650 m depth) and lower (1200 m depth) open slope during the RETRO project in 1991 and 1992 (Sardà *et al.*, 1994a; Company *et al.*, 2003; Ramirez-Llodra *et al.*, 2008). The two shallower sites are visited daily by a specialized commercial trawl fisheries fleet, while the lower site has not been impacted by fisheries.

Decapod crustaceans and fish (Fig. 2) are the most abundant groups in the deep Mediterranean Sea, including canyons, accounting for most of the biomass (Company *et al.*, 2004; Aguzzi and Company, 2010). In the Merenguera canyon and on the adjacent open slope, the biomass of decapod crustaceans (Sardà *et al.*, 1994a) and other invertebrates (Ramirez-Llodra *et al.*, 2008) was higher in the submarine canyon than on the open slope sites, while fish biomass was higher on the lower open slope (i.e. 1200 m depth). However, smaller species and juveniles of both decapod crustaceans and fish were most abundant in the canyon head (Sardà *et al.*, 1994a), suggesting that these sites can act as recruitment areas (Sardà *et al.*, 1994a, b; Stefanescu *et al.*, 1994).

The biodiversity studies conducted for non decapod-crustacean invertebrates showed that mollusks, echinoderms, polychaetes and cnidarians (Fig. 3) are the most speciose and abundant groups, with overall biodiversity (i.e., Shannon-Wiener index) higher in the canyon as compared to adjacent open slope (mudflat) areas. The biomass and abundance of most of the studied groups were lower on the middle open slope site, the most impacted by commercial

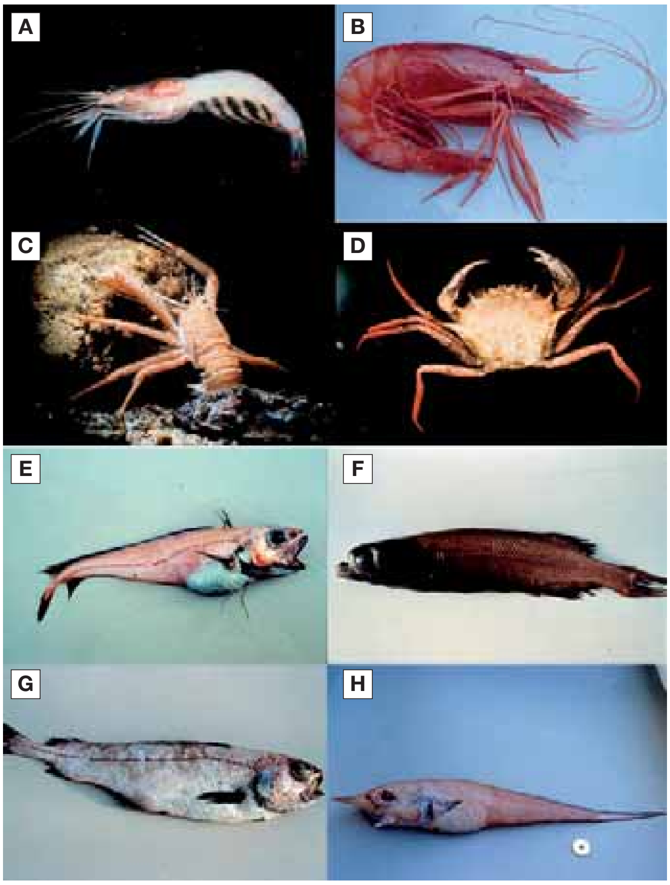

Fig. 2:

Common decapod crustaceans and fish from the deep northwestern Mediterranean continental margin. A, the glass shrimp *Pasiphaea multidentata*; B, the deep-sea red shrimp *Aristeus antennatus*; C, the galathied squat lobster *Munida intermedia*; D, the deep-sea geryionid crab *Geryon longipes*; E, the deep-sea gadiform *Lepidion lepidion*; F, *Alepocephalus rostratus*; G, the deep-sea gadiform *Mora moro*; and H, the deep-sea grenadier *Trachyrincus scabrus*. (© L. Dantart).

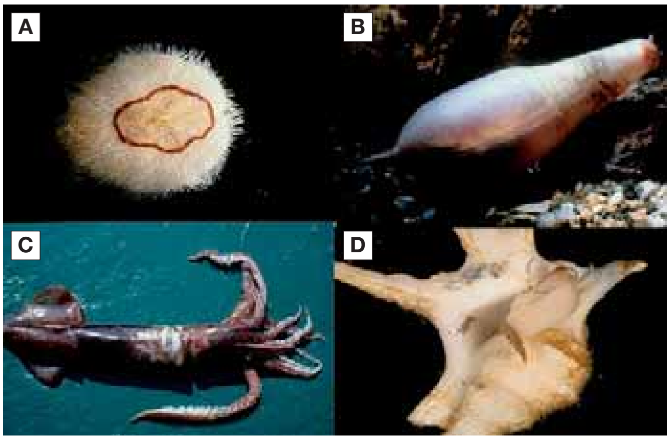

Fig. 3:

Invertebrate fauna found in the northwestern Mediterranean canyons. A, the irregular sea urchin *Brissopsis lyrifera*; B, the holothurian *Molpadia musculus*; C, the bathyal squid *Todarodes sagitattus*; and D, the mollusk *Aporrhais serresianus.* (© L. Dantart).

trawling activities. Furthermore, the upper part of the canyon and the middle open slope sites (i.e., 400 and 650 m depth) were dominated by echinoderms and mollusks, while the lower open slope site (i.e. 1200 m depth) was dominated by cnidarians and sponges. Although further detailed studies would be necessary in order to establish biodiversity patterns as a function of depth and other environmental or anthropogenic factors in and out of the canyon, it suggested that the higher abundance of sessile filter feeders (cnidarians and sponges) on the lower open slope site reflected a lack of physical disturbance from fishing. This factor should be considered in association with the enhanced hydrodynamic regime caused by the proximity of the canyon itself (Ramirez-Llodra *et al.*, 2008).

Blanes canyon

The Blanes canyon, one of the largest in the Catalan Sea (Canals *et al.*, 2004a), and the adjacent open slope, has been extensively studied for benthic species distribution and biodiversity patterns during two multidisciplinary Spanish research projects, RECS (400-900 m depth) and PROMETEO (900-1500 m depth), during the years 2003-2004 and 2008-2009, respectively.

The RECS project studied the distribution of biological communities in relation to changeable environmental patterns in three different continental margin sites: the canyon head (i.e., 364-585 m), the canyon wall (i.e., 402-603 m) and the open slope (i.e., 512-900 m). All these areas are exploited by the local Catalan trawl fleet, targeting the red shrimp *Aristeus antennatus*, one of the most appreciated fishery resources in the Mediterranean Sea (Sardà *et al.*, 2009). A total of 131 megabenthic species were identified, with decapod crustaceans and fish being the most abundant groups, accounting for the 80% of the total biomass (Ramirez-Llodra *et al.*, 2010). The faunal composition of non-crustacean invertebrates was very different than that reported in the Merenguera area (south of Barcelona) at similar depths a decade before (see previous section). While 88 species of non-crustacean invertebrates were collected in the Merenguera area, dominated by mollusks and echinoderms, only 24 species were reported from the Blanes area. In this latter site, gastropods, bivalves and ophiuroids were absent, with the diversity and abundance of echinoderms comparatively much lower than in the Merenguera area. It has been suggested that the prolonged and intensive fishery activity (i.e. over six decades) in the Blanes area may partly explain the differences observed in the Merenguera site. Although no significant differences were observed in total abundance and biomass of megafauna between the three sites, the community structure of the open slope presented a lower species richness, lower diversity and lower evenness (i.e. low dominance of any species in respect to the whole community) and a higher degree of disturbance than that observed from the canyon head and canyon wall (i.e., the abundance curve lies above the biomass curve in the ABC plot) (Fig. 4). Taken altogether, these results suggest that, although there is a canyon effect on the community structure of benthic megafauna in the Blanes area, this may be modulated by differing fishing pressures (Ramirez-Llodra *et al.*, 2010).

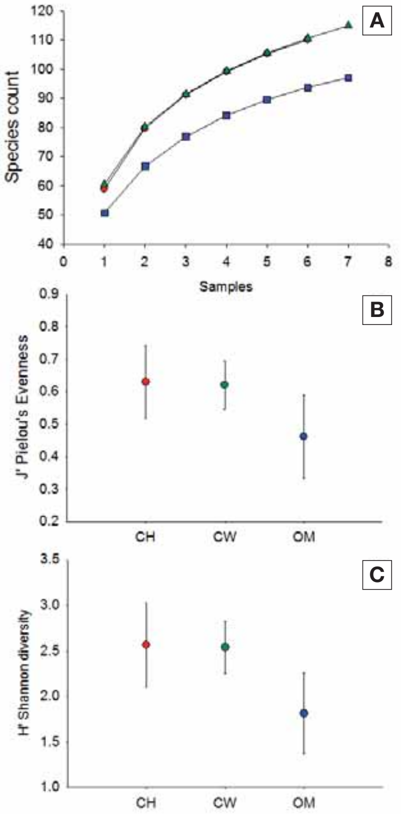

Fig. 4:

Diversity indices of megafaunal communities in the Blanes canyon and adjacent open slope (adapted from Ramirez-Llodra *et al.*, 2010). A, species accumulation plots; B, Pielou evenness; C, Shannon-Wiener diversity. CH and red dots: canyon head; CW and green dots: canyon wall; OM and blue dots: open slope.

The PROMETEO project studied biological communities and environmental patterns at 5 sites at different depths (i.e., 900, 1050, 1200, 1350 and 1500 m) on the Blanes canyon axis and on its adjacent western open slope. Because of the difficulty of sampling for megafauna with traditional sampling systems (i.e. towed nets, sledges or the Agassiz) within the narrow canyon axis, samples were only collected at 900 and 1500 m depth. The comparative analysis of species accumulation curves (i.e. the potential maximum number of species present in a specific habitat) for the open slope and canyon showed differences. While the open slope curve almost showed a plateau, suggesting that this area is relatively well sampled, the canyon curve was still rising steeply, indicating that the canyon community has only been sampled partially (Tecchio *et al.*, submitted) (Fig. 5). A total of 115 species were collected from these sites, with decapod crustaceans and fishes being the most abundant groups. A peak of biomass and abundance was reported at 1200 m on the open slope. The factors causing this peak are presently still not understood, but results from Tecchio *et al.* (submitted) suggest that a combination of different ecological forcings on deeper-living species made them better adapted to a more stable, photon-absent and high pressure system. These species would be unable to compete with the more active shallower ones (i.e. from the middle slope above 900 m depth). For these reasons a transition zone (i.e. ecotone-like boundary) may occur at 1200 m depth, with high levels of biomass but lower diversity, compared to the upper and lower slope areas. Total abundance and biomass were not significantly different between the open slope and canyon axis sampled at the same depths (900 and 1500 m), but canyon diversity was higher and community structure different from that of the open slope (Tecchio *et al.*, submitted). Species such as the echinoid *Brissopsis lyrifera* (Fig. 3A) were only collected within the canyon and were most abundant at 1500 m depth. This is similar to the distribution of this species in the upper part of the Blanes canyon and open slope

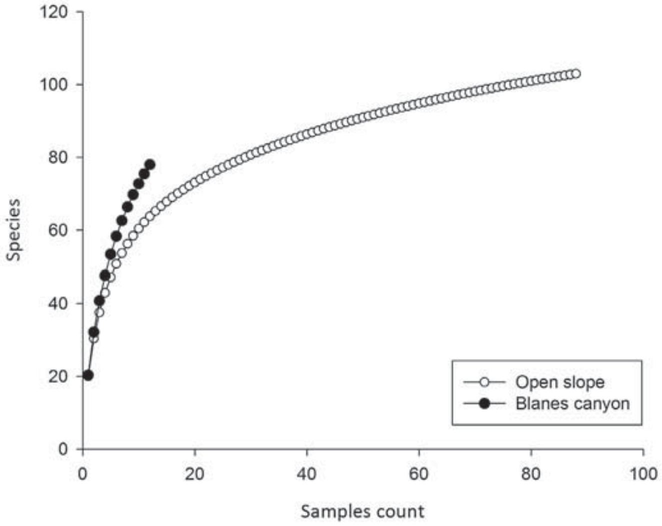

Fig. 5:

Species accumulation curves for the communities in the Blanes canyon (full circles) and adjacent open slope (open circles) (adapted from Tecchio *et al.*, submitted).

(Ramirez-Llodra *et al.*, 2010). On the contrary, *B. lyrifera* was very abundant in the Merenguera canyon and on the open slope, and fishermen report high quantities of this echinoid being previously collected in their trawl commercial gears. All this information, together with the fact that the Blanes canyon at 900 m depth is presently heavily impacted by commercial fishery, suggests a severely harmful effect of that commercial activity on benthic fragile species with low motility (e.g., the burrowing echinoid)(Ramirez-Llodra *et al.*, 2010; Tecchio *et al.*, submitted).

FISHERIES ISSUES

Fisheries on the Catalan coast related to submarine canyons: Cap de Creus, Palamós, Blanes, Arenys and Merenguera canyons

The Catalan continental margin supports an important commercial fishing activity related to the presence of several submarine canyons, from the north (i.e., Cap de Creus Canyon) to the south (i.e., the small canyons of the Ebro Delta area) (Fig. 1). The main target species of this extractive activity is a highly appreciated crustacean, the deep-sea red shrimp *Aristeus antennatus* (Risso, 1816). The annual average price in the fishery markets of this species is over 80 EU per kilo, but it can rise to 200 EU per kilo during the summer and Christmas season, this being one of the main reasons for the growing interest in this red shrimp by the Catalan fleet over the past 6 decades.

The populations of *A. antennatus* show seasonal migrations and its life-cycle is closely related to the geomorphology of the continental slope, characterized by the presence of submarine canyons (Sardà *et al.*, 1994b). Specialized fishing boats follow these seasonal movements around the canyon area. The fishing gear used by these boats is a benthic otter trawl, which is large in comparison to other traditional gears and can be operated by fishing vessels with 700–2000 HP engines. These bottom trawls have two heavy otter-boards that can spread as far as 100 m between them. The mouth of the net is 40–50 m wide, and the total length of the net is about 80–150 m. The sweeplines that connect the otter-boards to the net have a total length of 60–200 m. It is important to note that these fishing gears are much larger than those used near the coast.

Effects of dense shelf water cascading on the fisheries of the deep sea shrimp Aristeus antennatus

Dynamics of biological processes on the deep-sea floor are traditionally thought to be controlled on a seasonal scale by the vertical sinking of organic matter particles from more productive superficial photic layers, when photosynthesis occurs (Company *et al.*, 2003; Aguzzi and Company, 2010). The life histories of animals dwelling in the vast extensions of the deep-sea realm mainly rely on these sinking particles (Puig *et al.*, 2001; Company *et al.*, 2003). Despite a scenario of low productivity, the deep-sea areas sustain surprisingly large biomasses of predatory fish, crustaceans and other invertebrates (see Fig. 2 and 3) (Tecchio *et al.*, submitted). However, the increase in deep-sea fisheries often leads to rapid depletion of demersal stocks after only a few years of exploitation. Among the over-exploited stocks worldwide, Mediterranean fisheries are considered a high priority for recovery. But surprisingly, some Mediterranean stocks have not collapsed. One of the most striking examples of this paradox is the deep-sea red shrimp *Aristeus antennatus*.

Vertical and seasonal low input of organic material to the deep-sea floor is widely accepted as the main source of nutrients for canyon ecosystems (Bahamon *et al.,* 2011). However, some studies have pointed out the influence of lateral particle transport from continental margins to deep-sea ecosystems, mainly following the path of the central axis of the submarine canyons (Puig and Palanques, 1998; Canals *et al.*, 2006; Martin *et al.*, 2006; Company *et al.*, 2008). At present, we know that a climate-induced phenomenon, such as the formation of dense shelf waters and their subsequent abrupt downslope fall through canyons (i.e. like a cascade phenomenon), affects the population of *A. antennatus* (Company *et al.*, 2008). The northwestern Mediterranean is one of the regions of the world where massive, open ocean, dense water formation occurs because of cooling and evaporation of surface waters during winter-time (Fig. 6). Concurrent with this phenomenon, coastal surface waters over the wide shelf of the Gulf of Lion also become denser than the underlying waters and cascade downslope, mainly through submarine canyons, until they reach their equilibrium depth (Canals *et al.*, 2006; Palanques *et al.*, 2006a; Puig *et al.*, 2008). In very dry, windy and cold winters, such as in 2005, cascading was exceptionally intense. Under these circumstances, dense shelf waters propagate along and across the continental slope, reaching depths >2000 m, generating a thermohaline and turbidity anomaly in the Western Mediterranean Deep Water which spreads over the entire northwestern Mediterranean basin (Fig. 7). Previous intense cascading events of dense shelf waters (i.e. those reaching the deep basin) were identified after the analysis of historical hydrographic data: they occurred in 1971, 1980, 1988 and 1999, therefore showing a periodicity of between 6 and 11 years (Fig. 8) (Bethoux *et al.,* 2002).

Strong downward currents associated with intense cascading events cause the disappearance of *A. antennatus* populations from their traditional fishing grounds, producing a temporary collapse in landings, as witnessed during winters of the years 2005 and 2006 (Fig. 6). Despite this first negative effect, landings increase between 2 and 4 years after these major cascade events, preceded by an increase of juveniles (i.e. recruitment). The

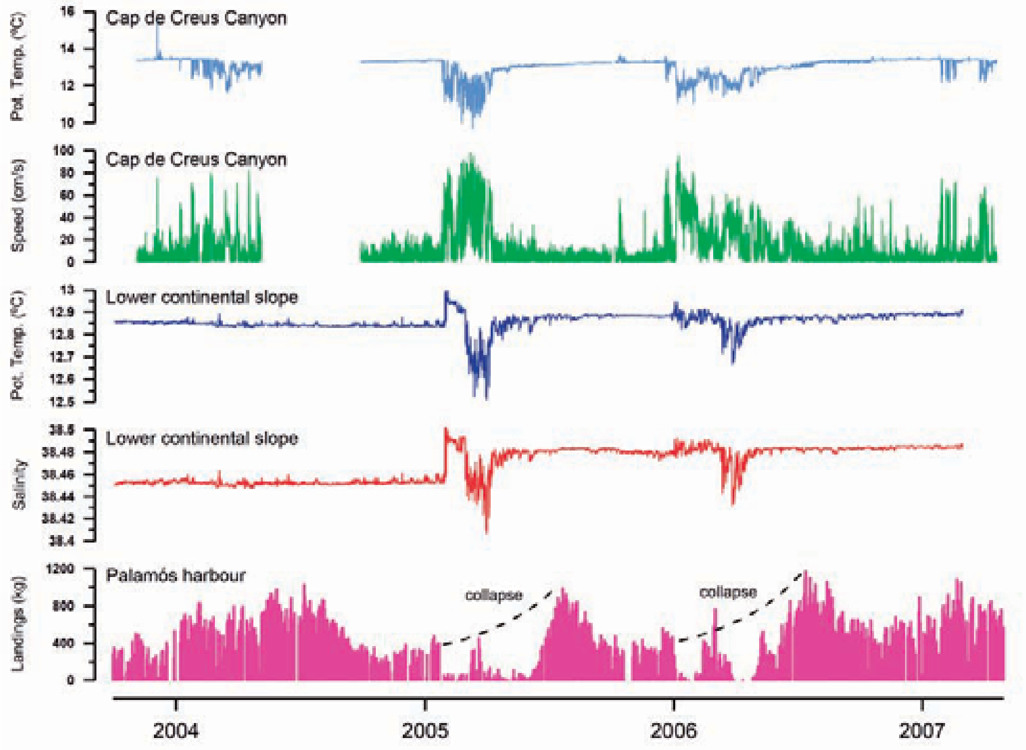

Fig. 6:

Environmental time series and daily catches from late 2003 to spring 2007. Four upper graphs: temperature and current speed at 500 m depth (Cap de Creus canyons); and temperature and salinity at the lower continental slope depths, before, during and after the dense shelf water cascading (DSWC) event of winter 2005 and winter 2006, showing the fishery collapse that encompassed over 6 months. Daily landings of *Aristeus antennatus* at the Palamós harbour are plotted as a violet bar in the bottom chart.

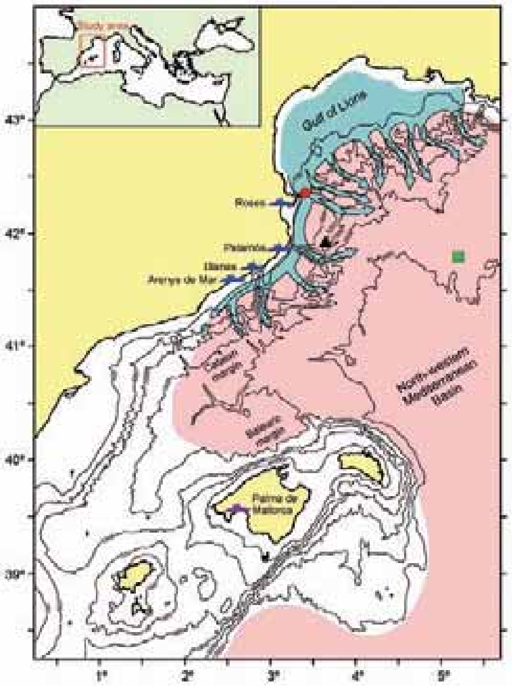

Fig. 7:

Bathymetric map of the northwestern Mediterranean showing the location of the main fishing harbors considered in this case study (blue ships). Pale blue arrows indicate the pathway of the dense shelf water cascading mechanism extending from the Gulf of Lion along and across the continental slope, while the faded pink area represents the region affected by the thermo-haline and turbidity anomaly observed in the Western Mediterranean Deep Water after the 1999 and 2005 major cascading events.

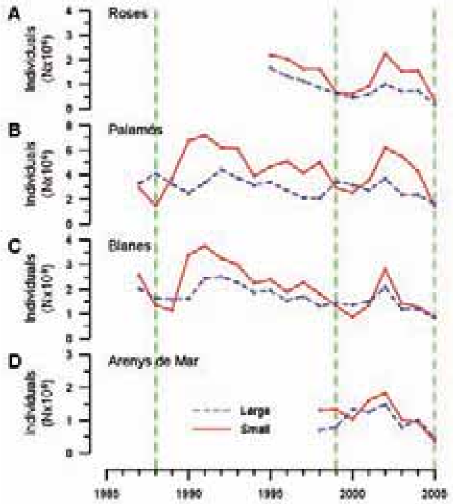

Fig. 8:

Yearly landings at the four most northern harbors of the Catalan cost expressed as number of individuals. Estimation of the abundance of small (continuous red line) and large (dotted blue line) individuals of *Aristeus antennatus* derived from the annual landings in the studied harbors. Green dashed lines indicate the years when major cascading events occurred, i.e. 1988, 1999 and 2005. The temporal evolution of the population structure of *Aristeus antennatus* in all harbors was linked to those cascading events. The number of small individuals increased two and three years after the event, prior to the increase in the number of large individuals, indicating that cascading events enhance the recruitment process of this species.

transport of particulate organic matter from shallower shelf areas associated with cascading thus enhances the recruitment of this deep-sea living resource, reversing the general trend of its over-exploitation (Company *et al.*, 2008).

Settlement and preferential recruitment areas for this species occurs well below 1000 m depth (Sardà *et al.*, 2004). Postlarval individuals (<10 mm CL; carapace length) have only been found at 1200 m depth during winter-time, and juveniles <20 mm CL are only present at non-fishing depths below 1000 m depth. Small juveniles of this species dwell at depths below 1000 m and undertake ontogenetic migrations to shallower grounds (500-900 m) in the canyon heads in the winter period, when fishing mainly takes place for adult populations in all submarine canyons off the Catalan coast.

This climate-driven mechanism of interaction across ecosystems originated in shelf environments and, occurring on a decadal time-scale, controls the biological processes of a deep-sea population and prevents fishery collapse. The physical disturbance originated by strong currents during intense cascading events displaces the individuals of a deep-sea living resource from the fishing grounds inside and around submarine canyons (Fig. 6). However, after 2-3 years, an increase in landings occurs, preceded by an increase in juvenile landings (Fig. 8). Thus, the increases in landings of this species can be explained by an enhancement of its recruitment process favored by the large transport of particulate organic matter to the basin during intense cascading events.

Climate-induced phenomena other than Dense Shelf Water Cascading affect water and sediment transport patterns and thus may have an impact on biological communities. They are related to the occurrence of coastal storms. The Mediterranean Sea is one of the most cyclogenic regions in the northern hemisphere during winter time, and severe weather conditions associated with storm development are common. Associated intense wind, heavy rains, flash floods, high waves and intensified currents commonly cause serious damage along the shoreline, occasionally including loss of human lives. Recently, a unique data set was published showing how one of the most extreme coastal storms of the last decades lashing the Western Mediterranean area, with measured wind gusts of more than 25 m s^{-1} and maximum wave heights over 14 m, rapidly impacted the deep-sea ecosystem in the Blanes submarine canyon (Sanchez-Vidal *et al.*, 2012). In addition to coarse shelf sediment remobilisation, a large reservoir of mostly marine organic carbon associated with fine particles subjected to wave resuspension along the shoreline and on the continental shelf was also mobilized and redistributed across the deep basin. Sanchez-Vidal *et al.* (2012) demonstrate that severe coastal storms are highly efficient in transporting organic carbon from shallow to deep, thus contributing to its sequestration. Thus, and in addition to Dense Shelf Water Cascading, other intermittent natural atmospheric drivers such as coastal storms may have the potential to highly impact the deep-sea ecosystems and their associated living resources.

Effects of trawling on turbidity, sediment transport and accumulation in canyons

Among the anthropogenic activities that can impact the seafloor and remobilize marine sediments, trawling is recognized as the most alarming due to its widespread geographical distribution and recurrent nature. The effect of trawling activities has been a topic of interest in ecology and fishery resource studies because of the impact of gears on benthic ecosystems (Watling and Norse, 1998). That effect recently also become a topic of interest because of its physical impact on muddy grounds of continental shelves and slopes and its consequent effect on the biodiversity of these habitats. The impacts of artificial resuspension on the seafloor tend to be more severe and long-lasting with increasing water depth, owing to the correlative decrease of natural disturbances which can overcome them. Furthermore, impacts associated with trawling may extend down-slope beyond the regions that are actually being fished. This is particularly true in steep environments such as submarine canyons, where previous studies have shown that trawling gears can generate far-reaching sediment gravity flows (Palanques *et al.*, 2006b).

Direct observations by Remote Operated Vehicles (ROV) shows that the continental margin along the Catalan coast is intensely fished down to 900 m depth and consequently presents a high density of trawl tracks (authors' own unpublished data).

Perhaps the most worrying issue is that, following the exhaustion of traditional coastal fisheries, commercial trawling has been progressively extending offshore during the last decades. In this context, the physical effects of trawling in submarine canyons are still poorly known, but recently Palanques *et al.* (2006b) showed the occurrence of a direct relationship between trawling activities, turbidity peaks and sediment flux, which increase during the calm, dry season. These authors also discussed the mechanisms that cause these unexpected increases in sediment transport in the Palamós canyon, and the relevance they have for present-day sediment dynamics.

Due to their peculiar hydrodynamic and biogeochemical features, submarine canyons and their rims harbor considerable biodiversity and faunal abundance and, as a consequence, the soft bottoms surrounding submarine canyons are often targeted by trawlers, which today can even venture within steep canyon walls. The studies conducted in the Palamós submarine canyon documented propagation to the canyon axis of trawling-induced resuspension within the canyon walls (Palanques *et al.*, 2006b) and the imprint of this anthropogenic activity in the deep sedimentary budget (Martin *et al.*, 2008). The Palamós Canyon is, together with Blanes Canyon, the largest submarine canyon in the Catalan margin south of Cap de Creus, and constitutes a remarkable ´hotspot´ for suspended and downward sediment fluxes in this margin (Martin *et al.*, 2006, 2007; Zuñiga *et al.,* 2009). The canyon is deeply incised in the continental shelf and its steep flanks, indented by networks of gullies, favor the active transport (both natural and human-driven) from the continental shelf and upper slope into the deep canyon axis. The canyon area hosts two fishing grounds, one on the northern canyon wall, which is called Sant Sebastià, and one on the southern canyon wall close to the canyon head axis, which is called Rostoll. The trawling fleet operating in the Palamós canyon walls mainly target *Aristeus antennatus* and, as said above, has been very active to depths up to 850 m during the last decades.

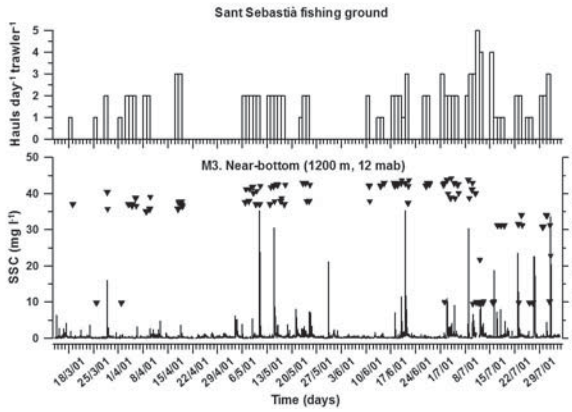

Fig. 9:

Number of hauls per day and per trawler recorded by a fishing vessel specializing in the red deep-sea shrimp *Aristeus antennatus* (adapted from Palanques *et al.*, 2006). The data corresponds to fishing activity in the fishing ground named Sant Sebastià (north canyon wall) in spring and summer 2001 (above). Water turbidity (SSC-suspended sediment concentration) and haul depth in the Sant Sebastià fishing ground in spring and summer 2001 (below).

The number of hauls per day by a single fishing boat and depths where it operates are shown in Fig. 9. The data shows that when the fishing activity is deeper, i.e. during late spring and summer months following the seasonal movements of the red shrimp, the suspended sediment concentration (SSC) in the canyon axis (>400 m deeper than fishing grounds) is correspondingly higher. The mechanism that connects both observations has been identified as sediment-laden flows triggered by the heavy fishing gears, as indicated by simultaneous and abrupt increases in near-bottom downslope current speed and SSC, and by the temporal coincidence of these turbidity peaks with the passage of the fishing fleet along the nearest fishing grounds (Fig. 10). Recent observations have highlighted the fact that these sediment gravity flows triggered by the trawling fleet are produced on a daily basis and during these events SSC increases over natural baselines by up to two orders of magnitude, from the seafloor to a minimum height of 100 m above it (Martin *et al.*, in prep.). It has also been proposed that the cumulative effect of this persistent anthropogenic mechanism of sediment resuspension and transport has resulted in noticeable changes of sediment accumulation rates inside the canyon, particularly since the accelerated industrialization of the fleets in the 1970s (Martin *et al.*, 2008). The ecological consequences of all these human-induced perturbations are compelling and are at present under study.

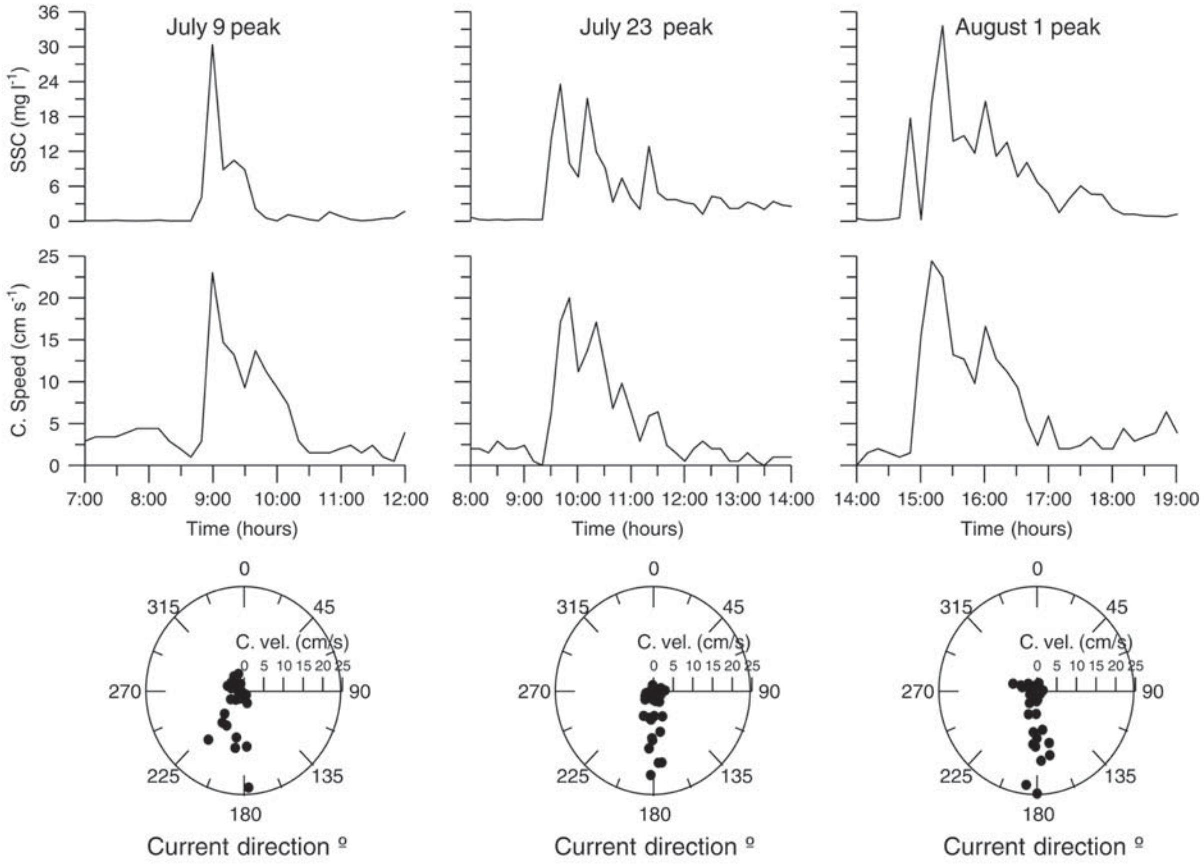

Fig. 10:

Detail of Suspended Sediment Concentration (SSC) peaks, current speed and current direction (in scatter plot) during the main gravity flow events (adapted from Palanques *et al.*, 2006). Turbidity and downslope current speed increases occurred about 2 h after the fishing fleet crossed the Mongrí gully along the Sant Sebastià fishing ground.

POLLUTION

Marine litter

The accumulation of marine litter on the deep-sea floor is of increasing concern to the scientific, political and Non Governmental Organization (NGO) communities. The main sources of marine litter include highly inhabited coastal areas (such as the Mediterranean coast), discharges from rivers, illegal dumping from ships, and accidents or natural disasters. The routine dumping of waste from ships was legally banned by the London Convention in 1972 and, in the framework of the Barcelona Convention (1976) for the protection of the Mediterranean Sea against pollution, the Mediterranean countries adopted a protocol in 1980 for the protection of the Mediterranean Sea against pollution from land-based sources (UNEP, 2009). Nevertheless, littering is a persistent problem, with approximately 6.4 million tonnes of litter being dumped in the oceans each year, part of which sinks to bathyal and abyssal depths (Ramírez-Llodra *et al.*, 2010). In the revised version of the Barcelona Convention protocol (1996), marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (UNEP, 2009).

Fig. 11:

Examples of marine litter collected with an otter trawl during scientific sampling for megafauna in the bathyal northwestern Mediterranean (© Ramirez-Llodra, ICM-CSIC).

Although to date most studies of marine litter have been conducted on floating debris, coastal areas and the shelf (Galgani *et al.*, 2000), and information on deep-sea habitats is scarce, some studies are available on bathyal and abyssal habitats and fauna (Galil *et al.*, 1995; Galgani *et al.*, 1996, 1998, 2000, 2010; Watters *et al.*, 2010; Miyake *et al.*, 2011; Ramirez-Llodra *et al.*, in prep.).

Recently, the accumulation and distribution of marine litter were quantified during the PROMETEO project, both on the Blanes canyon and adjacent open slope areas at 900 and 1500 m depth, from the otter trawl and Agassiz samples conducted for megafauna. The most abundant litter types found were plastics (e.g., bags, buckets, bottles), glass (e.g., bottles and broken glass) and metal (e.g., tins and cans) (Fig. 11). Clinker, the hard residue of burnt coal from steam ships that operated at the end of the 18th century for 150 years, was found in all samples, often colonized by the brachiopod *Grypheus vitreus*. A wide variety of domestic (e.g. shoes, toothbrushes, a chair) and industrial (e.g. oil drums, tires) waste objects were also collected during the PROMETEO survey, and lost or discarded longlines and fishing nets were also common in the samples.

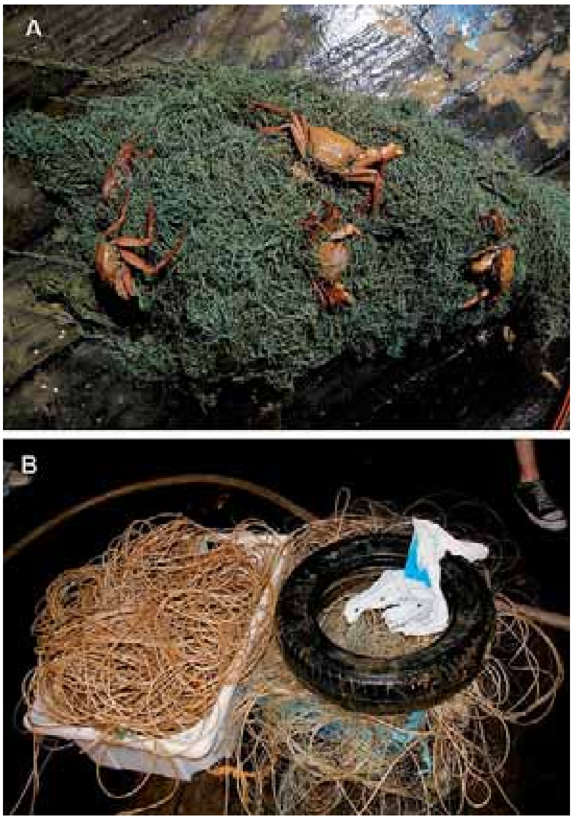

Fig. 12:

Lost or discarded fishing gear collected from the deep Mediterranean Sea. A, example of ghost fishing from a trawl net. B, longline. (© Ramirez-Llodra, ICM-CSIC).

Although variability in the type and abundance/weight of litter was high amongst samples, preliminary results indicate a trend of accumulation of litter at depth, mostly at the 1500 m sampling site, both in the canyon and on the open slope. Significant differences in litter abundance were not found between the canyon and open slope at comparable depths. Canyons can act as conduits for transport of matter from the shelf to the deep basin, and a higher amount of litter would be expected to be found in the canyon compared to the open slope. However, in our study, we only sampled down to 1500 m depth and therefore we could have missed the flushing effect of canyons, where litter would accumulate at the deeper parts of these marine geological structures, below 2000 m depth (Ramirez-Llodra *et al.*, in prep.). A study of marine debris in the Gulf of Lion (NW Mediterranean) showed that only small quantities of litter were found on the shelf, while most of the litter was found on the canyon and bathyal plain, and that up to 90% of the litter was plastics of various sorts (Galgani *et al.*, 1996). The accumulation of litter in certain areas has been related to the proximity of large cities, the topographic characteristics of the seafloor (e.g. canyons, rocks, crevasses) and hydrographic conditions (Galgani *et al.*, 1996, 2000).

The effects of marine litter on the habitat and fauna are still poorly understood, but they include suffocation of animals, physical damage of fragile communities such as cold-water corals or sponges, ingestion of small litter particles and microplastics, toxicity from paint chips or persistent organic pollutants (see below) and ghost fishing from lost or discarded fishing gear. Evidence of ghost fishing was provided by a net collected from the NW Mediterranean seafloor at 2000 m depth which contained several dead and moribund *Geryon* crabs (Fig. 12). Further dedicated studies following standardized methods are essential to provide a clear picture of litter distribution on the seafloor and to describe the effects of this litter on deep-sea habitats and their fauna. The results will provide crucial data to address the marine litter problem and propose solutions.

Chemical pollutants

In recent years there has been growing awareness that the deep-sea is not as pristine as often presumed and that it may actually act as a global sink for persistent contaminants that enter the marine environment (Ballschmiter *et al.*, 1997). Due to their shape and proximity to the coastline, submarine canyons have been shown to act as natural conduits for organic and particulate matter, including sediment-associated anthropogenic contaminants, transported from coastal areas to the deep-sea (Puig *et al.*, 1999; Paull *et al.*, 2002; Hartwell, 2008; Palanques *et al.*, 2008; Richter *et al.*, 2009; Jesus *et al.*, 2010). In particular, persistent organic pollutants (POPs) such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDTs) could be of major concern because of their high lipophilicity, persistence and toxicity. In the NW Mediterranean Sea, POPs have been found to bioaccumulate in a number of deep-sea organisms (García *et al.*, 2000; Porte *et al.*, 2000; Solé *et al.*, 2001; Borghi and Porte, 2002), but knowledge on the impact of anthropogenic contaminants on deep-sea ecosystems is still limited. Findings from a previous study indicated that fish caught inside the Blanes submarine canyon were exposed to higher contaminant levels compared to individuals from the adjacent open slope, although this trend was not reflected in the chemical body burden analysis of these same organisms (Solé *et al.*, 2009). Furthermore, in a more recent study conducted within the framework of the PROMETEO project (Koenig *et al.*, submitted), the combined analysis of chemical and biochemical parameters seemed to support these initial findings. Higher POP levels in muscle tissue and induced xenobiotic metabolism and antioxidant responses in the liver/hepatopancreas were observed in a fish and a crustacean species, indicating that animals within Blanes Canyon were exposed to higher contaminant levels (Fig. 13).

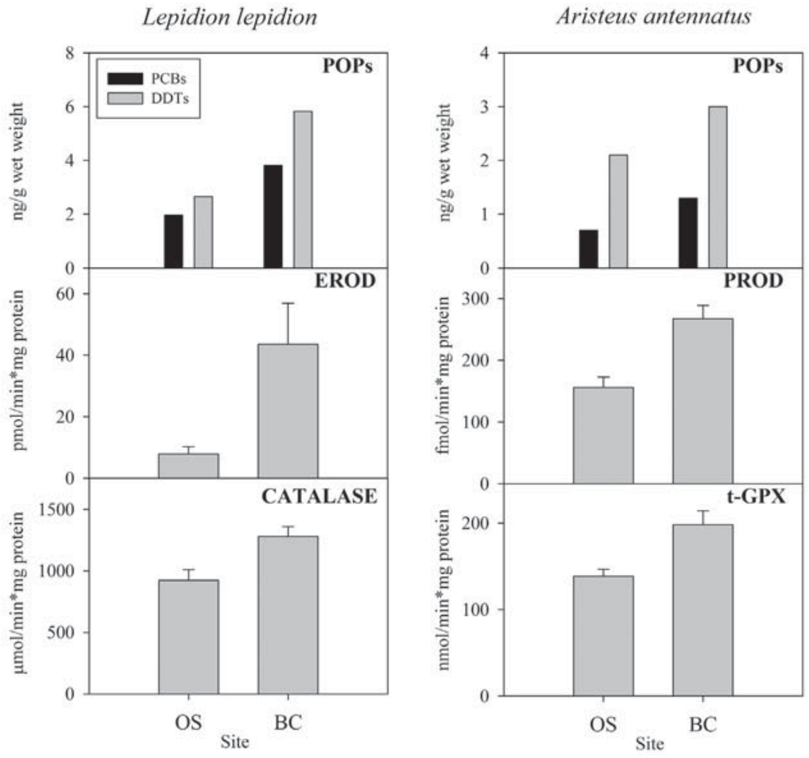

Fig. 13:

Contrast between samples from open slope (OS) and Blanes canyon (BC) of *Lepidion lepidion* and *Aristeus antennatus* at 900 m. Reported results include persistent organic pollutant (POP) levels (ΣPCBs and ΣDDTs) in muscle tissue and hepatic biomarker responses cytochrome P450 (EROD or PROD), and antioxidant (CAT or GPX) enzyme activities.

However, results also indicated that the accumulation of POPs within the canyon may be subject to spatial and temporal fluctuations. Because of the lipophilic nature of POPs, these compounds tend to bind to suspended particles in the water column and be transported along with them. Hence, the spatial and temporal distribution patterns of POPs are likely to be influenced by the periodicity and amplitude of sediment transportation and re-suspension processes. Higher pollution loads may thus be transferred to the canyon during local meteorological forcing events, which are known to principally occur from late autumn until early spring (Heussner *et al.*, 2006; Zúñiga *et al.*, 2009). Moreover, contaminant accumulation appears to be more important at the head of Blanes canyon (900 m) than at greater depths (1500 m). This can be explained by the fact that, as shown by previous studies, the propagation of mass fluxes within the canyon axis depends on the magnitude of these episodic events (Zúñiga *et al.*, 2009). Hence, it is possible that storms of relatively short duration result in higher sedimentation rates at shallower depths, while events of greater intensity such as dense-shelf water cascading (DSWC) could cause a transfer of larger amounts of material from the upper canyon regions to the deep-sea (Canals *et al.*, 2006; Palanques *et al.*, 2006a; Zúñiga *et al.*, 2009; Sanchez-Vidal *et al.,* 2012). The head of the canyon may thus act as a temporary trap for organic contaminants, which are episodically transferred to greater depths during major storm events that flush the canyon, propagating throughout the northwestern Mediterranean deep-sea basin (Canals *et al.*, 2006; Company *et al.*, 2008). Consequently, species inhabiting submarine canyon ecosystems may be at risk of experiencing higher levels of exposure to anthropogenic contaminants and consequent pollutant-induced adverse effects. It is important to further investigate the role of submarine canyons in the transport of organic contaminants from surface waters to the deep-sea and the potential impact this may have on organisms dwelling within the canyon.

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3.9. South iberian submarine canyons in the Alboran sea: geohabitats, associated communities and fisheries resources

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INTRODUCTION

The South Iberian continental margin of the Alboran Basin is crossed by numerous submarine canyons which play a key role in the transfer of matter and energy between the continent and the deep basin, as well as in the fertilization of the waters around their heads. In addition to feeding the deep basin with sedimentary deposits, these canyons are places of great biological activity, resulting from the vertical water mass motions favoured by their morphology.

The canyons cutting into the Alboran continental margin, and particularly those located in the western basin, are relatively small (not exceeding 10 km in length) when compared with the great oceanic submarine canyons that form in front of major deltas. However, they constitute one of the drainage networks with the greatest number of canyons per km^2 in the Mediterranean Sea. In addition to the six individual canyons dealt with in this study, plus the hierarchical complex that governs the Motril turbidite system, this network includes two other canyons: (1) the Algeciras Canyon located in the Strait of Gibraltar, and (2) the Ceuta Canyon located on the North African margin. Of the other canyons in the Alboran Ridge that are beyond the scope of this study, the best-known are the Al-Borani Canyon and the Piedra Escuela Canyon, both located on the southern slope of the ridge.

The phenomenon of water enrichment at the heads of submarine canyons is well-known. Although this phenomenon has not been sufficiently studied in the whole area, the available data on the Motril canyons and tributaries suggest that they are a major factor in increasing the productivity of the water column because they favour ventilation and thus facilitate fertilization. They are therefore places of high biological productivity and potential hot spots of great biodiversity.

Submarine canyons are very common on the continental margins of seas and oceans. Their origin, geomorphology and evolution are a reflection of a dynamic equilibrium between erosion and sedimentation. The mechanisms governing their genesis and development are highly varied and include factors such as tectonics, climate change, erosion and the regional hydrodynamic system in which they are located (Greene *et al*., 2002; Lastras *et al*., 2009; Mountjoy *et al*., 2009).

The drainage mechanisms and morphology of the slopes resemble the fluvial reliefs on the continent, to the extent that they may develop cross sections with common features, such as the asymmetry of their slopes. This fact reveals a similarity in their role as mass transfer systems, moving sediment load from the head on the continental shelf to the drainage channel in the deep basin. They are therefore highly active systems that facilitate the formation of deposits at the foot of the continental slope and rise, building voluminous sedimentary bodies with fan morphologies (Díaz-del-Río *et al*., 2009). These deposits are predominantly composed of fine materials which form vast turbidite bodies (sediment transported downslope by turbidity currents), whose development is conditioned by the tectonic framework and structural configuration of the margin (Alonso and Ercilla, 2003). These deposits usually have abundant sedimentary structures related to the dynamics at the sediment-water interface, which is mobilized by the effect of the tides. This fact has been observed in canyons that reach great depths, in which these structures are changed daily by the tidal effect. A similar dynamic has been found in bottom deposits of other turbidite systems not related to canyons, such as the Gulf of Cadiz (Stow *et al*., in press).

The morphology of the canyons does not follow a consistent pattern: each canyon develops its own. However, some common features can be observed, including terraces and landslides. Both submarine features occur mainly on the slopes of the upper and middle reaches of the canyon, but more extensively at the heads, a phenomenon that is linked to fractures that act as slide scars. For this reason, deposits inside the canyon are usually chaotic, with the slide material (coarser and less sorted) being mixed with the material transported along the axis (finer and better sorted). Landslides are also common in turbulent sediment transport and can reach the deep fan, generating collapse structures with lobate edges. Near the head, coarser materials predominate and the walls are steeper. The terraces are generated on the gentlest slopes, accentuating the asymmetrical nature of the valley and diversifying the morphology along its axis, with alternating reaches of terraces and landslides.

The canyon's valley form is shaped by a continuous succession of episodes of filling and erosion/incision, so this sequence of events must be related to fluctuations in sea level, which in turn cause situations of connection and disconnection from the mouths of rivers linked to the canyon heads (Mulder, 2011).

The incision produced by the head of submarine canyons on the continental shelf and upper slope increases the complexity of the hydrological processes in the two provinces of the continental margin. Rising of deep waters and sinking of upper slope waters have both been observed. In areas in which upwelling of deep waters takes place, the vertical dynamics can reach extremely high speeds, thus favouring the sediment dynamics of the canyon (García Lafuente *et al.*, 1999). Consequently, the nutrient-laden water has a fertilizing effect with important implications for the vertical flux of carbon in the water column (Tintoré *et al.,* 2001).

The study of these systems, and of the deposits that they generate, goes beyond the knowledge of the mechanisms governing them and the biological and geological role they play in marine basins. They have proven to be major deposits of hydrocarbons, and there is therefore an economic interest in studying them as a model applicable to ancient deposits. This has allowed us to further our knowledge of the canyons and to discover their natural values as habitats of great natural interest.

A REVIEW OF THE DYNAMICS OF ATLANTIC AND MEDITERRANEAN WATER MASSES IN THE ALBORAN BASIN

The exchange of water masses between the Atlantic Ocean and the Mediterranean Sea is the most important feature for understanding the present circulation pattern in the Alboran Sea and the Gulf of Cadiz. This exchange occurs in the Strait of Gibraltar and is favoured by the insufficient water inflow received by the Mediterranean Sea. Because of differences in density between the water masses, the Atlantic water enters the Alboran Sea at the surface, whereas the Mediterranean Outflow Water flows towards the Atlantic Ocean at depth.

The characteristics of the water masses (Fig. 1) that occur in the Alboran Sea are:

(1) Atlantic Surface Water (ASW), which flows to the east at a depth of 0 to 150-200 m, with temperatures between 9 and 16 °C and salinities of 36.2 to 36.6.

(2) Intermediate Mediterranean Water (IMW), which flows westward at a depth of 200 to 700 m, with a salinity of 38.45 to 38.50 decreasing from east to west in the Alboran Sea, temperatures of about 13.1 °C and an oxygen content of 4.2 ml/L.

(3) Deep Western Mediterranean Water (DMW), which flows below 1000 m depth, with a salinity of 38, a temperature of 12.7 °C and an oxygen content of 4.2 ml/L (Gil, 1990; Millot, 1987).

Water exchange through the Strait of Gibraltar is interpreted as a two-layer system which behaves according to a well-known pattern (Millot, 1987). The flow of incoming Atlantic water (NASW-ASW) is known as the Atlantic jet and follows an eastward route, resulting in the formation of the two anticyclonic gyres. The strong thermohaline gradient associated with the Atlantic Current makes both gyres clearly visible in satellite images. However this pattern shows high temporal variability (Vargas-Yañez *et al.*, 2010).

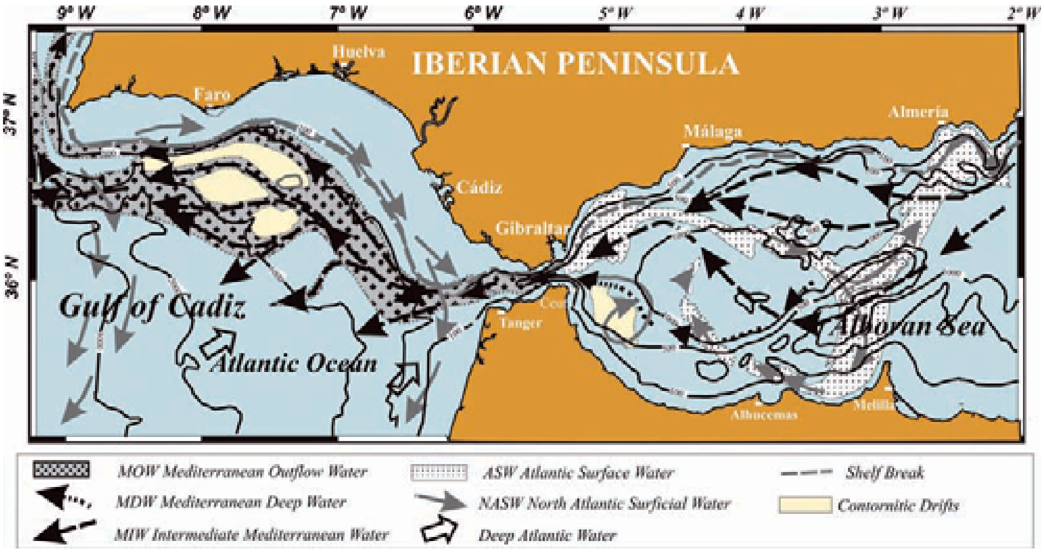

Fig. 1:

Sketch of water mass circulation in the Atlantic and Mediterranean forced by exchange through the Strait of Gibraltar (Hernández-Molina *et al.*, 2002).

The western anticyclonic gyre (WAG) covers almost the entire western sector of the Alboran Sea and runs almost parallel to the Spanish coast, following the geometry of the continental slope and interacting with the topography of the Iberian margin platform. This gyre is considered a quasi-permanent structure in time, although its size, shape and location are fairly dynamic because it is controlled by the exchange of Atlantic and Mediterranean water masses in the Strait of Gibraltar. The eastern anticyclonic gyre (EAG) is more fluctuating; it depends on the WAG and can reach as far as Cape Gata.

GEOMORPHOLOGY: THE MAIN FEATURES OF THE SUBMARINE CANYONS

The South Iberian submarine canyons of the Alboran Sea are smaller than other canyons described in epicontinental seas. On the South Iberian continental margin there is a high concentration of canyons, although two of them, the Algeciras and Ceuta canyons, are located outside the study area. From west to east, the canyons and tributary systems that will be considered herein include La Linea de la Concepcion, Guadiaro, Bóvedas, Torrenueva and Fuengirola, the Motril System (Almuñecar/Salobreña, Motril and Calahonda) and Almería. They are no more than 10 miles long and do not have major tributaries, with the exception of the Almería Canyon, which has a maximum length of 55 km and numerous tributaries with a dendritic configuration which drain its western side formed by the upper slope in front of the Campo de Dalías. The position of the canyons relative to the surrounding relief is important for understanding their genesis and evolution. The first group of five canyons excavated in the western basin margin are short and have steep slopes. They are concentrated off the stretch of coast between Punta Europa and Fuengirola (Fig. 1).

A second group is located off the central sector of the Alboran coast, on the continental slope that descends to the Motril marginal shelf. This motley group composed of three main canyons, Almuñecar/Salobreña, Motril and Calahonda, has built the Motril turbidite system, a very hierarchical and incised complex that is very active, channelling sedimentary material from the continental shelf to the foot of the slope. This system forms major clastic accumulations deposited at the distal part of the drainage channels, adopting morphologies characteristic of a submarine fan. In some ways, it is the most interesting one because it has developed a depositional system at shallower depths, on the high bottoms of the Motril marginal shelf. Moreover, not all submarine canyons in the Alboran Sea have major turbidite systems; the development of such systems depends on many factors, most notably the ability to accumulate load in a place where remobilization is difficult (Fig. 2).

Finally, cutting into the eastern edge of the South Iberian continental margin, we find the longest, deepest and most developed canyon of the ones under consideration: the Almería Canyon. It starts on the continental shelf off the Sierra de Gata, where its head is incised, and ends on the deeper bottoms of the eastern Alboran Basin, where it forms a massive turbidite fan, resulting from the large amount of solid load that it has transported since its incision into the continental slope.

The presence of canyons in the Alboran Basin is related to the glacio-eustatic oscillations that took place in the Plio-Quaternary and to tectonic activity, which has imposed geomorphological features such as the direction of some canyons (e.g. Almería). Variations in the position of the coastline on the continental shelf caused by sea level changes have led to an advance and retreat of the mouths of the major rivers. These result in the formation of a succession of fluvial deposits that extend from the inner shelf to the slope break (e.g. the Motril System). The erosive effect of the sediment load transported by rivers completed the modelling of the canyon heads, causing the retreat of the slope break to areas close to the coast (Tab. 1).

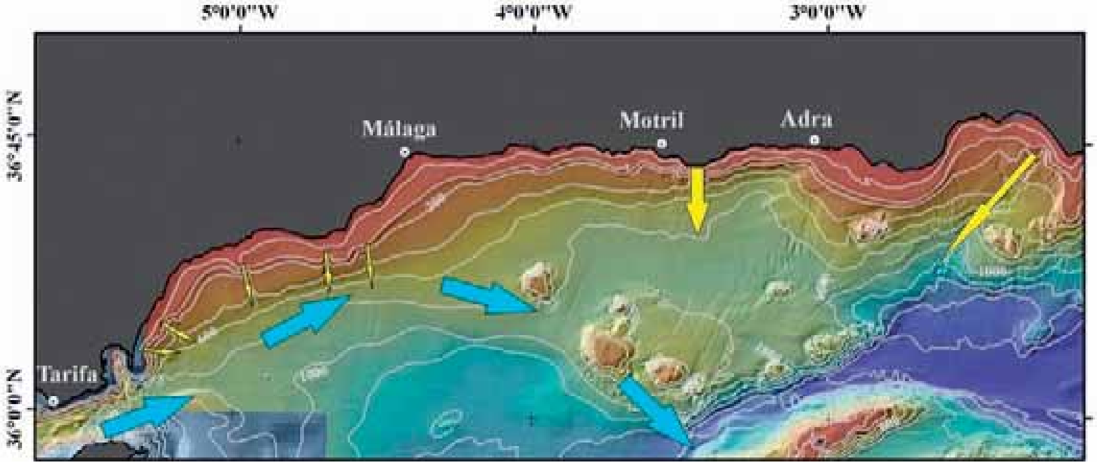

Fig. 2:

Location of the submarine canyons of the South Iberian continental margin of the Alboran Sea discussed in this paper. The location of these canyons (from west to east) is indicated with a yellow arrow: La Linea de la Concepción, Guadiaro, Bóvedas, Torrenueva, Fuengirola, Mijas and Almeria. Blue arrows indicate the location of the anticyclonic gyre of the Atlantic jet, which dominates the entire western basin and activates the vertical water motion, fertilizing the water at the heads of the submarine canyons.

Canyons of the Iberian Margin of the western Alborán Basin	Minimum distance from the head to the coast / depth of the head	Canyon length / depth of the far end of the drainage channel	Surface area of the deep fan
La Línea Canyon	1.8 km/57 m	13 km/756 m	41 km^2
Guadiaro Canyon	2.7 km/61 m	23 km/798 m	62 km^2
Las Bóvedas Canyon	6.2 km/52 m	33.7 km/871 m	64 km^2
Torrenueva Canyon	5.3 km/85 m	26.6 km/981 m	Diffuse
Fuengirola Canyon	6 km/93 m	35.5 km/1052 m	210 km^2

Tab. 1:

Some features of the submarine canyons of the western Alboran Basin and their turbidite deposits, expressed in numerical values.

The canyons of the western basin: geomorphology and habitats

In this section we consider a group of five short, steep submarine canyons. They are located on the Iberian continental margin close to the Strait of Gibraltar. They are all cut into the west of the Motril marginal shelf (Fig. 2), reaching as far as Punta Europa (Gibraltar), on a well-developed continental margin.

In this area of the basin we distinguish two well-defined physiographic provinces (Muñoz *et al.,* 2008; Palomino *et al.,* 2011) whose relief is strongly changed in the areas incised by the submarine canyons: (1) the shelf and slope, and (2) the continental rise and deep basin.

The continental shelf, with a clearly arched geometry parallel to the coastline, has a subhorizontal surface with a main slope break located at an average depth of 120 metres. It is dominated by consolidated and disaggregated sedimentary bottoms with scattered rocky outcrops, such as those of El Placer de las Bóvedas (Fig. 3). The heads of the submarine canyons are incised in the slope break, causing landward erosion that makes a deep incision in the continental shelf. Its effects result in a sudden increase in depth at points very near the coast (Table 1). This is a feature of great importance, because it facilitates the channelling of sediment transport from the continental shelf towards the deep basin. This involves a loss of material towards the turbidite systems of the canyons, whose facies are mainly chaotic (heterogeneous, intermixed sediments).

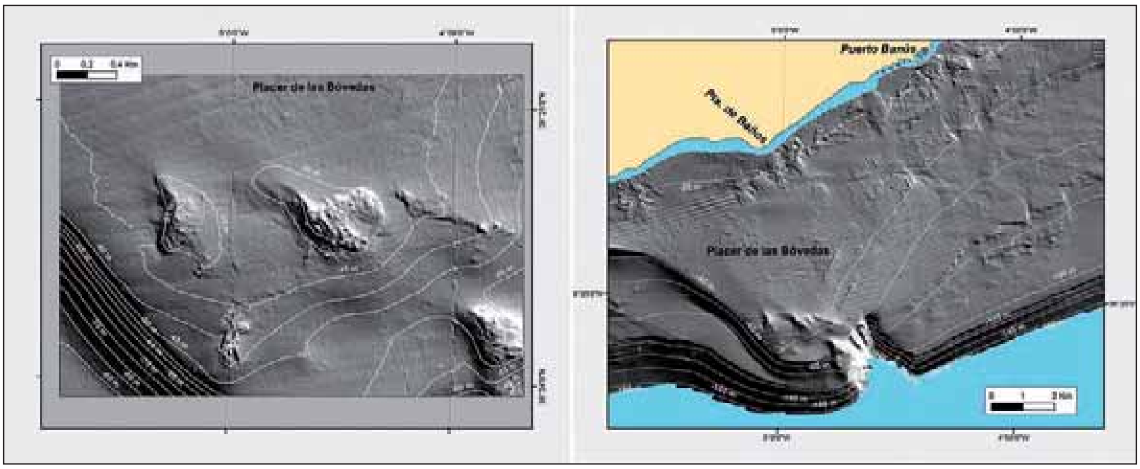

Fig. 3:

(Left) Relief of El Placer de las Bóvedas obtained with a multi-beam echosounder system. The bathymetric contours have been superimposed to highlight the depth of the rocky outcrops that are hot spots of high biological diversity. (Right) Deep environment of El Placer de Bóvedas, showing the position of the Las Bóvedas Canyon head on the eastern edge of the rocky reliefs.

The continental slope, with a concave-convex profile, is very homogeneous, highlighting the reliefs eroded by the submarine canyons in the form of furrows. In this sector, an increase in width is observed from west to east, reaching its maximum value (45 km) at the point of contact with the Motril marginal shelf (Vazquez, 2002; Palomino *et al.,* 2011). Its axial gradient decreases downslope, showing an average value of 1.6° to 0.8° (Alonso and Ercilla, 2000). At the foot of the slope is the continental rise, developed as a gently sloping wedge that links the continental slope to the deep basin. This area contains most of the fans constructed with the turbidite sediments transported through the canyons. The deposits can have a large volume and extensive spatial development. The very high resolution seismic profiles indicate the great thicknesses that these deposits can reach in a relatively short time as a result of the high transport activity of these systems. A good example of these deposits is found in the Fuengirola Canyon, which has constructed a large turbidite system occupying an area of about 210 km^2.

The value of the heads of these canyons as habitats has not yet been studied sufficiently or in sufficient detail, largely because of the difficulty of sampling their bottoms with the necessary equipment. Major differences between them have been observed, in particular in the hydrological conditions governing each system, though the associated benthic communities have not been studied to date. Two individual cases are the heads of the Las Bóvedas and Torrenueva canyons. The environments of these two areas have been studied in their shallower domain, down to a depth of 80 m (circalittoral) in some studies (El Placer de las Bóvedas) (Templado *et al.*, 1993; Oceana, 2008; García Raso *et al*., 2011). Tab. 1 and Fig. 3 show a remarkable proximity of the circalittoral bottoms to the head of the Las Bóvedas Canyon. In fact, the reliefs that form El Placer de las Bóvedas are the prelude to the head of the Las Bóvedas Canyon. The eastern flanks of the rocky outcrops form the western side of the canyon head (Díaz-del-Río *et al*., 2008).

The rocky relief of the El Placer de las Bóvedas outcrop on a highly sedimentary bottom forms a mixed habitat of great ecological value. They consist of two EW-oriented mounds about 15 m above the base level at 30 m depth, which produce lobate contour lines, thus allowing the development of a wide distal infralittoral area that provides different habitats for many species, some of which are highly characteristic of the area. This environment is a haven for marine mammals and for maerl and coral communities. Previous studies here have reported the presence of species which have national protection status, such as the sponges *Tethya aurantium* and *Spongia agaricina*, the gastropods *Charonia lampas* and *Mitra zonata* as well as the cowries *Erosaria spurca* and *Luria lurida,* the sea urchin *Centrostephanus longispinus* and the spider crab *Maja squinado* (Templado *et al*., 1993; Templado *et al*., 2004; Oceana, 2008). Other species with populations in the area which are included in the Red Book of Invertebrates of Andalusia (Barea-Azcón *et al*., 2008) are the gorgonians *Paramuricea clavata, Eunicella labiata, E. verrucosa* and *L. lusitanica*, the gastropods *Cymatium parthenopeum* and *C. corrugatum*, the starfish *Hacelia attenuata*, the bryozoan *Pentapora fascialis* and decapods such as the common lobster *Homarus gammarus* and the spiny lobster *Palinurus elephas.* Other populations of vulnerable marine flora of great ecological interest reported in the area are *Laminaria ochroleuca*, *Lithophyllum* sp., *Neogoniolithon mamillosum, Peyssonelia* sp., *Phyllariopsis brevipes*, *Phyllariopsis purpurascens*, *Saccorhiza polyschides* and *Cystoseira usneoides*, which appear to be very sensitive to habitat disturbance (Oceana, 2008).

The studies carried out on the infralittoral and circalittoral bottoms adjoining the Torrenueva Canyon, whose head is located west of the infralittoral shelf that forms in front of Punta de Calaburras, point to the existence of diverse habitats and especially diverse fauna associated with them (Garcia-Raso *et al*., 2010). This shelf is smaller and less complex than the one in El Placer de las Bóvedas. The site benefits directly from the incoming Atlantic water flow that practically collides with Punta de Calaburras and then starts the anticyclonic gyre which transports the Atlantic water mass to the Alboran Ridge. We can therefore understand the presence at this site of palaeoquaternary african species (*Strombus bubonius*) which remain as witnesses in the most recent deposits generated after the opening of the Strait of Gibraltar. The canyon head is situated 1 km closer to the coast than that of Las Bóvedas Canyon but has a greater depth (80 m), suggesting that the interference between the water flows could be even more active in this area than in the previous one.

This area is a place of passage, meeting and coexistence of Atlantic and Mediterranean species as well as European and African species, but it is also a barrier to genetic exchange of populations of some species. Among other attributes, it is one of the westernmost sites for meadows of the seagrass *Posidonia oceanica*, an EU priority habitat that led to the recognition of this area as a Site of Community Interest. These meadows have very different characteristics to those in other areas of the Mediterranean, because they mainly occur in shallow waters (less than 5 m deep), probably because of the lack of light, the turbulence of the waters, which resuspend very fine shaley sediments, and the presence of bedrock at these depths that protects them from trawling activities.

This stretch of coastline also contains the easternmost point at which typically Atlantic species, such as some kelps and *Fucus spiralis*, are found. Complexes of species with both an Atlantic and a Mediterranean representative, such as the gastropods *Gibbula pennanti/rarilineata* and *Patella caerulea/depressa* have also been reported. The only European populations of West African species also occur in this area, such as those of the bivalves *Ungulina cuneata* and *Modiolus lulat*, probably because of upwelling rather than the average surface temperature, which is not the highest on the Andalusian coast (García Raso *et al*., 2011). An example of the rich biodiversity of this area is provided by the molluscs, of which there are about 500 species. The presence of species which are protected in Spanish waters makes this place a privileged refuge that must be considered for conservation purposes. These species include the seagrass *Posidonia oceanica*, the gastropods *Patella ferruginea, Cymbula nigra* and *Charonia lampas* and several species of cowries, the bivalves *Pinna nobilis* and *P. rudis*, the sea urchin *Centrostephanus longispinus* and fishes of the genus *Hippocampus*. One of the flat rocky reliefs located at a depth of between 15 and 25 m (often called slabs), has a good development of bioconstructor organisms such as rhodoliths, gorgonians and bryozoans, and it is also possible to find species that are included in the Red Book of Invertebrates of Andalucía, such as the gorgonians *Eunicella verrucosa, E. gazella, E. labiata* and *Leptogorgia* spp. and the bryozoan *Pentapora fascialis.*

In deeper areas (about 100 m) and close to the canyon, the megafauna communities are composed of fish species such as *Capros aper, Micromesistius poutassou, Pagellus acarne* and *Macroramphosus scolopax*, crustaceans such as *Dardanus arrosor, Liocarcinus depurator, Plesionika heterocarpus, Pagurus prideaux* and *Macropodia longipes*, molluscs such as *Alloteuthis media, A. subulata, Calliostoma granulatum, Ranella olearium* and *Venus nux*, echinoderms such as *Echinus acutus* and *Anseropoda placenta* and cnidarians such as *Alcyonum palmatum* and the pennatulaceans *Veretillum cynomorium* and *Pennatula rubra*. However, in contrast with the adjoining areas and other areas of the Mediterranean, which have begun to be studied, little or no information is available on the habitats and benthic communities associated with the Torrenueva and Las Bóvedas canyons. There is therefore a clear need to study these habitats and communities in the Alboran Sea, an area of great biodiversity.

The Motril System of canyons and tributaries

This system is located in the central sector of the continental margin. It is a complex system composed of three main groups of canyons, each of them with a very different morphology, and the turbidite deposits that it has generated since its formation.

The three groups, listed from west to east, are: Almuñecar, Motril and Calahonda. The Almuñecar group is highly hierarchical, with two main channels; the Motril group is meandering, with two deep main valleys; and the Calahonda group is more ramified, with several heads distributed along almost 5 km of the outer shelf and considerably less activity than the first two. The area of influence of this system is very broad because of the active role that it has played as a turbidite transport system which has generated extensive fans at relatively shallow depths (800 m).

The Almuñecar group has a shorter length than the Motril group. Of its two main valleys, the eastern one is more hierarchical than the western one. It has six poorly developed heads located at depths of around 100 m, three of them feeding the main channel and the other three feeding two tributaries that dump their loads in the central section of the channel. The western valley has a simple structure and its drainage channel is at the same depth as that of its neighbour to the east (about 700 m).

The Motril group consists of two deep individualized incisions, with highly meandering channels that converge in the drainage channel to form a single depositional lobe. Its maximum width of 1.5 km gives an idea of its importance in the area. The heads of the two channels reach points very close to the coast (Fig. 4), at depths of less than 10 m, so the river channels are practically connected to the submarine valleys. The upward erosion experienced by the canyon heads has affected the infralittoral prograding wedges, creating many gullies on the slopes.

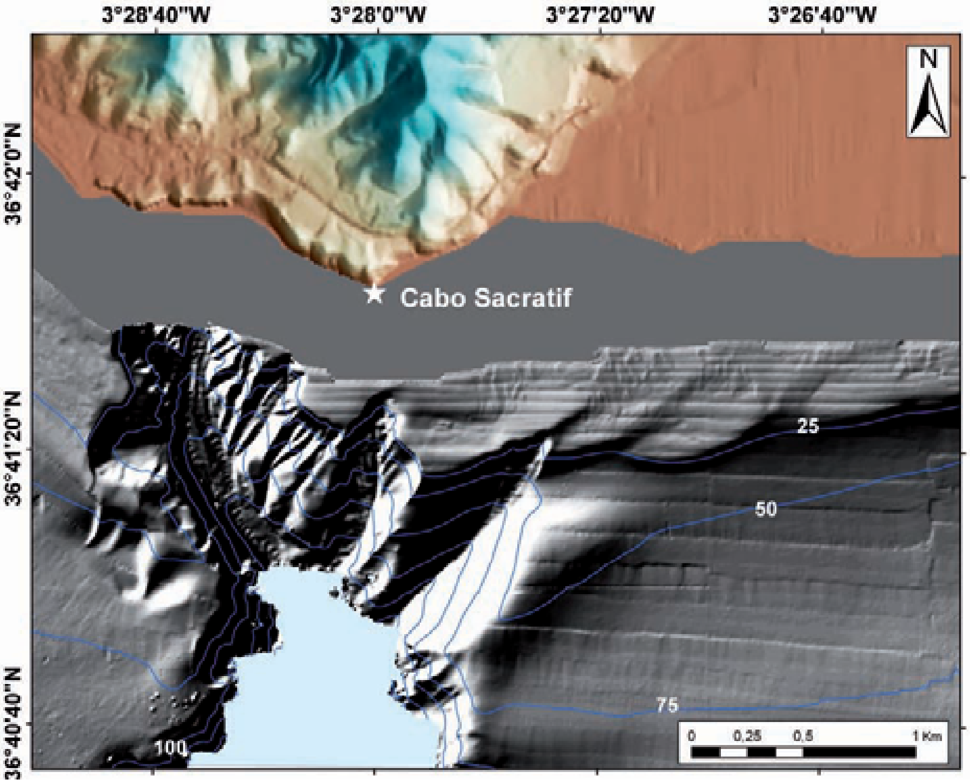

Fig. 4:

Head of the Sacratif or Carchuna Canyon, which belongs to the Motril System. The multibeam studies (with illumination from the NW) recorded the edge of the head at 8 m depth, which is the closest distance to the coast of a submarine canyon in the Alboran Sea. Gullies predominate in the first reach of the head, with very steep walls resulting from the erosion of infralittoral prograding wedges. The bottom of the canyon has a well-defined channel.

Two canyons make up this system, the Motril Canyon to the west and the Sacratif/Carchuna Canyon to the east. Both have four reaches: (1) The head, defined by an abrupt escarpment and many gullies giving onto an erosive depression 500 m wide and 250 m deep; (2) the upper channel, between about 250 and 450 m depth, characterized by the incision of the valley with a width of 1.5 km; (3) the middle channel, with abundant landslides on the slopes (most notably on the western sides of the two systems, where the meanders are accentuated) and a strongly meandering axis, showing a deepening of the channel excavated in the deposits transported along the canyon; and (4) the lower channel and the drainage channel, with a somewhat diffuse morphology which is resolved in a depositional lobe crossed by many smaller channels.

Finally, the Calahonda group consists of a total of 12 deep furrows excavated on the edge of the continental shelf (sometimes starting from the middle shelf), which are slightly meandering or straight (Muñoz *et al*., 2008). Some of them are hierarchical at the head, but those with a simple structure are predominant. The distance between the side slopes of the head (measured between the edges of the escarpment that defines the slope break) can range from 250 m to 1 km, while in the drainage channel it ranges from 180 to 400 m. Compared with the Motril group, the canyons of the Calahonda group do not cover a long distance over the continental slope (between 1 and 17 km), and some of them have a very short channel ending at the middle reach of the Carchuna Canyon.

The canyons of the eastern basin

This system is composed of a single canyon with numerous tributaries on both sides of the main valley divided into three systems (García *et al*., 2006): (1) the Dalías tributary valleys covering an area of 300 km^2, (2) the Andarax tributary valleys covering an area of 65 km^2, and (3), the Gata tributary valleys covering an area of 100 km^2. Some of them could form a canyon in themselves, if they were not linked to the main channel, contributing as tributaries to the general dynamics of the canyon.

The Almería Canyon is located in the context of the Bay of Almería and flanked in its middle stretch by two towering volcanic submarine ridges (the Chella Bank - also called Seco de los Olivos by fishermen -, and the Sabinar and Pollux banks) which constrain the incision of the canyon axis. The canyon runs in a NE/SW direction for nearly 55 km to reach a depth of 1800 m, where it forms a large turbidite lobe with a thickness of 45 to 50 m. The predominant feature of the tributary systems is the perpendicular geometry on the margin with a dendritic distribution.

In the Dalías tributary valley system there are 31 incisions about 1 km apart at the shelf edge, forming the characteristic morphology of canyon heads. The valleys are between 7 and 22 km long. Their direction varies from NNW/SSE to N/S and their geometry varies from meandering to straight. The Andarax tributary system develops from a depth of 40 m at the base of the Andarax River prodelta to a depth of about 300 m. From that depth, there is a convergence of channels discharging into a less hierarchical channel crowned by three heads that link to the upper reach of the canyon's main channel (Fig. 5). The Gata tributary system extends from the edge of the shelf of Cape Gata, at about 200 m depth, to 650 m where it converges with the Almería Canyon. Nine valley heads feed a single branch of the canyon, whose southern development is constrained by the volcanic outcrops of the Pollux and Sabinar banks.

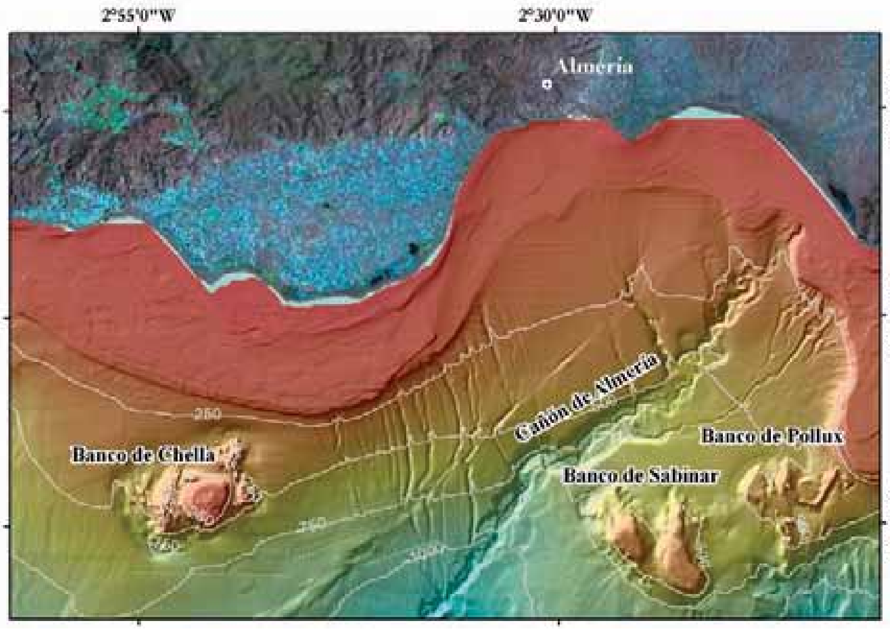

Fig. 5:

The Almería Canyon (Cañón de Almería), the easternmost of the ones we are dealing with, starts its route on the middle shelf. It has a head with very pronounced features and a simple structure (three main incisions). It runs in a NNE/SSW direction imposed by the Carboneras Fault and other accompanying structures. The tributaries have three very different drainage networks on each slope. While in the west there is a highly hierarchical network which is mainly concentrated in one sector of the upper slope, in the east there is a single tributary which starts from the very edge of the continental shelf and connects to the main channel in its middle reach (Banco: Bank).

LIVING RESOURCES IN THE AREA OF INFLUENCE OF THE SUBMARINE CANYONS

The submarine canyons of the western Mediterranean Sea are important areas of biodiversity and presence of endemic species (Gili *et al*., 1999; Gili *et al*., 2000). They are complex and heterogeneous systems which can provide a wide variety of habitats (Cunha *et al*., in press). Recent studies have highlighted their importance as preferential areas for the recruitment of megafauna species (Sarda *et al*., 2004).

The implications of sediment inputs in deep communities (Ramírez-Llodra *et al*., 2007) and the complexity of biological communities (Weaver *et al*., 2004) are poorly known, although they seem to have great importance in the processes of transport of energy and organic matter from the continental shelf to the deeper bottoms of the basin (Puig *et al*. 2000). Submarine canyons play an important role in the structure of the benthic megafauna populations which contain fishery resources (Gili *et al*., 2000). For example, they are important habitats for demersal species such as hake (*Merluccius merluccius*) and red shrimp (*Aristeus antennatus*) (Stefanescu *et al*., 1994; Tudela *et al*., 2003; Sarda *et al*., 2009; Capezzuto *et al*., 2010). Because enrichment processes change seasonally, they can have a great influence on the composition of communities, the life cycles of benthic species, and trophic relationships such as those between deep-water shrimp and their prey (Carter, 1994) and fish (Madurell and Carter, 2005; Fanelli and Cartes, 2010).

In the Alboran Basin, a species traditionally associated with submarine canyons is the red shrimp *A. antennatus*, which is a target species for the deep-water trawl fishery. The results of a study on the geographical distribution and abundance of this species during the period 1994-1997 at a depth range of 25 to 786 m indicated that the yields of the species were rare in the northwestern sector of the basin, but that most of the individuals captured displayed large sizes (Carbonell *et al*., 2000) (Fig. 6).

The deep-water trawl fisheries in the study area show some peculiarities in the species caught. In the eastern sector of the basin, dominated by the Almería Canyon and its tributary system, the target species *par excellence* is the red shrimp, while in the Motril System and the western sector of the basin this species hardly appears in the catches. In fact, in the vicinity of the canyons La Linea de la Concepción, Guadiaro, Las Bóvedas, Calahonda and Fuengirola, the bottom-trawl fleet does not tend to fish at depths greater than 500 m, concentrating a significant part of its activity at the canyon heads rather than in the deeper areas where red shrimp are caught.

In a recent study (Baro *et al*., 2008) performed at depths of 600 to 850 m in the Motril turbidite system in order to explore new fishing grounds using more selective trawling techniques, it became clear that the captured animals were the characteristic ones of these depths, regardless of the morphological characteristics of the area. Surprisingly, the captures of red shrimp were very low.

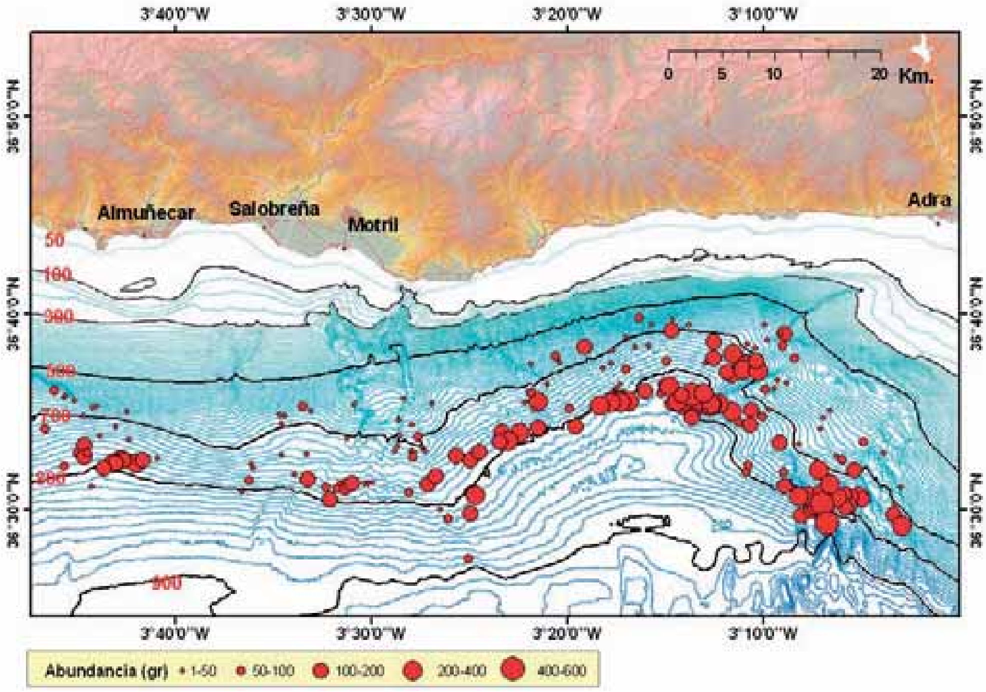

Fig. 6:

Distribution of catches obtained in the experimental fishery of *Aristeus antenatus* conducted in the Motril System of canyons and tributaries (Abundancia: Abundance).

The most widely caught fish species include *Trachyrincus scabrus*, which gave average yields of 42 to 61323.7 g/h and 106 to 200 individuals/h. The next in importance was *Galeus melastomus* (31854.9 g/h and 13.4 individuals/h), *Phycis blennoides* (9285.7 g/h and 9 to 19 individuals/h) and *G. atlanticus* (72 to 13199.2 g/h and 1 to 42 individuals/h). For molluscs, the cephalopod *Todarodes sagittatus* was the most abundant, with yields of 0.5 to 4096 g/h, and 2 to 11 individuals/h. For crustaceans, the highest yields were achieved for *Geryon longipes*, with yields of 0.2 to 1999.4 g/h, and *Pasiphea multidentata*, with 1118 g/h. However, yields of *Aristeus antennatus*, a target species of the study, were very low, with a maximum of only 50.5 g/h.

How could we interpret the shortage of such a characteristic species of the canyons as *Aristeus antennatus*? It is well known that there are profound differences in the dynamics of the submarine canyons and that many of them simply transport sediment along their axis (Puig *et al*., 2000). This difference may explain the disparities in abundance of certain species. In the case of *Aristeus antennatus*, the formation of dense water on the continental margins as a result of climatic phenomena and its sinking to deep zones through an intense cascade effect are correlated with the temporary disappearance of the species from its usual habitats. Furthermore, transport of particulate organic matter associated with this effect seems to improve the recruitment of this resource (Company *et al*., 2008). This could explain the presence or absence of red shrimp in some of the systems of the Alboran Sea, although in order to confirm these findings more detailed studies are needed on the functioning of the canyons, their level of activity and the associated habitats and fauna.

In the area of the Almería Canyon, demersal communities at 200-250 m depth are dominated by the fish *Micromesistius poutassou, Gadiculus argenteus, Epigonus denticulatus, Lepidopus caudatus, Hoplostethus mediterraneus* and *Helicolenus dactylopterus*; the crustaceans *Plesionika heterocarpus, Parapenaeus longirostris, Liocarcinus depurator, Solenocera membranacea, Pontocaris cataphracta* and *Chlorotocus crassicornis*; and the molluscs *Rossia macrosoma, Todarodes sagittatus, Bathypolipus sponsalis, Aporrhais serresianus* and *Xenophora crispa*. At 450 m depth the communities are dominated by the fish *Coelorhynchus coelorhynchus, Hymenocephalus italicus, Phycis blennoides* and *Capros aper*; the decapods *Plesionika martia, Solenocera membranacea, Pontocaris lacazei, Bathynectes* spp. and *Goneplax rhomboides*; and the molluscs *A. serresianus* and *Galeodea rugosa*. However, as in the other canyons of the Alboran Sea, the benthic communities and habitats along the Almería Canyon have not been studied in detail to date. The study of these habitats and associated communities is of great importance, because they contain natural resources and are therefore subject to anthropogenic impact.

CONCLUDING REMARKS

Although we know little more about the submarine canyons of the Alboran Basin than their dominant geomorphological features, these unique places and the adjacent areas may contain habitats of high ecological value, as has been found in other areas of European seas. The oceanographic conditions that govern submarine canyons create a refuge for demersal and benthic species, some of them protected by law. Bearing in mind their high environmental and ecological value, it is therefore surprising that they do not enjoy a status of protection or conservation to ensure their sustainability against the hazards of exploitation.

There are several pressures looming over them, particularly at their heads, which are very close to the coast and therefore subject to the impact of anthropogenic activities that affect the coastal zone. These activities include leisure activities that cause noise pollution, the discharge of rainwater and treated water, sport fishing and commercial fishing, and shipping. They are also affected by the environmental changes related to climate change. Some of these changes are sharp, particularly in shallow habitats (*Posidonia oceanica* meadows and coralline formations) which require a thermal environment with little variation and a very consistent and homogeneous hydrodynamic regime. A sustained rise in temperature of the water and air, accompanied by a slight increase in the average sea level (a steady increase of 1.5 mm/yr is observed in the Alboran Sea), could be lethal to many species that live near the heads of the submarine canyons. Changes in the velocity of circulation of intermediate or deep Atlantic water layers could cause profound changes in the biogeographical distribution of many benthic and pelagic species.

In view of the large number of submarine canyons in the Alboran Basin and their great ecological potential as habitats, there is a need to regulate their use on the basis of detailed knowledge of their systems, habitats and species. The protection status of these particular places is limited to a few sites of Community interest in nearby areas that do not take into account the location of the heads and the importance of the canyon itself. There is therefore a need for information on the location of the canyons and a detailed analysis of the benefits that they offer to the ecosystem and to the marine environment.

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4. GOVERNANCE

4.1. Legal governance of submarine canyons in the Mediterranean

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INTRODUCTION

Mare medi terra, the Mediterranean is more than just a sea; rather than separating its different lands, it unites them, ensuring the physical and human unity of countries placed by geography on its shores, lands between which history has built bonds of culture and civilization which transcend the political, economic and religious differences of the 21st century.

In human terms, it is *Mare nostrum*, though today this ancient expression recalling the grandeur of Rome naturally takes on a new meaning: it no longer conjures up a dominant power, but the common responsibility of peoples who share the Mediterranean and are duty-bound to preserve this heritage handed down by their ancestors.

A strategic area from all points of view, the Mediterranean is the meeting-point of three continents and one of the world's 34 hot-spots for biodiversity; it must therefore be a privileged place for sustainable development and the protection of marine biodiversity.

The challenges and stakes involved in submarine canyons form part of this strategic position. From a scientific standpoint, the Mediterranean can be regarded as one and the same system or, more precisely, as an integrated ecosystem within which all oceanographic and biological parameters are interdependent and constantly interacting. In this global ecosystem, naturally subjected to anthropogenic impacts, and within which submarine canyons play an essential and systemic role, there are no frontiers…

This is a reality that the law and, in this case, public international law, whether applying to the sea or the environment, is, of course, poorly equipped to take into account or integrate into its rules and regulations. Classic legal instruments are, in fact, profoundly marked by the territorial and even terrestrial approach that presided over their enactment; they are not the most appropriate tools with which to obtain a global grasp of an area which is, by its very nature, mobile and, moreover, from this point of view, marked by the original concept of the freedom of the seas and their non-appropriation; *a fortiori* because the new law of the sea is henceforth based, on the contrary, on an essentially spatial logic leading to a zoning of the areas involved, combined with an appropriative approach towards living and non-living resources.

In the face of such a challenge, the lawyer's role is more modest than ever, but needs to be imaginative. The jurist is never the person who decides; but in the law of the sea and the environment, he must be capable of listening to the scientist and working with him to inform the stakeholders and public opinion, in order to convince politicians to take action. To this end, the jurist must propose legal instruments and, firstly and most often, those of governance, seen as an informal process which then contributes to the formulation of regulations addressing practical issues and new challenges which are revealed by scientific research, but can only be taken up by sovereign States. This approach is all the more humble in that it must usually function first as *soft law* in order to contribute to the drafting of a *hard law* which is acceptable and accepted by the States and can, on this sole condition, thus become effective.

As everywhere else in the world, the Mediterranean region is naturally subject to contemporary international law, by its very nature universal and UN-related, though while within this framework solutions specific to the region are also possible, as the Mediterranean is in many respects a particular case in geological, geographic, oceanographic and biological, but also political and legal terms. Today, and this notwithstanding the political projects of the Union for the Mediterranean (UfM), the Mediterranean can in fact be characterized by the existence of its own cooperation system, the Barcelona System, which serves as both a model and a symbol for other comparable entities since established within the context of the Regional Seas Programme of the United Nations Environment Programme (UNEP), complemented by a dedicated regional fisheries organization, the General Fisheries Commission for the Mediterranean (GFCM).

In the multi-disciplinary process aimed at furthering awareness and inciting the appropriate powers to take action, the proposal of legal governance instruments thus comes after the establishment of scientific facts and prior to political decisions, halfway between the two, and thus necessarily leads to a consideration of *governance strategies derived from universal law* (I) but also *governance strategies specific to the Mediterranean* (II), aimed at protecting the system formed by submarine canyons, its precious role in and for the ecosystem, and the biodiversity in which these canyons thus play a role in the Mediterranean Sea.

I - GOVERNANCE STRATEGIES DERIVED FROM UNIVERSAL LAW

Aimed at protecting submarine canyons in the Mediterranean and thus at working towards the preservation of marine biodiversity and environment, the new law of the sea embodied in the Convention of December 10th, 1982 **(3)**, serves indisputably as a benchmark. Designed to encompass and manage the entirety of the law of the sea, the Montego Bay Convention could not in itself alone embody the entire subject matter but was intended as an umbrella treaty and is, with every passing day, getting closer to achieving this purpose. At both universal and regional level, dedicated legal strategy can thus only be imagined as being *in pursuance of the United Nations Convention on the Law of the Sea* (A) or at least *in conformity with the United Nations Convention on the Law of the Sea* (B).

A – In pursuance of the United Nations Convention on the Law of the Sea

The legal framework laid down by the 1982 Convention necessarily imposes an obligation to reason *within an approach inevitably marked by costal nationalism* (2), but with certain limits *in the particular case of an enclosed or semi-enclosed sea* (1). For the purposes of conservation and governance of submarine canyons, *i.e.* areas beyond the territorial waters of riparian states, this is even more important because the Mediterranean is always globally seen today as an exception to the legal regime governing offshore maritime areas.

1) In the particular case of an enclosed or semi-enclosed sea

If submarine canyons in the Mediterranean play such an important systemic role, it is, of course, due to the fact that the Mediterranean is an enclosed sea or, at the very least, semi-enclosed. The fundamental legal framework applicable to this not very homogeneous category is determined by the Convention in *Part IX*, *ie. Articles 122 and 123* (a). However, *the specific nature of the Mediterranean,* a large part of which can be considered as *high seas by default* (b) appears to be totally decisive in this case, *a fortiori* from a conservationist point of view.

a) Part IX : Articles 122 and 123

The new law of the sea can, above all, be defined as a law for the oceans, and it is thus almost *a contrario* that the Montego Bay Convention devotes its Part IX and its Articles 122 and 123 to *Enclosed or semi-enclosed seas*. Even if these two hypotheses are not legally distinguished, but rather purely and simply assimilated, the expression embodies a certain geographical reality which ultimately resides in the self-evident distinction between oceans and seas, particularly these so-called “Mediterranean”, restricted areas characterized by their relative crampedness, as well as by the solidarities and disputes which naturally arise therefrom.

The largest and deepest of all enclosed or semi-enclosed seas, the Mediterranean thus fits perfectly into this conceptual logic, of which it seems to be the most iconic example. In scientific terms, the narrowness of the outlet to the oceanic space affects the ecosystem functioning and the schema of circulation and renewal of the water, with all the biological consequences thus induced. In legal terms, the criteria for definition as laid down by Article 122 are all satisfied: the geographic criterion - "*an "enclosed or semi-enclosed sea" means a gulf, basin or sea*" -, the political criterion – "*surrounded by two or more States*" -, and two alternative criteria, one geographic - "*and connected to another sea or the ocean by a narrow outlet*" -, the other legal - "*or consisting entirely or primarily of the territorial seas and exclusive economic zones of two or more States*". It is, in fact, not only the Mediterranean, but also some of the seas of which it is composed, and which form its basins and sub-basins, which fulfill these conditions, a fact which may be useful in understanding, from a legal viewpoint, the biological reality of the currents and exchanges to which the Mediterranean's submarine canyons make a contribution, and in working towards their conservation.

Given the specific features arising from the physical geography, Article 123 of the Convention in fact defines the principle of *Cooperation of States bordering enclosed or semi-enclosed seas*. This is indeed necessary here more than elsewhere (Simard, 2010), and the traditional reference to "bordering State", used here in preference to the newly sanctioned expression "coastal State", testifies to this by illustrating the particularity of bordering States invited to form a community around the shores of such a sea.

Cooperation indeed seems to be the obvious solution, given the relative crampedness of such maritime areas and consequently the converging interests of bordering States, even though in reality the Convention hardly goes beyond a petition simply encouraging the principle. On this point, conventional law has something in common with material *soft law*, with regard to both the principle of cooperation ("*States bordering an enclosed or semi-enclosed sea should cooperate with each other in the exercise of their rights and in the performance of their duties under this Convention*") and also the ways in which it is applied, which prove quite literally to be those of simple coordination: "*To this end, they shall endeavour, directly or through an appropriate regional organization: (a) to coordinate the management, conservation, exploration and exploitation of the living resources of the sea; (b) to coordinate the implementation of their rights and duties with respect to the protection and preservation of the marine environment; (c) to coordinate their scientific research policies and undertake where appropriate joint programmes of scientific research in the area; (d) to invite, as appropriate, other interested States or international organizations to cooperate with them in furtherance of the provisions of this article*".

In theory, the legal basis exists for all State or institutional initiatives, which seems perfectly applicable to the issues surrounding protection of submarine canyons in the Mediterranean. In practice, however, cooperation is a matter of specifics, depending on the stakes involved and the individual interests of States bordering the enclosed or semi-enclosed sea, as well as their political willingness to collaborate in order to preserve their biological resources, the marine environment and biodiversity which constitute their shared heritage. Nevertheless, among Mediterranean States, the necessity for effective cooperation undoubtedly seems more pressing, given the *specific nature of the Mediterranean: high seas by default*.

b) The specific nature of the Mediterranean : high seas by default

In the eyes of the law, conventional and customary, laid down by the 3rd Conference of the United Nations on the Law of the Sea, the main particularity of the Mediterranean is that it is the only sea in the world where the States initially abstained from systematically extending their jurisdiction up to 200 nautical miles, in other words, from taking full advantage of the coastal dimension of the new law of the sea. To a very large extent, this specific feature still exists today, as the extension of national jurisdictions would result in the disappearance of the Mediterranean's high seas, as its span never exceeds 400 nautical miles.

The reasons why the States originally came to a tacit agreement not to proclaim exclusive economic zones (EEZs) are linked to the special topography of the Mediterranean Sea which, more than any other enclosed or semi-enclosed sea, is a space constricted by the presence of islands and peninsulas contributing to the physical existence of separate basins. It was therefore mainly for fear of opening the Pandora's Box of delimitation disputes, and thus sowing the seeds of discord among themselves, that the States set their own limitations on themselves, but also for fear of causing political problems and contestations from maritime powers regarding the freedom of navigation, given the geostrategic importance of the Mediterranean.

However, some evolution has been seen due to necessity and a certain realism, giving rise to a phenomenon of "jurisdictionalization" of the Mediterranean (Andreone, 2004). For political reasons, this was first the case on the southern shore (Morocco 1981, EEZ not really effective in the Mediterranean, given territorial problems with Spain; Tunisia 2005) and the eastern shore (Syria 2003; Cyprus 2004), when States proclaimed EEZs without always putting them into effect, then mainly on the northern shore (but also in Libya, fisheries protection zone, 2005) with the proclamation, as per the saying "*who can do more can do less*", of functional *sui generis* zones, constituting dismemberments of the conventional zone (Treves, 1995; Treves, 2003): a fisheries protection zone in Spain (1997), an ecological protection zone for France (2004) and Italy (2006), and a mixed fisheries and ecological protection zone (Croatia, 2003, suspended in 2004 following European Community pressures, especially from Italy) (González Giménez, 2007).

Beneath the sea, the legal situation is, of course, slightly different, with continental shelves in fact existing *ipso facto et ab initio*, which is theoretically likely to make protection of submarine canyons easier, even if they are not always delimited, notably due to problems posed by the existence of possible triple points and the presence of islands; some Mediterranean States have in fact been obliged to resort to the International Court of Justice to delimit their continental shelves (*cf. Continental shelf* (Tunisia/Libya), judgment delivered on February 24th, 1982 ; *Continental shelf* (Libya/Malta), judgment delivered on June 3rd, 1985).

Canyons are physical submarine structures; geologically, the head of the canyon is theoretically situated at the level of the continental margin, *ie.* at the very limit of the physical continental shelf. In the Mediterranean, this zone may lie very near the coasts, which explains why, in the eyes of the law, submarine canyons may be subject either to the legal regime of sovereignty applying to the subsoil of the territorial sea, or to that of the legal continental shelf which carries sovereign rights and jurisdiction for the coastal State. In both cases, there is always at least one sovereign or competent State in the submarine space where the canyon exists. This factor is *a priori* of a nature to create favourable conditions for legal governance, though the conservation of canyons and their role nevertheless implies that protection will also extend to areas surrounding the canyon's geological structure: the subsoil situated on the periphery, but also the superjacent waters.

As this is a matter of governance of the water column and measures liable to be prescribed for it, a perspective both dynamic and evolutive, but also already realistic, must be adopted: high seas by default, the Mediterranean is, by law and by destination, a collection of zones under national jurisdiction, which implies reasoning *within an approach inevitably marked by coastal nationalism*.

2) Within an approach inevitably marked by coastal nationalism

For the time being, coastal nationalism is still retained in the Mediterranean, though the Convention nonetheless serves as a framework for claims put forward by the States and for the purposes of governance, between the *law of the sea and biodiversity* (b). Given the narrowness of the continental shelf in certain parts of the Mediterranean, the canyons may extend far out towards the open sea, while their heads can be very close to the coasts, which implies protection strategies integrating, rather than dissociating, *areas of sovereignty and areas of jurisdiction* (a).

a) Areas of sovereignty and areas of jurisdiction

Notwithstanding the persistence of the Mediterranean's specific character, it seems that protection strategies for submarine canyons, and for all the marine environment and its biodiversity, will have to incorporate the coastal nationalism dimension of the new law of the sea, such as it is inevitably called upon to determine the legal entitlement of the coastal State(s) and jurisdiction arising therefrom.

In theory, the new law of the sea thus first demands a distinction to be drawn between areas of sovereignty and areas of jurisdiction, because quite obviously the States do not all enjoy the same powers. But practice presupposes a more realistic view of the stakes involved and, in terms of effectiveness, solutions such as protective measures and the adoption of a more global approach which serves more to harmonize strategies than disrupt them.

Exceptions aside, as in the case of States, which have opted for a less wide territorial sea, such as Greece and Turkey, areas of sovereignty extend up to 12 nautical miles beyond the baselines. They include the waters, but also the bed and subsoil of the territorial sea over which the coastal State exercises its sovereignty, on the sole condition of respect arising from the principle of the right of innocent passage. In the exercise of its sovereignty, and in reference to the terrestrial area which is adjacent to the territorial waters and carries rivers and streams flowing out to sea, the coastal State is also competent and *a priori* best placed to implement a strategy aimed at fighting, and providing legal protection against pollution from land-based sources, possibly in cooperation with the State(s) further upstream. Given the geological origin and physical configuration of many submarine canyons, this form of pollution, usually comprising 80% of that which affects the marine environment, can in fact be a real scourge and a serious danger for the ecosystem balance and biodiversity of submarine canyons, whence the importance of an effective conservation strategy.

Areas of jurisdiction are those, which lie beyond territorial seas; they include the seabed and subsoil as well as, potentially or at least fragmentarily in the Mediterranean, the superjacent waters. As for the continental shelf, it has no need to be claimed or proclaimed by the coastal State as it exists *ipso facto et ab initio*, thus offering legal competence in terms of protection of submarine canyons, *a fortiori* because the corresponding geological structures are static and therefore more easily comprehended by international law. The coastal State is then entitled to take all measures of protection and conservation, on condition that it observes the provisions associated with the principle of the freedom of the seas, *i.e.* freedom to lay submarine cables and pipelines. In such a case, the main legal obstacle likely to exist is thus the one, which may arise from delimitation disputes, though here again this is in fact a false problem. Contrary to preconceived ideas, there is absolutely no need for maritime areas to have been delimited in order for States to cooperate in their conservation and common management; quite the opposite, if one thinks of the positive effect an active and practical collaboration can potentially have in encouraging the pacific and *a fortiori* negotiated settlement of such a dispute. A co-managed area then becomes a pragmatic solution, even more satisfying in practice as, notwithstanding the possibility of a pending delimitation, the geophysical reality of Mediterranean submarine canyon systems refers the goal of efficient protection and effective governance to international cooperation, or at least to bilateral collaboration (Spanish-French, for example, for the Cap de Creus canyon), trilateral (Algero-Spanish-Moroccan, for instance, for the canyons in the Alboran Sea), or collaboration developed as part of a basin strategy (as, for example, in the Levantine Aegean Sea).

A true conservation strategy can, in fact, only transcend frontiers and reasoning based on delimitation or differentiation of areas and legal regimes, which is perhaps even truer in the case of superjacent waters over the continental shelf and their biological resources, also characterized by their mobility. It is in this fragmented area of the high seas by default that legal evolution is first of all necessary and desirable, not only to ensure that the territorial sea is not the only space in which certain States have the ability to act, but also in order for its protection to be more homogeneous and therefore more effective. In fact, existing areas of jurisdiction are characterized by their diversity and poor level of integration: the exclusive economic zone (EEZ), fishing zone, fisheries protection zone and ecological protection zone do not pursue the same goals and do not provide the same tools for fight or protection (IUCN/UICN, 2010). Essentially speaking, their purpose is not to preserve biodiversity, and they only marginally allow for dedicated measures to be taken in this respect. Harmonization would therefore not only require a concerted proclamation, but undoubtedly also the introduction of real biodiversity protection zones, capable of effectively transcribing the existing dialectics between the *law of the sea and biodiversity* into positive international law.

b) The law of the sea and biodiversity

The relationship between the law of the sea and biodiversity indeed lies at the core of contemporary issues surrounding protection of the marine environment, which include conservation of submarine canyons.

The new conventional law of the sea, as formally defined in the United Nations Convention on the Law of the Sea, neither mentions nor recognizes biodiversity as such. It would, in fact, be hard for it to be otherwise, as the emergence of the concept in the second half of the 1980's and its legal consecration, in the Convention on Biological Diversity in 1992, came after the adoption of the Convention on the Law of the Sea in 1982. In the conventional law of the sea, the first legal reference in fact comes even later, with the Agreement for the implementation of the Montego Bay Convention dated August 4th, 1995, relating to straddling fish stocks and highly migratory fish stocks; its Article 5, para. g, is the first to specifically prescribe protection of "*biodiversity in the marine environment*".

On this basis, and thanks to a highly constructive teleological interpretation of the provisions laid down by the Convention of 1982, the concept of biological diversity, then of biodiversity, appears however to have gradually won its right to be used in the general and customary international law of the sea, but without benefiting from a direct legal foundation nor dedicated competences explicitly recognized to the States. In concrete terms, this makes its application more difficult, especially as it is potentially likely to interfere with the coastal nationalism and the classical logic of the law, whether with regard to the appropriation aspect of areas and resources or, on the contrary, to the continuing existence of the principle of freedom and non-appropriation.

Placed within the context of the era, the 3rd United Nations Conference on the Law of the Sea - whose official sessions began in 1973, *i.e.* one year after the United Nations Conference on the Human Environment held in Stockholm in 1972 - can undoubtedly be seen as having played the part of precursor. It in fact wrote *Protection and Preservation of the Marine Environment* into the agenda of the 3rd Commission, then devoted Part XII of the Convention to the subject; Part XII's innovative provisions thus ratified the introduction of environmental concerns into the Convention on the Law of the Sea, concerns which are today indissociable from it.

Article 192 in fact transposed the principle, already well-known in the law of the environment, into the law of the sea, by stating that "*States have the obligation to protect and preserve the marine environment*", though this obligation is understood within the context of a utilitarian kind of logic, finalized and functional, which is not the one which must today preside over the conservation of biodiversity, when there even exists a certain tendency towards the monetization of ecosystem services. In fact, Part XII recognized the need to protect and preserve the marine environment, but essentially in connection with various kinds of economic usage of the sea. In the Montego Bay Convention, environmental concerns were, in fact, firstly marked by the fight against pollution, giving rise to an "anthropocentric" approach, or at least primarily centred on the impact of human activities which the new law of the sea was precisely intended to limit. It was not yet a matter of preserving the environment in itself and for itself, through the biological diversity that constitutes its ecological richness and its future in terms of sustainable development, and even less so as part of an ecosystem approach based on the precautionary principle. Basically, Part XII was aimed at fighting the various forms of pollution likely to affect the sea (pollution from land-based sources, pollution from seabed activities subject to national jurisdiction, pollution from activities in the Area, pollution by dumping, pollution from vessels, and pollution from or through the atmosphere), and thus at containing and limiting as much as possible the potentially harmful effects of corresponding activities, and primarily navigation and offshore exploitation. As regards conservation of biological resources in areas under jurisdiction and, *in fine*, in the high seas, the Convention more or less followed a similar approach, since it was concerned not with preserving species, whose diversity is one of the factors constituting biodiversity, but with ensuring the profitability of their exploitation.

Defined in terms of governance, a strategic approach towards the protection of submarine canyons was clearly therefore not part, either entirely or directly, of the logic behind the Montego Bay Convention. Even if the conservation of canyons and the preservation of their role within the ecosystem imply minimizing pollution of the marine environment, including pollution from land-based sources, and the impact associated with the human activities of offshore exploitation, navigation and fishing, they imply an approach, which necessarily incorporates biodiversity. The legal instruments of the law of the sea must therefore be amended and completed, as part of an intersectoral approach, by techniques and concepts specific to the law of the environment and sustainable development, elaborated *in conformity with the United Nations Convention on the Law of the Sea*.

B – In conformity with the United Nations Convention on the Law of the Sea

If preservation of biodiversity, to which the protection of canyons is intended to contribute, can only be paradoxical under the 1982 Convention, all universal strategies must then aim to develop an approach based on complementarity, which would be respectful of it, but also offer other legal basis. These instruments of governance naturally reside first and foremost *in the Convention on Biological Diversity* (1), but also in other functional systems developed *with a cross-sectoral approach* (2).

1) In the Convention on Biological Diversity

The emergence of the concept of biodiversity (a) dates back to the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992, and was legally sanctioned by the Convention on Biological Diversity. Recourse to *Marine Protected Areas* (b) as a privileged instrument for conservation, and as such applicable to submarine canyons, derives directly from this normative procedure, thus transformed into factual existence, then completed and made more explicit by the Conference of States Parties to the Convention.

a) The emergence of the concept of biodiversity

The term *biodiversity* was first coined in 1985 as a contraction of the expression *biological diversity* invented in 1980; more compelling in terms of communication, the word *biodiversity* began to be used as from 1986, though it was first mentioned in a publication dated 1988. Etymologically, the word is a neologism based on the Greek *bios*, meaning "life", and *diversity* designating the variety and diversity of the living world. Biodiversity can thus be simply defined as the natural diversity of living organisms as it develops in space and time, and consequently that of ecosystems, species and genes.

In legal terms, it was the "Earth Summit", or United Nations Conference on Environment and Development held in Rio in 1992, which sanctioned the concept and notion of biological diversity as a component of sustainable development, through the adoption of the Convention on Biological Diversity on June 5th, 1992 **(4)**. Article 2 in fact gives the first conventional definition of biological diversity as the "*variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems*"; the same Article defines an ecosystem as "*a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*".

As such, biodiversity thus includes the diversity of the marine ecosystems and ecological complexes of which they are part, and the conservation and protection of submarine canyons are therefore wholly within the logic of the Convention on Biological Diversity. Canyons are, in fact, directly capable of contributing to the maintenance and preservation of biodiversity, especially in a hot-spot like the Mediterranean Sea, and even more so, given the specific oceanographic, hydrodynamic and biological features which characterize this enclosed, or at least semi-enclosed, sea (Würtz, 2010).

Furthermore, the Preamble of the Convention on Biological Diversity innovates by inviting the States to adopt a precautionary approach "*where there is a threat of significant reduction or loss of biological diversity*" or a "*lack of full scientific certainty*"; and pragmatism inevitably requires concern for biological diversity, especially marine, due to the biological resources of which it is composed, which then leads to the concept of sustainable development. Recalling the importance of biological diversity and the need to conserve it, the Preamble of the 1992 Convention naturally reaffirms the sovereign rights of the States over their own resources in this respect, but combines them with a dual responsibility: " *States are responsible for conserving their biological diversity and for using their biological resources in a sustainable manner*". In the case of marine biodiversity, the meaning and scope of the equation sovereign rights over resources/obligations to conserve biological diversity are confirmed in Article 22, *Relationship with Other International Conventions*, and notably in § 2 stating that "*Contracting Parties shall implement this Convention with respect to the marine environment consistently with the rights and obligations of States under the law of the sea*".

In areas under national jurisdiction, the sovereign rights of States over maritime areas and their resources thus form the legal framework governing effective observance of their obligations to preserve biological diversity. In the Mediterranean, high seas by default thus potentially forming a group of areas under national jurisdiction, this approach seems particularly relevant, placing bordering States, individually and collectively, before their shared responsibility towards the conservation of biodiversity. In this respect, the case of submarine canyons can provide a case study, as any initiative aimed at protection of biological diversity - a concept not formally sanctioned by the United Nations Convention on the Law of the Sea - can only be envisaged in conformity with its rules, and in this case within the context of the maritime areas and corresponding jurisdictions.

If the creation of a network dedicated to *Marine Protected Areas* seems like an appropriate strategy, as per Article 8 of the Convention on Biological Diversity, it can thus *a priori* only be envisaged with strict observance of the universal legal schema defined by the new law of the sea.

b) Marine Protected Areas

Article 8 of the Convention on Biological Diversity establishes the principle of priority awarded to *In-situ Conservation*, quite obviously the only kind possible in the case of submarine canyons. The concept of protected areas, and in this case Marine Protected Areas, envisaged as a network, follows directly, as Article 8 states that "*each Contracting Party shall, as far as possible and as appropriate: a) Establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity*" (para. a), and "*Regulate or manage biological resources important for the conservation of biological diversity whether within or outside protected areas, with a view to ensuring their conservation and sustainable use*" (para. c).

The first instrument of legal governance for submarine canyons that comes to mind is precisely the one that rests on the existence of a coherent network of Marine Protected Areas. Such a strategy seems even more likely to be effective in terms of conservation given that canyons are geological structures physically located on the subsoil of the sea, a fact which is, by its very nature, likely to reduce the negative impacts inherent in the mobility of the marine element: nevertheless, truly effective protection of submarine canyons can, of course, only be three-dimensional.

In the eyes of international law, Marine Protected Areas (MPAs) as defined on the universal basis of United Nations law must therefore be included within the double framework of the United Nations Convention on the Law of the Sea of 1982 and the Convention on Biological Diversity of 1992.

In the case of submarine canyons, the Montego Bay Convention made it possible to consider the triple spatial dimension of MPAs, depending on whether they concern the waters or the subsoil of areas of sovereignty and jurisdiction, or the high seas. Furthermore, as it here concerns the Mediterranean, where the physical continental shelf is often very narrow and the continental margin is therefore very close to the coasts, protection of the canyon may come under several areas and legal regimes. It then becomes necessary for the measures that are envisaged to be coherent over the entirety of the geological structure, *ie.* not limited to the canyon *stricto sensu,* but also incorporating the neighbouring continental shelf and the superjacent waters over which a coastal State in the Mediterranean may not so far have jurisdiction. In many cases, several States are then also obliged to combine their efforts, which supposes either the unilateral creation of adjacent national MPAs, or the creation of a joint MPA by two or more States. This solution is, of course, the most coherent and the most efficient; for these two reasons, it should be given preference. This is even more applicable when the waters of the high seas, even by default as in the particular case of the Mediterranean, are likely to be included therein; it is then not in fact so much the creation of the MPA - in the same hypothesis necessarily proclaimed within the context of an organization or regional system - which poses the greatest problem, but the thorny matter of its opposability to third parties, notably with regard to the principle of the freedom of the seas, and consequently that of its enforcement.

In the case of the Convention on Biological Diversity, the initial context has been made more precise and completed, precisely with regard to the high seas and deep seabed, to guarantee and reinforce the effectiveness of Marine Protected Areas which may be created; this was achieved by improving the basis for their identification and thus designation, thanks to the introduction of scientific criteria, also even more applicable, of course, in waters under national jurisdiction, as the reference to the high seas is here primarily oceanographic and not strictly legal. Following a preparatory workshop held in the Azores in 2007 **(1)**, the CoP9 of the Convention on Biological Diversity held in Bonn in 2008 thus adopted Decision IX/20 *Marine and Coastal Biodiversity*, whose Annex 1 lists the *Scientific Criteria for identifying Ecologically or Biologically Significant Marine Areas in need of Protection in Open-ocean waters and Deep-sea habitats* - EBSA criteria (*Ecologically or Biologically Significant Areas*) -, while Annex II gives five examples of *Scientific Guidance for selecting Areas to establish a Representative Network of Marine Protected Areas, including in Open-ocean waters and Deep-sea habitats* (Ecologically or biologically significant areas; Representativity; Connectivity; Replicated ecological features; Adequate and viable sites) **(6)**.

The seven EBSA criteria established by the Convention on Biological Diversity are: uniqueness or rarity; special importance for life-history stages of species; importance for threatened, endangered or declining species and/or habitats; vulnerability, fragility, sensitivity, or slow recovery; biological productivity; biological diversity; naturalness **(9)**. In the case of submarine canyons in the Mediterranean, the usefulness of such criteria needs no scientific demonstration, being so self-evident, even for a jurist.

This is all the more true because the said ESBA criteria correspond very closely to other criteria defined for practical purposes by various specific instruments relating to the law of the sea, especially at universal level: pragmatism thus extends its invitation to reinforce the effectiveness of the Convention on Biological Diversity, as well as the various existing systems, by reasoning based on *a cross-sectoral approach*.

2) A cross-sectoral approach

In the case of submarine canyons, the effectiveness of a network of Marine Protected Areas in fact presupposes the possibility of superimposing instruments of protection in order to tailor solutions to the diverse activities liable to harm ecosystem functioning. Such a cross-sectoral strategy must at least be *founded on maritime safety* (a) and *fisheries management* (b), which undoubtedly could be facilitated by combining applicable conditions with EBSA criteria.

a) Founded on maritime safety

In accordance with the principles of the new law of the sea, initiatives for sectoral protection undertaken by the International Maritime Organization (IMO) in connection with maritime safety are older than EBSA criteria, and pre-date current overlapping strategies programmed at international level and designed in terms of marine spatial planning.

In the context of the MARPOL 73/78 Convention and its Annexes, from which it is indissociable, one finds the concept of "*Special Area*" which is defined as being "*a sea area where for recognised technical reasons in relation to its oceanographic and ecological conditions and to the particular character of its traffic, the adoption of special mandatory methods for the prevention of sea pollution by oil, noxious liquid substances, or garbage, as applicable, is required*". The designation of a Special Area is thus based on environmental criteria (oceanographic and ecological), as well as the characteristics of maritime traffic. The designated maritime areas are then awarded a higher level of protection, depending on the type of pollution addressed by the various Annexes, with very strict regulation of the dumping of waste materials in the sea, verging on prohibition of principle. Today, this status only remains effective in two MARPOL Annexes: Annex 1 *Regulations for the Prevention of Pollution by Oil* and Annex V *Regulations for the Control of Pollution by Garbage from Ships*.

In both cases, the Mediterranean was designated by IMO as a Special Area, a fact likely to contribute towards ecosystem protection and in particular the conservation of submarine canyons. But this type of measures may well seem too general, both spatially and practically, whence the need to create specific protection for the most vulnerable maritime areas.

The concept of *Particularly Sensitive Sea Areas* (PSSA) originated in studies carried out from 1986 by the IMO and its Marine Environment Protection Committee (MEPC), leading to adoption in 1991 of Resolution A.720(17), since amended on several occasions, and whose most recent version corresponds to

Resolution A.982(24), adopted on December 1st, 2005, with a revision by the Secretariat concerning the identification and designation of Particularly Sensitive Sea Areas **(15)**.

The PSSA concept is totally independent from that of a convention and aims to provide for better protection of Particularly Sensitive Sea Areas from the impact of international shipping from an ecological, socio-economic or scientific point of view. This thanks to the IMO's adoption of associated protective measures, including measures for the organization of maritime traffic, instructions regarding notification, prohibition of certain activities, or designation of a Special Area under MARPOL Annexes (Oral & Simard (Ed.), 2008). Three categories of identification criteria (ecological; social, cultural and economic; scientific and educational) are specified in Annex I to Resolution A.982(24), together with two kinds of approaches to the effects of international shipping (vessels traffic characteristics; natural factors). The eleven ecological criteria listed naturally bear strong similarities to the EBSA criteria, though the designation of a Particularly Sensitive Sea Area is part of a logic which is more institutional (it is the work of IMO and its bodies), more functional (it is linked to shipping and maritime safety), more operational (it obligatorily implies concrete measures) and wider in its scope (it does not solely focus on the high seas, and can concern territorial waters).

Applied to the protection of submarine canyons in the Mediterranean, the PSSA approach therefore seems capable of providing protection which would complement that offered by EBSA criteria in terms of preservation of biodiversity, *a fortiori* from the perspective of an intersectoral approach also *founded on fisheries management*.

b) Founded on fisheries management

Under the terms of its Resolution 61/105 adopted in 2006, the United Nations General Assembly introduced the concept of Vulnerable Marine Ecosystems (VME) into the law of the sea, emphasizing the need to provide them with effective protection from the destructive effects of deep-sea fishing in the high seas. However, Resolution 61/105 does not define the notion, and it fell to the FAO to develop a participatory process, based on work carried out by the COFI in 2007, which led to the adoption, in 2008, of International Guidelines for Management of Deep-Sea Fisheries in the High Seas (8), whose § 7 recalls that they "*are to be interpreted and applied in conformity with the relevant rules of international law, as reflected in the United Nations Convention on the Law of the Sea of 10 December 1982*".

These Guidelines are intended to provide for the implementation of a functional and sectoral protection strategy directly based on the VME concept. To this purpose, they propose a management framework aiming to prevent the negative impacts of deep-sea fisheries on Vulnerable Marine Ecosystems and the preservation of the marine biodiversity of these ecosystems, *i.e.* not only conservation of target stocks, but also that of non-targetted species and affected habitats. The strategy consists of identifying the VME, then adopting appropriate management measures in order to prevent the occurrence of significant negative impacts, *i.e.* those compromising the integrity of the ecosystem, its structure or function, in a way that affects the ability of the affected populations to renew themselves, damages the long-term natural productivity of habitats, and causes a significant or irreparable loss of the richness of the species, habitats or types of community.

The logic inherent in the notion of VMEs can therefore undoubtedly be found to apply in the case of submarine canyons in the Mediterranean, and offer answers to certain aspects of protection. The system's aim is, in fact, to adopt concrete measures to protect said Vulnerable Marine Ecosystems from the effects of deep-sea fishing in the high seas, in the oceanographic rather than legal sense of the term, that of *open sea*, hence its applicability to areas under national jurisdiction, especially when the physical continental shelf is narrow and the head of the canyon is very close to the coasts, as is often the case in the Mediterranean.

The governance strategy defined by the FAO in the case of deep-sea fisheries in the high seas relies on the identification of Vulnerable Marine Ecosystems and the definition of vulnerability given in § 14-16 of the Guidelines. Vulnerability can in fact be physical, when direct contact with the fishing vessel is of a kind to alter the ecosystem's structural elements, or functional, in the hypothesis whereby selective elimination of a species resulting from halieutic activity is likely to upset the functioning of the ecosystem. Furthermore, the most vulnerable ecosystems are naturally those which are both the most easily disturbed and the slowest to reconstitute themselves, where the lack of scientific certitudes and knowledge must advocate a precautionary approach.

Starting from the principle whereby "*a marine ecosystem should be classified as vulnerable based on the characteristics that it possesses*", § 42 of the Guidelines lays down five criteria to be applied to the identification of a VME: uniqueness or rarity, functional significance of the habitat, fragility, life-history traits of component species that make recovery difficult, and structural complexity. The similarity between the criteria defined by the FAO and the EBSA criteria has been stressed by experts, but technical and functional differences do exist between the two systems, which does not in any way impair their complementarity. Just like criteria applicable to PSSAs, the identification criteria for VMEs call for a response in terms of functional management of the activity, in this case deep-sea fishing, by States or Regional Fisheries Management Organizations (RFMOs), whereas the EBSA system appears essentially as a scientific and technical approach, within which no particular body is designated as being specifically competent to identify the areas, nor to take appropriate management measures.

In the case of submarine canyons, the advantage of the complementarity likely to result from such a cross-sectoral approach is thus self-evident: it would serve to reinforce the functional efficiency of EBSA criteria, so that generalized marine spatial planning could be set in place, incorporating in particular the impact of navigation via the PSSA concept, and that of fisheries by reference to the VME notion. In the Mediterranean, it could especially be the case because the instruments of universal law are, on all these points, applicable at regional level and it could therefore naturally arise that *governance strategies specific to the Mediterranean* could be set in place.

II - GOVERNANCE STRATEGIES SPECIFIC TO THE MEDITERRANEAN

Given the physical and legal specificities of the Mediterranean, regional solutions are, in fact, perhaps more conceivable, and above all necessary, here than elsewhere. They are feasible, within the universal framework imposed by the United Nations Convention on the Law of the Sea and in conformity with it, by reference to the schema of the UNEP Regional Seas Programme. In positive law, legal instruments exist, in this case *in the context* *of the Barcelona System* (A), which are likely to contribute to a real regional protection strategy for submarine canyons, though this strategy must also necessarily be understood *in the spirit of the Barcelona System* (B), in other words, from the dynamic perspective of legal governance in the making.

A - In the context of the Barcelona System

As at universal level, specifically Mediterranean strategies can only be effective if they are incorporated into an intersectoral approach. Even within the context of the Barcelona Convention, and first of all *with reference to SPAMIs of the Protocol Concerning Specially Protected Areas and Biological Diversity* (1), governance of submarine canyons cannot be considered independently of other applicable instruments potentially capable of reinforcing its effectiveness, *ie. as per a logic of conceptual superimposition* (2).

1) With reference to SPAMIs of the Protocol Concerning Specially Protected Areas and Biological Diversity

The revision of the first Barcelona Convention of 1976, and its replacement by the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean in 1995 **(5)**, for the purpose of incorporating the result obtained in Rio and the imperatives imposed by sustainable development, created a normative framework propitious to the assimilation and protection of biodiversity, in which submarine canyons play a role. Furthermore, *the 1995 Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean* (a), then adopted to replace the 1982 Protocol Concerning Mediterranean Specially Protected Areas, constitutes a unique case in the UNEP's regional seas system, consisting of a specifically dedicated agreement, but also of the possibility of proclaiming *Specially Protected Areas of Mediterranean Importance* (SPAMIs) (b) including in the high seas.

a) The 1995 Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean

Thanks to the coherent framework provided by the conventional system of the Mediterranean Action Plan (MAP), of which only the 1995 Protocol for the Prevention and Elimination of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft or Incineration at Sea is not yet in force, the Mediterranean benefits from a specific legal framework adapted to the case of an enclosed or semi-enclosed sea. The Mediterranean Sea is, in particular, the first and only regional sea in the UNEP Programme to benefit from such specific protection in terms of biodiversity.

Article 10 of the Convention for he Protection of the Marine Environment and the Coastal Region of the Mediterranean, adopted on June 10th, 1995, and entered into force on July 9th, 2004, is expressly dedicated to *Conservation of Biological Diversity* and obviously had no equivalent in the Convention for the Protection of the Mediterranean Sea Against Pollution, initially adopted on February 16th, 1976. It stipulates that: "*the Contracting Parties shall, individually or jointly, take all appropriate measures to protect and preserve biological diversity, rare or fragile ecosystems, as well as species of wild fauna and flora which are rare, depleted, threatened or endangered and their habitats, in the area to which this Convention applies*". The field of application of this commitment to protect and preserve biodiversity is thus very wide, as all the coastal States are Parties to the new convention, with the exception of Bosnia-Herzegovina and Lebanon, in whose case acceptance of the 1995 amendments is, however, underway.

Adopted in Barcelona on June 10th, 1995, and entered into force on December 12th, 1999 **(10)**, the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean develops the principle laid down by the Barcelona Convention by introducing a system specifically dedicated to biological diversity, which Article 1 para. b defines in literally the same terms as Article 2 of the 1992 Convention. As such, it fits perfectly into the new schema resulting from the general revision carried out in 1995 in follow-up to the Summit held in Rio, consideration of the stakes involved in sustainable development and transposition at regional level of the universal obligations arising from the adoption of the Convention on Biological Diversity. The resulting field of application for instruments designed to protect Mediterranean biodiversity is wide and innovative, but unfortunately does not encompass all the coastal States; its overall ratification should thus be encouraged, as Bosnia-Herzegovina, Greece, Israel and Libya are currently still not Parties to the 1995 Protocol.

The strategy implemented by the Protocol Concerning Specially Protected Areas and Biological Diversity is based on the conservation and importance of factors related to biodiversity and its conservation. Completed by three Annexes adopted in Monaco in 1996, the conventional text attempts to go beyond petitions for purely declaratory principles and aims to develop a functional approach articulated around *Protection of Areas* (Part II completed by Annex 1) and *Protection and Conservation of Species* (Part III completed by Annexes II and III), backed up by the strengthened role of the pre-existing dedicated structure: the Regional Activity Center for Specially Protected Areas (RAC-SPA/ CAR-ASP) based in Tunis.

The Mediterranean thus finds itself endowed with a conventional instrument, so far uniting 17 of the 21 bordering States and the European Union, and the operational means to protect biodiversity which encompass ecosystems, habitats and species (Slim, 2003). The 1995 Protocol thus appears to be a vital tool in scientific and legal terms for the preservation of submarine canyons in the Mediterranean, especially as, besides the Specially Protected Areas already covered by the text of 1982, it henceforth provides for the networking of *Specially Protected Areas of Mediterranean Importance* (SPAMIs), including those beyond areas under jurisdiction, in other words, the entire maritime space of the Mediterranean.

b) Specially Protected Areas of Mediterranean Importance (SPAMI)

Section II of the afore-mentioned Part II of the 1995 Protocol is in fact devoted to an innovative concept : *Specially Protected Areas of Mediterranean Importance*.

Article 8 § 1 lays down the principle of the establishment of a "*List of Specially Protected Areas of Mediterranean Importance*" (SPAMI List), "*in order to promote cooperation in the management and conservation of natural areas, as well as in the protection of threatened species and their habitats*". Three categories of sites can be included in the list: those which "*are of importance for conserving the components of biological diversity in the Mediterranean*", those which "*contain ecosystems specific to the Mediterranean area or the habitats of endangered species*", and those that "*are of special interest at scientific, aesthetic, cultural or educational levels*" (Article 8 § 2). Submarine canyons are therefore perfectly eligible for inclusion in the list and, as it happens, the concept even seems to be an appropriate instrument for governance, *a fortiori* given the functional protection supposed to result from SPAMI status as per the terms of Article 8 § 3. In fact, the goal being sought is not only "*to recognize the particular importance of these areas for the Mediterranean*" (para. a), but also, for Parties subscribing to the conventional system, "*to comply with the measures applicable to the SPAMIs and not to authorize nor undertake any activities that might be contrary to the objectives for which the SPAMIs were established*" (para. b).

Devoted to the *Procedures for the Establishment and Listing of SPAMIs*, Article 9 is indisputably the most innovative and most interesting in the Protocol, in terms of protection of biodiversity and, more generally, with regard to the international law of the sea. In view of the fact that the Protocol applies to the seabed and subsoil as much as to the waters (Article 2), Article 9 § 1 in fact stipulates that "*SPAMIs may be established*" not only in "*marine and coastal zones subject to the sovereignty or jurisdiction of the Parties*" (para. a), but also in "*zones partly or wholly on the high seas*" (para. b). Even in the case of high seas by default, by nature called upon to be integrated, over time and in one form or another, within national maritime zones of the coastal States, given that there is nowhere in the Mediterranean where the coasts are more than 400 nautical miles away, this innovation is sizable because it allows for homogeneous and effective protection to be granted to the entirety of the Mediterranean area. The importance of cooperation is, moreover, underlined by the Protocol, both for proposing a SPAMI (Article 9 § 2) and for organizing and implementing its management (Article 9 § 3). In all cases where a SPAMI is not "*situated in a zone already delimited, over which [a State] exercises sovereignty or jurisdiction*" (Article 9 § 2 para. a), but "*partly or wholly, on the high sea*" (article 9 § 2 para. b) or "*in areas where the limits of national sovereignty or jurisdiction have not yet been defined*" (Article 9 § 2 para. c), proposals for inclusion must be jointly submitted by the "*neighbouring Parties concerned*", who are also called upon to consult each other "*with a view to ensuring the consistency of the proposed protection and management measures, as well as the means for their implementation*" (Article 9 § 3 para. a).

Protection, which could well be offered by the SPAMIs, seems, *a priori*, of a kind that could be adapted to the needs and requirements of conservation of submarine canyons. SPAMIs in fact allow for the seabed and superjacent waters to be protected, and this, whatever the legal status of the areas concerned. As emphasized in Article 9, the existence of delimitation conflicts and the absence of proclaimed jurisdiction, of which it is supposed to be the result, definitely do not constitute obstacles. Neighbouring States sharing the same intentions do not need to have defined their maritime boundaries precisely in order to cooperate efficiently in preserving biodiversity. Quite the contrary, protection and management measures then defined and implemented jointly by the "*neighbouring Parties concerned*" can only be more effective, as the marine space is indifferent, by its very nature, to the legal boundaries of sovereignty and jurisdiction that governance strategies must, therefore, precisely attempt to transcend.

The system's effectiveness is in fact reinforced by the provisions in the Annexes and first of all, in the case of SPAMIs, by Annex I devoted to *Common Criteria for the Choice of Protected Marine and Coastal Areas that could be included in the SPAMI List*. If, quite logically, "*regional value is a basic requirement of an area for being included in the SPAMI List*", Parties to the Barcelona Convention had defined a set of five assessment criteria over 10 years prior to the CoP9 of the Convention on Biological Diversity. They consist of uniqueness, natural representativeness, diversity, naturalness, presence of habitats that are critical to endangered, threatened or endemic species, and cultural representativeness. Convergence with universal criteria, particularly EBSA criteria, but also those leading to identification of PSSAs and VMEs, is therefore *a priori* patently obvious, except perhaps for the cultural dimension which, however, is also marginally taken into consideration in the IMO approach. It is, in fact, with reference to EBSA criteria that the RAC/SPA already seems to have made an intense effort towards concertation, with the aim of identifying 12 areas, which could lead to the creation of a coherent system of SPAMIs, capable of incorporating submarine canyons **(14)**.

Furthermore, as borne out by this example, and as is assumed by the very idea of a "*SPAMI List*", and as Annex I expressly states, SPAMIs are required to build a network which is coherent in terms of representativeness and connectivity, in itself making them particularly well-suited to take the systemic functioning of submarine canyons in the Mediterranean into account. Defined case by case by the "*neighbouring Parties concerned*", protection and management measures are nevertheless still capable of being adapted to the particularities of each site and, in this case, of each canyon. Quite specific, this protection has its effectiveness guaranteed in principle by the real legal status deriving from its inclusion in the SPAMI List; as stated in Annex I, "*all areas eligible for inclusion in the SPAMI List must be awarded a legal status guaranteeing their effective long-term protection*".

In practice, the question of the SPAMIs' effectiveness remains no less real, though it is expressed in different terms depending on whether it is related to the risk of seeing SPAMIs relegated to *paper parks,* due to the lack of logistical resources or political willingness on the part of the States, or is formulated in legal terms pertaining to the relative effect of treaties. Opposability of SPAMIs is to be settled between Parties to the Protocol as per the combined reading of Articles 9 § 4 para. c and 9 § 5: in cases where the SPAMI is situated in the high seas or in a non-delimited zone, "*the decision to include the area in the SPAMI list shall be taken by consensus by the Contracting Parties which shall also approve the management measures applicable to the area*" (Article 9 § 4 para. c) and, in all events, "*the Contracting Parties undertake to observe the rules thus laid down*" (Article 9 § 5).

However, this provision leaves open the question of the SPAMIs' legal opposability with regard to the four Mediterranean States which are not Parties to the 1995 Protocol, and above all third-parties to the Barcelona System, *ie.* non-Mediterranean States, concerning which Article 28 *Relationships with Third Parties* innovates by stipulating that "*the Parties shall invite States that are not Parties to the Protocol and international organizations to cooperate in the implementation of this Protocol*" (§ 1) and, above all, that they "*undertake to adopt appropriate measures, consistent with international law, to ensure that no one engages in any activity contrary to the principles or purposes of this Protocol*" (§ 2), which in truth only leaves States Parties very little means of action other than those of a purely incitative nature.

The adoption of "*sectoral and intersectoral policies*" provided for in Article 3 § 4 of the Protocol thus only seems the more appropriate for reinforcing the effectiveness of governance strategies offered by SPAMIs: in practice, it invites them to approach the protection of submarine canyons in the Mediterranean also *as per a logic of conceptual superimposition*.

2) As per a logic of conceptual superimposition

The particular nature of canyons, whose protection should be both ecosystemic, spatial and functional, requires that the effectiveness of the SPAMI network to be created is guaranteed by a cross-combination of instruments and concepts. In practice, this means accepting the support of other systems whose concepts and standards can be superimposed on the reasoning behind the Protocol. This intersectoral approach implies resorting first of all to *the functional but global approach of the General Fisheries Commission for the Mediterranean* (a), but also by attempting *a minima* to reinforce the schema of the Barcelona System through *the spatial but partial approach of the European Union* (b).

a) The functional but global approach of the General Fisheries Commission for the Mediterranean

The cross-sectoral logic advocated at universal level can, in fact, also be usefully applied at the regional level of an enclosed or semi-enclosed sea, and with great effectiveness in the Mediterranean area, where all the factors, both biological and anthropological, comprise as many parameters in constant interaction. Fishing is by its very essence one of the human activities most likely to have a negative and even destructive impact on ecosystems, and the Mediterranean is not an exception in this respect.

Regional organization for the management of fisheries uniting all the States bordering the Mediterranean (as well as Japan), the General Fisheries Commission for the Mediterranean (GFCM) thus offers a global framework for action at Mediterranean level, even though the instruments of protection liable to be implemented are, of course, essentially functional and aimed at preventing impacts on ecosystems caused by halieutic activity, and even some of its forms most likely to prove destructive for biodiversity, such as deep-sea fishing.

As part of a dynamic of cross-sectoral governance, and complementary to instruments either existing or to be developed, notably SPAMIs, the GFCM can thus contribute effectively to the protection of submarine canyons in the Mediterranean, by nature particularly sensitive to the destructive effects of deep-sea fishing. Certain initiatives undertaken over the past few years by the Commission, as part of a logic confirming certain aspects of the VME concept initiated by the FAO, testify to the role likely to be played, in the Mediterranean, by suitably adapted measures for the management of fisheries; and first of all, this is the case of *Fisheries Restricted Areas (FRAs)*.

As per its Recommendation GFCM/29/2005/1 on the Management of Certain Fisheries Exploiting Demersal and Deepwater Species, the GFCM, reasoning in reference to the "*precautionary principle*", decided that States should "*adopt measures aimed at increasing the selectivity of demersal trawl nets*" (§ 1) in respect of demersal fisheries, and "*prohibit the use of towed dredges and trawl nets fisheries at depths below 1,000 m*" (§ 2), *i.e.* deepwater fishing **(11)**.

A year later, on the basis of this recommendation, and the universally recognized need to "*protect vulnerable marine ecosystems*", the GFCM adopted Recommendation GFCM/30/2006/3 on the Establishment of Fisheries Restricted Areas in order to Protect the Deep Sea Sensitive Habitats. In conformity with the recommendations of its Scientific Advisory Committee (SAC), it in fact created, in three sectors in the Mediterranean, a "*fisheries restricted area*" where "*fishing with towed dredges and bottom trawl nets shall be prohibited*" (§ 1), and which is also intended over time to be protected "*from the impact of any other activity jeopardizing the conservation of the features that characterize these particular habitats*" (§ 2). The first of these areas is intended to protect coral in the "*Deep Sea [...] "Lophelia reef off Capo Santa Maria di Leuca"*", situated in international waters (§ 1, para. a), the second to award full protection status to the area situated in the "*Deep Sea [...]"The Nile delta area cold hydrocarbon seeps"*" and the unique living community which has developed there (§ 1 para. b), and the third to ban trawling activities in order to protect the sensitive habitat in the "*Deep Sea [...] "The Eratosthemes Seamount"*", located in the Eastern Mediterranean between the Levantine Platform to the south and the Cyprus margin to the north near the subduction zone of the African plate (§ 1, para. c). The contribution made by this recommendation is all the more interesting as the GFCM approach clearly subscribes to a cross-sectoral dynamic; very significantly, it in fact emphasizes that "*integration of environmental concerns in fisheries management is a way to protect the structure and functioning of the marine ecosystems that are in turn fundamental to the overall production of the seas, including the exploited resources and to the benefit of sustainable fisheries*", adding that "*human activities other than fisheries should care of the structure and functioning of the marine ecosystems to the benefit of healthy environment and sustainable fisheries*" **(12)**.

Even though it does not concern submarine canyons, Recommendation GFCM/30/2006/3 opens the way to a possible widening of the logic of Fisheries Restricted Areas, as does Recommendation GFCM/33/2009/1 on the Establishment of a Fisheries Restricted Area in the Gulf of Lion to protect Spawning Aggregations and Deep Sea Sensitive Habitats. On the basis of Recommendation GFCM/29/2005/1, and as proposed by the European Community, the SAC advising "*to ban the use of towed and fixed gears and longlines for demersal resources in an area on the continental shelf and slope of the Eastern Gulf of Lions*", the GFCM decided to establish a fisheries restricted area with, as its sole limitation, the level of the fishing effort applied in 2008, in the eastern part of the Gulf of Lion, this time pertaining to a sector that includes a submarine canyon south of Marseille. Still pursuing a cross-sectoral line of reasoning, the Commission also emphasizes the need to "*call the attention of the appropriate national and international authorities in order to protect this area from the impact of any other human activity jeopardizing the conservation of the features that characterize this particular habitat as an area of spawners' aggregation*" (§ 7) **(13)**.

As such, that's to say, as fisheries management measures, and also because of their vocation to incorporate the impact of other human activities and cross-reference with other instruments, Fisheries Restricted Areas thus offer the kind of measures capable of being used and developed to reinforce the protection of canyons. Though in this respect, the degree of protection offered should undoubtedly be capable, depending on the case, of going beyond the sole freezing of the level of the fishing effort, in order to be really effective.

Given that submarine canyons are particularly numerous on the northern shore, *the spatial but partial approach of the European Union* can also provide support for other applicable legal instruments.

b) The spatial but partial approach of the European Union

Today, the European Union has a really objective dimension, especially within the Mediterranean area where its politico-economic, but also legal and normative influence cannot be ignored or even under-estimated. The southern border of the European Union is the shoreline of the Mediterranean, and EU strategies, particularly in environmental and maritime matters, can no doubt contribute towards effective protection of Mediterranean biodiversity and, at the same time, better legal governance of submarine canyons.

However, only 7 of the 21 States bordering the Mediterranean, thereby Parties to the Barcelona System, are also members of the European Union, itself a Contracting Party to the Mediterranean Action Plan and its conventional provisions; furthermore, only 7 States out of the 27 members of the European Union are Mediterranean. There is therefore very little spatial and legal coincidence between the two entities, which are the European Community and the Mediterranean.

European Union law thus appears to be a legal instrument with limited spatial application in the Mediterranean.

This is firstly the case depending on whether or not the Mediterranean States are also members of the EU. With regard to the 14 non-member States, EU law is naturally not opposable to them *de jure*, as per the principle of the relative effect of treaties. In practice, however, this may not exclude the possibility of the EU attempting to impose *de facto* certain aspects, either in the case of candidate States wanting to join the EU, or via an extensive view of the applicability of its standards, notably founded on economic or political considerations, as in the case of Council Regulation (EC) N° 1005/2008 of September 29th, 2008, establishing a Community system to prevent, deter and eliminate illegal, unreported and unregulated fishing. As clearly demonstrated by this example, the demands of European Community law appear in practice even less transposable outside the circle of its member States, since the other Mediterranean States do not usually have the same financial or technical capabilities to implement them. This remark is no doubt just as valid with regard to biodiversity, in the case of Directive 2008/56/EC of the European Parliament and of the Council of June 17th, 2008, establishing a framework for community action in the field of marine environmental policy ("Marine Strategy Framework Directive"), and this, even though the text is undeniably of a kind to create in the Mediterranean a propitious environmental and ecosystemic context, notably through the notion of "*good environmental status*", notwithstanding the concept of spatial fragmentation it implies between member States and also between basins and sub-basins that it distinguishes in the Mediterranean (Western Mediterranean Sea, Adriatic Sea, Ionian Sea and Central Mediterranean Sea, Aegean-Levantine Sea).

For member States, the question of applicability naturally does not arise in the same terms, and the interest of EU law may be evident yet limited, insofar that it is necessarily required to apply within political boundaries which are without pertinence to the shared maritime area of an enclosed or semi-enclosed sea. An EU act of law such as the Council Directive 92/43/EEC of May 21st, 1992, on the conservation of natural habitats and wild fauna and flora **(7)** thus appears to be an appropriate instrument of legal governance in the case of submarine canyons under the jurisdiction of member States. An essential element in the EU's strategic policy, the so-called "Habitats Directive" in fact aims to establish a conservation system for wild species and natural habitats based on the Natura 2000 ecological network of protected sites applicable to the sea. Furthermore, its importance for the protection of Mediterranean biodiversity is confirmed by Council Decision 1999/800/EC of October 22nd, 1999, on concluding the Protocol concerning specially protected areas and biological diversity in the Mediterranean, and on accepting the annexes to that Protocol (Barcelona Convention), whereby the Community declares that it will participate in the implementation of said Protocol and its Annexes, which thus includes the notion of SPAMIs, via the Natura 2000 network. The Natura 2000 network is thus capable of providing support for protection offered by SPAMIs, in waters placed under the sovereignty, or possibly the jurisdiction, of European Union member States, which could potentially concern canyons on the northern shore.

The second kind of brake on the spatial application of EU law in the Mediterranean Sea specifically concerns the member States and derives from the legal status of maritime areas. In the high seas by default, by its nature required to fall under the jurisdiction of member States, European Union law is not currently supposed to apply other than marginally in the case of *sui generis* zones, in which EU principles are capable of exercising their vocation towards integration, which can notably be the case in environmental matters. Thus, *a contrario,* the question then arises of the opportunity for a generalized proclamation of EEZs which, due to the concept's primarily halieutic objective, would hand over management of Community waters in the Mediterranean (with the exclusion of territorial waters) directly to the European Union, in which Mediterranean States are in the minority, as well as specifically Mediterranean interests perceived as peripheral and thus marginalized in a Europe comprised of 27 member States.

To avoid the effect of fragmentation which could result from this on the scale of the entire Mediterranean area, global protection of marine biodiversity in which the submarine canyons system participates therefore undoubtedly implies giving priority to a specifically Mediterranean approach and developing new legal strategies *in the spirit of the Barcelona System*.

B – In the spirit of the Barcelona System

Whatever the instruments of positive law, truly effective legal governance of submarine canyons implies further improvement of the Barcelona System and consequently adopting a position within a prospective approach. The legal expert can then conceive and propose new strategies *for going beyond classic legal reasoning* (1) and thus strengthen the protection offered by regional instruments, notably *by means of shared governance* (2).

1) For going beyond classic legal reasoning

Improvement of the protection liable to be offered to biodiversity can be obtained through a legal prospective approach, as the classic logic of the law is almost ontologically unsuited to deal with what is at stake in the marine environment and hence to the challenges of conservation of submarine canyons in the Mediterranean. A new form of governance is a matter for legal imagination but, in the current state of the juridicisation of the international system, realism demands that it can, however, only be developed *in compliance with the States' territorial jurisdiction* (a) and *notwithstanding national appropriation of resources* (b).

a) In compliance with the States' territorial jurisdiction

An effort of imagination is required of the jurist in order to develop new governance strategies, more effective in terms of protection for submarine canyons and biodiversity, either by combining existing legal instruments, or by transposing them, or even by having recourse to innovative concepts. But in the case in point, the lawyer's imagination is necessarily conditioned by the umbrella treaty consisting, for the marine area, of the 1982 Convention, whose principles are usually expressly transcribed in universal or regional conventions of environmental law in the form of traditional "without prejudice" territorial clauses (articles 4 and *in fine* 8 of the Convention on Biological Diversity; articles 2 § 2, 3 § 6, 5 and 9 of the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean).

On sea as on land, respect and compliance with the coastal State's territorial jurisdiction and powers are imposed, as witnessed by the legal logic of territorialization of maritime areas, a real conquest of space in seas subjected to the shadow cast by the sovereign State, which results from the doctrine of coastal nationalism and its triumph at the 3rd United Nations Conference on the Law of the Sea. This approach also prevails in the Mediterranean Sea, underwater where the subsoil is nowhere vast enough for the seabed to be legally covered by the Area nor its regime of positive internationalization, but also prospectively for the superjacent waters where evolution is henceforth headed towards progressive jurisdictionalization of a maritime area which has long remained *res nullius*.

In the case of submarine canyons in the Mediterranean, the question is expressed in different terms depending on whether the area to be protected extends within or beyond 12 nautical miles, and beyond that limit, which is that of the sovereignty over the sea, depending on the dimension being taken into account: the static area of the seabed and subsoil on which the coastal State has, *ipso facto et ab initio,* sovereign rights, or the mobile area of the water column whose legal status can vary but is always subject to proclamation.

As geological structures, submarine canyons in the Mediterranean thus find themselves in all events automatically covered by State jurisdiction, with which any governance strategy will have to deal: sovereignty for the subsoil of the territorial sea, sovereign rights for the legal continental shelf. The coastal State alone is thus entitled to authorize or prohibit certain activities constituting a potential danger for submarine canyons, such as exploitation of underwater sand deposits to replenish beaches, in the form of samples or extracts taken out at sea or in canyon heads. The jurisdiction and powers that follow from its status as a coastal State must therefore also be seen as a responsibility.

The same is naturally true of exploration and exploitation of other resources in the subsoil, particularly hydrocarbons, addressed in the 1994 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, henceforth in force, and also, even though this may seem partly prospective, biological resources in the superjacent waters, for which the effectiveness of the ecosystem approach requires joint protection. It is thus in keeping with this reasoning, and *notwithstanding national appropriation of resources*, that the preservation of biodiversity and the governance of canyons must be envisaged over time.

b) Notwithstanding national appropriation of resources

Even in the Mediterranean, and in the current state of proclamations, the majority of existing areas under jurisdiction - exclusive economic zones, fishing zones, fisheries protection zones - pursue an economic goal of national appropriation of resources. It was, in fact, mostly reasons of political strategy, originally mainly linked to the existence of a delimitation conflict with Spain, that led France, then imitated by Italy, to proclaim an ecological protection zone. Even if this has not so far been followed by action, France in effect officially announced, on August 24th, 2009, the up-coming creation of a French EEZ in the Mediterranean, which could undoubtedly have a knock-on effect likely to speed up the generalization of proclamations in accordance with the United Nations Convention on the Law of the Sea, and the appropriation of biological resources resulting therefrom.

Exploitation of sea resources, or at least their appropriation by coastal States, even if this is only putative in the absence of a dedicated area, does not, however, in theory, exclude protection of the species that it conditions in any event in terms of jurisdiction and responsibilities. Confirmed by Article 10 *Sustainable Use of Components of Biological Diversity*, the Preamble to the Convention on Biological Diversity does not treat it any differently: "*States have sovereign rights over their own biological resources*", and they are consequently "*responsible for conserving their biological diversity and for using their biological resources in a sustainable manner*".

While there is naturally no going back on the principle of appropriation of resources which lies at the core of the new law of the sea and which, in time, is required to assume all its significance in the Mediterranean, the legal development which came out of the Summit in Rio, and the integration of concerns relating to sustainable development, imply an emergence of certain imperatives of protection and conservation. In the Mediterranean, the 1995 revision of the conventional system of the MAP can be seen as part of this new approach. The Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean thus devotes its Part III to *Protection and Conservation of Species*, and Article 11 § 1 introduces the innovative principle whereby "*the Parties shall manage species of flora and fauna with the aim of maintaining them in a favourable state of conservation*".

In practice, preservation of the species requires striking a balance which reconciles the right of the State to exploit the resources placed under its jurisdiction, and the responsibilities which it therefore bears in terms of conservation and sustainable use. Sectoral management measures can then prove appropriate to provide the right to exploit with the necessary restrictions, in order to guarantee sustainable exploitation of the target species, and thus preserve biodiversity. These measures can be decided unilaterally by the coastal State or adopted collectively, for example within the context of a regional fisheries management organization, such as the GFCM's Fisheries Restricted Areas. Legal governance of submarine canyons can thus also be approached in this way.

In fact, and contrary to a frequently preconceived idea, appropriation does not in itself, and in itself alone, provide an assurance of sustainability nor the preservation of ecosystems and the biodiversity in which they play a role. It is therefore important to ensure the States' awareness of the exhaustible nature of biological resources, *a fortiori* in the marine environment where mobility and the absence of physical frontiers can make appropriation and management measures quite illusory. In this respect, the declaration of biodiversity protection zones may even seem a good alternative, given other problems liable to arise from a generalized proclamation of EEZs, especially on the northern shore of the Mediterranean.

The individual responsibility of coastal States does not, however, exclude their collective responsibility, and less than elsewhere in an enclosed or semi-enclosed sea like the Mediterranean, the necessary cooperation of bordering States *by means of shared governance*.

2) By means of shared governance

Respect of the coastal State's jurisdictional competences does not prevent the Mediterranean from in fact being a dynamic ecosystem, by its very nature reluctant to the separative logic of differentiation of areas and determination of frontiers. Effective protection of submarine canyons and their systemic role thus implies surmounting the obstacles resulting from this legal fragmentation, and apprehending the Mediterranean as both a global area and a common heritage which should be the subject of shared governance. Between imagination and prospective approach, the concept extends an invitation to define *a heritage-based approach to Mediterranean biodiversity* (a) but *a heritage-based approach founded on the responsibility of the coastal States* (b).

a) A heritage-based approach to Mediterranean biodiversity

In the current state of the law, shared governance must, of course, be seen above all as an informal process, as this approach is resolutely turned towards the future and belongs more to *soft law* than *hard law*. It can, in fact, only be conceived, justified and understood in reference to a heritage-based approach to Mediterranean biodiversity in which submarine canyons play a part. In an enclosed or semi-enclosed sea like the Mediterranean, with a unique ecosystem and biology marked by interdependence, common civilizational culture and heritage, the idea is almost self-evident but, so far, only has a marginal legal dimension. In essence, it is to be found in the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean, whose Preamble expressly refers to the "*Mediterranean natural and cultural heritage*" and the need to "*improving [its] state, in particular through the establishment of specially protected areas and also by the protection and conservation of threatened species*".

At universal level, the 1972 UNESCO Convention concerning the Protection of World Cultural and Natural Heritage **(2)** already laid down the principle of "*natural heritage*", defined in Article 2 as comprising "*natural features consisting of physical and biological formations or groups of such formations, which are of outstanding universal value from the aesthetic or scientific point of view; geological and physiographical formations and precisely delineated areas which constitute the habitat of threatened species of animals and plants of outstanding universal value from the point of view of science or conservation; natural sites or precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty*".

Even before the invention of the concept, the idea of incorporating, even subsidiarily, the heritage aspect of biodiversity thus appears to have benefited from a conventional legal basis. This explains why inclusion in the World Heritage List, provided for by Article 11 of the UNESCO Convention, would also seem to provide a solution for strengthening the protection and governance of submarine canyons in the Mediterranean, even if the universal character of said system is, no doubt, in practice, unlikely to facilitate it; inclusion in the said list is, moreover, with declaration of a biosphere reserve also provided for by UNESCO, one of the associated protective measures cited for designation of a Particularly Sensitive Sea Area (PSSA) by Resolution A.982(24) of IMO (§ 6.2).

The Barcelona Protocol of 1995 is, however, the only conventional text specifically dedicated to biodiversity to expressly reason in reference to the notion of "*Mediterranean heritage*", *ie.* to adopt a heritage-based approach to biodiversity, with a wide view of the concept integrating the dual natural and cultural aspect of such heritage (Articles 4 and 8 § 2, Annex I points A para. a and B § 2 in particular), even if the latter seems, in the point in case, naturally secondary with regard to the actual subject of the treaty.

Despite this conventional basis, the heritage-based aspect of Mediterranean biodiversity and ecosystems has remained until now practically a dead letter in legal terms; or at least, coastal States have paid it little attention due to a certain reticence regarding what this type of approach inevitably implies in an enclosed sea such as the Mediterranean, in terms of common heritage and sharing. If a "*Mediterranean natural and cultural heritage*" does exist, it is, in fact, necessarily a shared heritage.

Far from being antithetical from all points of view, the heritage-based approach and the dimension of coastal nationalism can, and must, nevertheless be reconciled, which is perfectly illustrated by the challenge of protecting submarine canyons in the Mediterranean. In practice, it in fact matters very little whether a State has jurisdiction over such and such a canyon and takes the appropriate measures to ensure its conservation, as the canyons form together a system whose impacts on global hydrodynamic and ecosystem functioning are decisive. In this respect, the efforts undertaken by one State alone can be reduced to nil by the inertia or laxity of neighbouring States, and protection measures must transcend limits of jurisdiction in order to function in a physical area rid of all frontiers, and be organized in networks endowed with sufficient connectivity.

Legal governance of canyons can thus only be effective and efficient if it is shared and developed in accordance with *a heritage-based approach founded on the responsibility of coastal States*.

b) A heritage-based approach founded on the responsibility of coastal States

In the international legal system, the existence of States is an ontologically material fact. In the law of the sea, it is expressed by the zoning of areas resulting from the spatially degressive projection of sovereignties, from the coast to the open sea. But in an enclosed or semi-enclosed sea like the Mediterranean, it could not exclude a heritage-based approach to biodiversity and shared governance founded on the individual and collective responsibility of bordering States.

Contemporary international law in fact attributes primary responsibility to coastal State comprised of rights and obligations: rights to the maritime areas and their resources such as provided for in the United Nations Convention on the Law of the Sea; duties to protect and preserve the marine environment for which Part XII established the legal basis, which were then confirmed by universal and regional treaties on environmental law, by reference to biological diversity. The evolution of legal concepts therefore invites the jurist to consider the coastal State, more or less prospectively, as a *trustee* of biodiversity in which the marine areas and resources over which it has jurisdiction play a part, and, as far as the Mediterranean is concerned, all the bordering States as depositaries, in time and in space, of a real shared heritage.

This approach is not entirely new and this kind of dialectic between the State's responsibility and the heritage-based approach is not unknown in public international law, whose Convention Concerning the World Protection of Cultural and Natural Heritage, adopted by UNESCO on November 16th, 1972, offers an edifying example. The conventional system embodied in the World Heritage List (Article 11), and the role attributed to the World Heritage Committee (Articles 8 and following), in fact reconcile "*national protection and international protection of the cultural and natural heritage*" (Title II);

it resides in the notion of "*world heritage*" defined as "*world heritage for whose protection it is the duty of the international community as a whole to co-operate*" (Article 6), but for which responsibility "*belongs primarily*" to the State on whose territory the heritage is situated and whose sovereignty must therefore be fully respected (Articles 4 and 6).

The primary responsibility of the territorial State does not therefore in any way exclude the sharing of governance for which, on the contrary, it constitutes a legal support. The approach retained for "*world heritage*" is thus *in fine* likely to be found to apply in the Mediterranean. Moreover, the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean already includes the concept of "*Mediterranean heritage*", whose protection is entrusted to its List of SPAMIs. As such, it offers means of taking action, not all of which, perhaps, are sufficiently exploited, though amendments could also be envisaged to make the existing mechanism more operational and well-suited. It might then be the right moment in which to define the principle of shared governance and the individual and collective responsibility of the States, in terms of *trusteeship*, by reconciling respect of the coastal State's jurisdiction over marine areas and resources, and imperatives related to preservation and protection of the associated ecosystemic heritage; to sanction the existence of the biodiversity protection zone as a minimum legal basis for the rights and duties of the coastal State in this respect, beyond 12 nautical miles; to make the SPAMI List a real multilateral framework for shared governance, incorporating a variable geometry management system (unilateral, bilateral, trilateral, on the scale of a sub-basin, basin or the entire Mediterranean, depending on the purpose of the areas, their localization and specific characteristics); to give an organic dimension to shared governance within the context of the RAC/SPA or a new entity to be set up, but including at least one body which is not entirely interstate, thus ensuring representation of the different stakeholders concerned, to conform to the principle of governance itself…

In many respects, which are emblematic of the stakes involved in biodiversity and protection of the environment in the Mediterranean (Ros, 2011), the conservation of submarine canyons would be perfectly in keeping with such a schema, but also with the more ambitious prospect of a new protocol dedicated to Mediterranean heritage, whose adoption would then be justified by its enlarged scope, incorporating natural and cultural heritage, for the purpose of thus providing Mediterranean solutions of shared governance to meet the challenges of preserving biodiversity, but also the problems posed by the protection of a heritage which is underwater, historic, archaeological, and also unique throughout the world.

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14) UNEP RAC/SPA, 2010. *Report of the Extraordinary Meeting of the Focal Points for SPAs*, Istanbul Turkey, June 1st 2010, (Annex 3 *List of priority conservation areas lying in the open seas, including the deep sea, likely to contain sites that could be candidates for the SPAMI List*).

http://195.97.36.231/acrobatfiles/10WG348_5_Eng.pdf

15) IMO, 2005. *Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas* (Annex *Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas*). Resolution A.982(24), adopted on 1st December 2005 (Agenda item 11).

http://www.gc.noaa.gov/documents/982-1.pdf

4.2. Superposition of marine protected areas: an original legal solution for the protection of Mediterranean canyons

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Whether in the case of canyons or other marine areas vulnerable to, and/or threatened by, activities carried out in them, we now expect marine protected areas (MPA)[1] to be instruments ensuring full and effective protection of these marine areas. In this respect, scientists justifiably believe that only the development of a global and fully integrated approach to MPAs, sometimes also described as holistic, is likely to guarantee full operational protection of the areas involved.

This global approach is necessary at ecological level, but also at political, economic and social levels. The quality of the protection provided in fact depends not only on all the interacting elements in the ecosystem being taken into account, but also on consideration of all the human activities which affect the environment in the sites concerned. Finally, protection can only be global and effective if all the competent authorities are included in the decision-making process.

Advocated by many participants in the protection of the marine environment, such a concept for the creation and management of MPAs seems, however, to be missing from operational reality as soon as one addresses areas which are not covered by state sovereignty. The evident cause of this loophole seems to lie in the absence of an appropriate legal framework, as the law is often characterized by its frontiers, either spatial or functional. In fact, as soon as one steps beyond the outer limit of the territorial sea, the jurisdictions of the States concerned are limited and overlap.

CREATION OF MPAs DOMINATED BY A SECTORIAL APPROACH

Thus, in the context of its Exclusive Economic Zone (EEZ), the extent of a State's authority with regard to all the ships present in its EEZ is restricted to controlling fishing activities and fighting pollution within a legal framework which does not allow it to control navigation except in the case of accidents and wilful pollution. Navigation continues to be governed by the legal framework pertaining to the high seas and the exclusive jurisdiction of the State whose flag it flies. In such a context, setting up multisectorial MPAs aimed at comprehensive protection of canyons present in an EEZ, and thus allowing for the control, and possibly prohibition, of all activities which may be developed in the EEZ, is obviously a very difficult undertaking. In fact, except for those relating to resources management and the fight against pollution, the measures applicable in the MPA, and particularly those concerning navigation, require the agreement of all the States whose ships are present within the EEZ. On the other hand, such a context does not prevent the competent coastal State from taking various measures as part of its management of the resources within its EEZ and consequently establishing MPAs specifically aimed at conserving and managing the resources in its canyons.

Furthermore, if the State has not established an EEZ, it many consider adopting measures aimed at organizing the exploitation of its continental shelf, over which it exercises sovereign rights not requiring any proclamation. It can thus create MPAs around the canyons, aimed at prohibiting any exploitation of mining resources or sedentary biological resources. It should, however, be noted that these rights do not include jurisdiction for protection of the environment[2], as is the case for the EEZ (see UNCLOS art. 77 §1).

In addition, States may also create MPAs in the high sea without referring to their empowerments, under the aegis of an EEZ or the continental shelf. However, provisions laid down by these MPAs can only be imposed upon ships flying the States' respective flags. This mechanism has been used by France, Italy and Monaco to

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[1] The term « Marine Protected Area » will be used here generically as relating to all forms of protection of a specific marine area, whether it benefits or not from a management plan. In fact, we will refer in particular to zones where fishing is prohibited, even though they are not considered by all specialists as «MPAs». They are not, in fact, subjected to the implementation of a management plan which, for many authors, is a fundamental factor in their definition. *A contrario,* it will however be specified that France, and also Canada, incorporate fishing restriction zones and zones closed to fisheries activities into their approach to MPAs (For Canada : « *Canada's Ocean Strategy* », Cf. Fishery and Ocean Canada website URL : http://www.dfo-mpo.gc.ca/oceans/publications/cos-soc/index-eng.asp. For France : Ministère de l Ecologie, du Développement et de l Aménagement Durable, « *Stratégie nationale pour la création d aires marines protégées - Note de doctrine pour les eaux métropolitaines* », 20 novembre 2007. Cf. French MPAs Agency website: http://www.aires-marines.fr). Likewise, the FAO describes specific fisheries restriction zones as MPAs (see FAO website, pages on MPAs in the high seas: http://www.fao.org/fishery/topic/16204/en)

[2] Cf. Article 77 § 1 of the United Nations Convention on the Law of the Sea signed in Montego Bay on December 10th, 1982.

create the Pelagos Sanctuary[3] with, however, extensive operational limits linked to the legal regime governing the high seas, and the absence of jurisdiction in respect of foreign ships. This type of technique would only be operational for the protection of canyons on condition that the threats concerning them derive from activities being performed under the control of the State(s) setting up the MPA. This could particularly be the case in the fight against pollution of telluric origin. However, as regards navigation, this presupposes that ships flying the flags of third-party State do not usually pass through the zone concerned. Otherwise, a multisectorial MPA could only be effectively established on condition that all the States whose ships use the site participate in the agreement establishing the MPA. Furthermore, any such agreement should cover all the restrictions envisaged in the area involved, whether they concern conservation of vulnerable species or areas, or the control of activities being carried out, such as fishing, navigation, mining exploitation, bio-prospection or storage of CO_2. Such an agreement among several States is often hard to achieve without resorting to the adoption of specific international legal structures.

Despite these difficulties related to the international character of the area concerned, it should be pointed out that, on the high sea~~s~~ and particularly in the case of Mediterranean canyons, other mechanisms of sectorial protection can be considered, three in particular. Thus, in the case of protection of the marine environment, States which are parties to the "SPAMI protocol" may establish MPAs, part of which extend into the high sea. With regard to the management of fisheries activities, the GFCM established zones where fishing is prohibited in 2006, designated as MPAs, with regard to certain equipment, aiming to protect "corals, cold hydrocarbon seeps and seamounts"[4]. Finally, as regards control of navigation, the IMO introduced the possibility of establishing "Particularly Sensitive Sea Areas" (PSSA) on the basis of ecological considerations[5]. All these international mechanisms have a wider field of application than the tripartite agreement establishing the Pelagos Sanctuary, due to the higher number of States which are parties to the agreements provided for. Nevertheless, the legal scope of sectorial protection remains relatively limited for SPAMIs and measures undertaken by the GFCM. In fact, the first are only applicable to Mediterranean States which are parties to the "SPAMI protocol", while the second apply to members of the GFCM which, in addition to Mediterranean States, includes the European Union and Japan. Measures taken by the IMO on this issue have, on the other hand, a much wider scope, as they apply to all the ships belonging to the 170 member States.

It thus seems possible to create so-called sectorial MPAs, each one having protection goals applying to a specific field of activity, whether fisheries activities, the fight against pollution or the protection of biological diversity. On the other hand, the creation of a multisectorial MPA, taking into account all the factors likely to interact within the area concerned, and associating all the competent authorities, is rarely possible beyond territorial sea for lack of an appropriate legal framework. In legal terms, the creation and management of an MPA in the Mediterranean therefore depends on sectorial mechanisms deriving either from instruments aimed at conservation of the marine environment (SPAMI), or instruments aimed at sustainable development of an economic activity which incorporates the environmental dimension (GFCM, IMO). This diversity of mechanisms is further complicated by the fact that, while the main part of the Mediterranean is currently covered by international law on the high sea, an increasingly important part of this area, especially as concerns canyons, is subject to jurisdiction exercised by the States, which also dispose of multiple instruments to create and manage MPAs. The entire array of these mechanisms is not only governed by highly varied legal procedures, but most importantly, their diversity clearly demonstrates a sectorial approach towards the management of marine areas which does not seem to meet the aim of global management of MPAs.

HOLISTIC APPROACH TO MPAS THROUGH SUPERPOSITION OF SECTORIAL MPAs

One might think that, to overcome this difficulty, multisectorial MPAs should be created under, and become as such, a holistic approach. However, legal instruments enabling this type of creation do not currently exist in the Mediterranean. The case of canyons further exacerbates this problem, due to the fact that their floors do not necessarily depend on the same legal regime as the superjacent water columns. Even so, implementation of a global approach to specific marine areas in the Mediterranean, and especially to its canyons, through the creation of an MPA, is not impossible. The practice which is being developed in the North-East Atlantic (1) and the Strait of Bonifacio (2) is exemplary in this field. It aims to set up a holistic approach to the protection of a marine area by means of superposition of sectorial mechanisms. This technique, known as "millefeuilles" ("layer-cake"), thus offers an intersectorial and therefore globalizing approach to the protected zone.

1) This approach can be illustrated by a case of advanced cooperation mainly between a regional fisheries organization (NEAFC)[6] and an organization dedicated to the protection of the environment (OSPAR)[7]. It involves the protection of particularly fragile ecosystems in marine depths in the North-East Atlantic[8]. Although the legal, political and geographic context of this cooperation is far

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[3] This sanctuary has also been listed as a Specially Protected Area of Mediterranean Interest (SPAMI), under the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean established by the Barcelona Convention for the Protection of the Mediterranean Sea against Pollution. Designated hereinafter as the «SPAMI Protocol".

[4] Cf FAO. © 2007-2012. Marine Protected Areas as a Tool for Fisheries Management. Marine protected areas in the high seas. FI Project Websites. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 26 April 2007. [Cited 10 June 2012]. http://www.fao.org/fishery/topic/16204/en. See also_REC.CM-GFCM/33/2009/1, On the establishment of a Fisheries Restricted Area in the Gulf of Lions to protect spawning aggregations and deep sea sensitive habitats.

[5] Guidelines on designating a "Particularly Sensitive Sea Area" (PSSA) are contained in resolution A.982(24) *Revised guidelines for the identification and designation of Particularly Sensitive Sea Areas (PSSAs)*.

[6] North East Atlantic Fisheries Commission.

[7] Organization established by the Convention for the Protection of the Marine Environment of the North-East Atlantic ("OSPAR Convention").

[8] The measures undertaken particularly concern the Charlie Gibbs Fracture Zone, several seamounts and the Mid-Atlantic Ridge north of the Azores. These zones are characterized by a wide diversity of vulnerable habitats and speciesinclude whales, sharks, turtles, seabirds, cold watincluding whales including whales, sharks, turtles and seabirds, but also cold-water coralcorals, deepwater sponge fields and vulner, beds of sponges in deep waters and, above all, stocks of fish with long life spans but slow growth in deep waters, which appear to be the most vulnerable. Cf. OSPAR Commission, Annual Report 2007-2008, p.8 (OSPAR Commission website, Publications pages: http://www.ospar.org/)

removed from that of the Mediterranean, the pilot-zone character of the entire MPA which has been established, and also the natural characteristics of the targeted areas, make it an interesting model to observe with a view to the protection of Mediterranean canyons. Furthermore, as the ecosystems concerned are in the high seas, the legal problems encountered are very closely related to those presented by the Mediterranean, where the EEZ still shows limited use or effect.

As certain ecosystems under threat in the North-East Atlantic are situated beyond national jurisdictions, the creation of an MPA is governed by international cooperation mechanisms, not only between the member States of the various competent organizations but also, and above all, between the organizations themselves. In fact, protection of the ecosystems concerned necessitates the adoption of an integrated multisectorial approach ; while fisheries activity initially appeared as a threat to these ecosystems in deep waters[9], their great fragility makes them particularly vulnerable when confronted by threats posed by all the marine activities carried out within the zone. The latter may involve research and exploitation of the seabed , but also maritime activities such as navigation, which may have a direct impact on the site by affecting the quality of the superjacent water column.

For these reasons, several international and regional organizations, in particular the NEAFC and OSPAR Commission, worked in cooperation to establish an MPA in the various sites concerned. The NEAFC thus rapidly adopted restrictive measures for fisheries activities. Implemented in 2001, these measures were originally intended to prohibit trawling in several zones in the North-East Atlantic. They were reinforced in 2007 and 2009 with the creation of real MPAs in the high sea[10]. They target five zones along the Mid-Atlantic Ridge with the aim of protecting vulnerable deep-water marine ecosystems. However, the MPAs thus established only benefit from protection limited to deep-water fisheries activities and do not provide for protection of these vulnerable ecosystems against other threats.

In order to ensure more comprehensive protection of these fragile ecosystems in the Atlantic, it thus became necessary to go beyond the sectorial approach adopted by the NEAFC. The OSPAR Commission seemed to be the most appropriate body to develop a policy pursuing this direction via the creation of MPAs. In fact, the scope of its jurisdiction must enable it to undertake measures which are both compulsory for a considerable number of States[11] but also, and above all, which guarantee protection against a number of activities[12]. At the meeting for representatives of the member States held in Bergen in April 2010, it was therefore decided, following a long process of studies and reflexions[13], to establish six MPAs in different marine zones in which ecosystems seem to be under particular threat[14].

The scope of the measures thus adopted by the OSPAR Commission is therefore different to that of the NEAFC at functional, but also geographical, level. In fact, the MPAs established by the OSPAR largely cover the “protected zones” of the NEAFC, with a few notable differences[15]. Superposition of protected zones is thus not fully complete, though it is extensive, and two sites benefit from total superposition. However, while the Commission has effectively established new MPAs since April 2012 (the date when its decisions entered into force), it has not yet attached any constraints to them, and no application measures for these decisions have yet been taken.

The decisions adopted nevertheless specify that “*the purpose of this Decision is to establish this Marine Protected Area with the goal of protecting and conserving the biodiversity and ecosystems of the seabed*[16] *and the superjacent waters of the site*”. In zones of superposition, protection offered by the combination of the measures taken by the NEAFC and those which are to be taken by the OSPAR Commission should therefore already provide protection for the area which, if not entirely global, is relatively wide-ranging. Furthermore, if superposition of the measures introduced by both organizations does not yet result in totally global and multisectorial management, the dynamics for cooperation set in place by the OSPAR Commission tend to offset this disadavantage.

The OSPAR Commission has, in fact, developed a network of consultations and agreements with all the international and regional organizations[17] exercising jurisdiction over this area. Among these organizations, one will note in particular the International Seabed

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[9] The first action taken by the NEAFC can be explained by the fact that trawlers exploiting underwater seamount zones in the 1970's began to cause deterioration of these fragile sites. At the time, the trawlers left behind ghost nets which are responsible, even today, for damaging the fragile biodiversity of these sites.

[10] As per the designation adopted by the FAO, op cit. See the different zones protected: http://www.neafc.org/page/closures

[11] Member States subscribing to the OSPAR Convention: Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom, together with the European Community.

[12] The aim of the Convention is to protect the environment in the North-East Atlantic, and is completed by several annexes: Annex I: Prevention and elimination of pollution from land-based sources; Annex II: Prevention and elimination of pollution by dumping or incineration; Annex III: Prevention and elimination of pollution from offshore sources; Annex IV: Assessment of the quality of the marine environment; Annexe V: Protection and conservation of the ecosystems and biological diversity of the maritime area.

[13] In conformity with its decision to create a network of MPAs by December, 2010. OSPAR Recommendation 2003/3 concerning a network of marine protected areas. Cf. the Commission's website, op cit.

[14] Cf. OSPAR Decision 2010/1 to 2010/6 In OSPAR 10/23/1-E, Annex 34.

[15] See the map of OSPAR MPAs in the «Quality Status Report 2010» pages of the Commission's website: URL : http://qsr2010.ospar.org/en/ch10_03.html. See the map of the NEAFC protected zones in the “Managing Fisheries” pages - “Map of NEAFC Regulatory Area and All Closures” on the NEAFC's website: http://www.neafc.org/page/closures

[16] The reference to the seabed is, however, abandoned when the MPA is superposed in a zone which could belong to a State's extended continental shelf. In this case, cooperation with the State concerned is, however, provided for in the decision. This is notably the case for Portugal in respect of the «Mid-Atlantic Ridge north of the Azores». Cf. OSPAR Decision 2010/6, op cit.

[17] Such as the NEAFC, ICES (International Council for the Exploration of the Sea), IMO, FAO, NATO, NAMMCO (North Atlantic Marine Mammals Commission), NASCO (North Atlantic Salmon Conservation Organization), ISA and the United Nations Division for Ocean Affairs and the Law of the Sea (DOALOS) (Dotinga and Molenaar, 2008).

Autority (ISA) which could, over time, become an important player in conservation of the zone. Finally, the IMO can play a significant role with regard to the fight against pollution by navigation. These three organizations are the ones with which the OSPAR has built up the most important relations. The latter have been formalized, notably in a cooperation agreement with the IMO[18] and through the signing of a Memorandum of Understanding on protection of the environment with the NEAFC[19]. Finally, another MoU has been adopted with the ISA[20].

These different forms of cooperation are of interest as they demonstrate that the setting up of an MPA with a multisectorial vocation is complex and suffers from the fact that no specific mechanism has yet been established by the UNCLOS. Nevertheless, when the OSPAR Commission has taken the management measures necessary for protection of the MPAs it has established, the superposition of the protection thus provided together with that ensured by the NEAFC will make it possible to envisage a very comprehensive degree of protection. Which could also be further consolidated, if cooperation with the IMO and ISA is developed and also results in their adopting spatial management measures for the site.

This example shows that superposition of MPAs currently practised in different sectors of marine regulations again appears to be the fastest way of making progress in the pursuit of global protection for a site, even if the level of integration for this protection depends on the number of accumulated MPAs and their intrinsic quality as conservation mechanisms. This example of superposition is also especially instructive on what could be envisaged in the Mediterranean, particularly for the protection of canyons. In fact, in the absence of any rapid progress in the extension of EEZs, the legal context is the same. It is identically characterized by the application of the legal regime governing the high sea, and international organizations have the same areas of jurisdiction, whether it be the GFCM for fisheries, structures established as part of the Barcelona Convention for protection of the marine environment, or the IMO for navigation. The only difference at legal level concerns jurisdiction of the coastal States over deep-sea waters in the case of the continental shelf. Yet here again, the example of the North-East Atlantic is useful, insofar as certain MPAs established by the OSPAR Commission could be superposed over the States' extended continental shelf, and as the Commission has already provided for cooperation procedures with these States in order to establish concerted management of the area concerned[21].

2) Fragile ecosystems in the North-East Atlantic are not the only ones to benefit from this kind of process of superposition of MPAs aiming to guarantee conservation of an ecosystem in respect of all the activities pursued therein. Confronted in particular by certain dangers resulting from navigation, protection of the Strait of Bonifacio is also tending towards a form of organization based on an MPA superposition process. One might well think that the context here is very far removed from the situation faced by the canyons. Yet, to begin with, one finds here the legal and political specificities proper to the Mediterranean. And secondly, the International Maritime Organization (IMO), which does not play a major role in the case of MPAs in the North-East Atlantic, has authorized the establishment of a protection scheme for a fragile area in the Strait of Bonifacio.

The Strait of Bonifacio is both a sensitive natural site due to its ecological richness, and a danger zone highly frequented by international maritime navigation[22]. Furthermore, although it is a coastal area, the problems posed serve to exemplify issues related to the management of marine areas situated beyond territorial seas. In fact, as an international strait, the zone is the subject of an international legal statute guaranteeing the rights of third-party States in conditions very close to those applying to the high sea. Faced by risks of potential accidents, the States bordering the strait, Italy and France, developed joint actions in the 1990's aiming to achieve conservation of the zone that would be as complete as possible. They introduced an integrated international management process for the site, aiming to conserve the zone by giving it the status of a "protected zone"[23] and prohibiting navigation in the strait for the most dangerous ships flying their flags. This process of organization of navigation was gradually developed, although the two States cannot unilaterally extend prohibition measures to all international navigation. In fact, navigation in the Strait of Bonifacio is governed by the law on international straits, which does not allow States to close the passage to ships, but enables them to organize said passage[24].

In parallel to these measures, the two States have developed the use of spatial protection mechanisms for marine areas, firstly by pursuing a shared project for an international marine park and, secondly, by pursuing classification of the strait as one of the sites able to benefit from SPAMI status[25]. This joint policy of spatial protection undertaken by the two States was extended in 2010. They then made an official request to the IMO for classification of the Strait of Bonifacio as a "Particularly Sensitive Sea Area" (PSSA). This request thus targeted enhanced protection of the zone in the face of dangers posed by navigation, by means of creating a protected

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[18] The NEAFC has signed an agreement for cooperation with the IMO : cf. OSPAR website, pages «Works Area Biological Diversity Fish and Ships»: http://www.ospar.org

[19] In September 2008, these two regional organizations signed a memorandum of understanding relating to cooperation for protection of the marine habitat of the North-East Atlantic. The MoU is available on the NEAFC's website, pages Documents - Basic texts: http://www.neafc.org/basictexts.

[20] Agreements, N° 2010-09 : Memorandum of Understanding with the International Seabed Authority, in OSPAR Commission, Decisions, Recommendations and other agreements, p.13.

[21] Cf OSPAR Decision 2010/6 on the Establishment of the MAR North of the Azores High Seas Marine Protected Area, in OSPAR 10/23/1-E, Annex 44.

[22] Each year, 3,000 ships pass through the Strait of Bonifacio between Corsica and Sardinia, over 150 of them transporting dangerous cargoes such as hydrocarbons or chemical products.

[23] The nature reserve of the Strait of Bonifacio was created in Corsica by decree N° 99-70056 dated 23 September 1999 (JORF N° 222, 24 September 1999, p.14243). The Parc National de l'Archipel de la Maddalena was created in Sardinia by Law N° 4 in January, 1994.

[24] The two States thereby obtained the introduction, within the context of the IMO, of an assistance scheme for navigation and a surveillance procedure: SN/Circ.198 Routing Measures Other Than Traffic Separation Schemes and SN/Circ.201 Mandatory Ship Reporting Systems (26 May 1998).

[25] UNEP, Mediterranean Action Plan, Ninth Meeting of Focal Points for SPAs, Floriana, Malta, 3-6 June 2009, «Proposals for inclusion in the SPAMI List». CAR/ASPUNEP(DEPI)/MED WG.331/5, 7 May 2009, RAC/SPA, Tunis, 2009, pp.3-4.

zone[26]. The positive decision announced by the IMO in July 2011[27] consecrated the efforts undertaken by the two States. Furthermore, it can be considered that declaration of the site as a PSSA should facilitate the development of other actions of spatial protection, to which the two States committed themselves in 2010. They still involve the creation of an international marine park, based on the establishment of a European Grouping of Territorial Cooperation (EGTC) among the afore-mentioned protected zones. Finally, the goal of spatial protection is to make it easier to obtain UNESCO heritage status for the region around the Strait of Bonifacio. If all these initiatives succeed, the legal status of the Strait of Bonifacio will come close to resembling a real “millefeuilles” (“layer cake”), in which no less than five international protected zone categories would be superposed: SPAMI, PSSA, international marine park and UNESCO classification, not forgetting its “Natura 2000 in the Marine Environment” classification.

This kind of juxtaposition of legal mechanisms is a major factor in the implementation of integrated global management of an MPA, as it should allow for development of marine management of a larger area encompassing the entire ecosystem concerned. A similar legal approach could be envisaged for the protection of Mediterranean canyons, or at least the most fragile among them.

Whether they are aimed at management of an economic activity or direct conservation of the environment, the superposition of these MPAs implies cooperation between the various components of the sectorial management processes. This kind of coordination then leads to the introduction of integrated management equivalent to what should permit the creation of an MPA, by virtue of its being a multisectorial instrument, though less simple to set up. At international level, this type of cooperation between sectors of marine regulations is more difficult to organize due to the necessary harmonization of the positions of the many member States of the various international or regional organizations which participate in the creation of management measures[28].

Despite these difficulties, superposition of MPAs would seem to be the most pertinent tool for ensuring relatively complete protection of the zone concerned. By superposing distinct but complementary MPAs, it is possible to acquire a more satisfactory level of coherence between the various sectorial management methods involved, and indirectly ensure integrated management of the areas under consideration. Furthermore, this approach fits in perfectly with the goal of establishing MPA networks, backed by many national and international organizations.

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[26] Initially, this measure could strongly incite, then oblige commercial ships passing through the Strait of Bonifacio to take a pilot on board. The creation of this service will comprise the first protection measure resulting from such classification.

[27] Resolution MEPC.204(62), adopted on 15 July 2011 in IMO, MEPC 62/24/Add.1, Annex 22, page 1.

[28] The «Livre bleu du Grenelle de la mer» announced France’s wish to promote the creation of a nature reserve at international level in the red tuna reproduction zone in the Baleares. In the «Livre bleu des engagements du Grenelle de la mer», 10 et 15 juillet 2009, p.30. Cf Grenelle de la mer website : URL: http://www.legrenelle-mer.gouv.fr It should, however, be noted that, at a meeting of experts held by the ICCAT, it was reported that the data regarding the establishment of an MPA related to tuna protection was insufficient to warrant a decision on the subject. In «Report of the joint tuna RFMOs meeting of experts to share best practices on the provision of scientific advice, (Barcelona, Spain, May 31 to June 2, 2010), KOBE2 – WS1 Report, Doc. No. TRFMO2_W1-020/2010, p.4.

4.3. Managing canyons and similar marine features. Lessons learned from the Far West

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INTRODUCTION

The need to protect marine environments has been progressively increasing. While initially focused on protecting regional fisheries resources, the scope of marine environmental protection has been extended to include the assessment of a broader spectrum of human impacts, leading to the establishment of an international agreement with the United Nations Convention on the Law of the Sea (UNCLOS or MBC for Montego Bay Convention, 1982[1]). The United Nations Convention on Biological Diversity (CBD, 1992[2]) provided guidance to address environmental issues at ecosystem scale with emphasis on precautionary stewardship, thereby complementing the UNCLOS mandate.

Traditional species/fishing-related agreements (International Whaling Commission, IWC[3]; International Commission for the Conservation of Atlantic Tuna, ICCAT[4]; General Fisheries Commission for the Mediterranean, GFCM[5]; etc.) have been complemented with environmental agreements either on geographical considerations, namely the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Commission[6]), the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention[7]), the Convention on Wetlands (Ramsar Convention[8]) or human activities other than fishing (London Convention/Protocol on dumping, including nuclear pollution[9]).

Despite many attempts of setting up international Ad Hoc committees, multiple governance bodies and mandates regarding marine environment have led to gaps in coordination, weakening the marine protection framework. These management issues have been tackled in different ways, and this paper intends to present available regional instruments as well as the management framework; it will underline strategies which have been put forward to address marine environmental challenges with a special emphasis on canyons. In the first part of this paper, human activities impacting canyons will be reviewed. In the second part, the main players and the manner in which they interact will be discussed. The third part will provide specific examples of actual protection strategies carried out at different scales, while covering a specific set of actions that have been taken to provide direct or indirect canyon protection. Finally, management issues and potential solutions to ensure effective canyon protection will be addressed, followed by a short conclusion.

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[1] UNCLOS: http://www.un.org/depts/los/index.htm

[2] CBD: http://www.cbd.int

[3] IWC: http://iwcoffice.org

[4] ICCAT: http://www.iccat.es/en

[5] GFCM: http://www.gfcm.org/gfcm/en

[6] OSPAR Commission: http://www.ospar.org

[7] Barcelona Convention:
http://www.unep.ch/regionalseas/regions/med/t_barcel.htm

[8] Ramsar Convention:
http://www.ramsar.org/cda/fr/ramsar-home/main/ramsar/1_4000_1__

[9] London Protocol:
http://www.imo.org/OurWork/Environment
SpecialProgrammesAndInitiatives/Pages/London-Convention-and-Protocol.aspx

DEEP SEA AT STAKE

What we know is what we see

Our knowledge of the Moon is more comprehensive than that of the oceans. Until the end of the XX^{th} Century, oceanographic manuals collectively agreed that oceans and seas were deserts beyond the continental shelf (Fig. 1).

Thanks to new investigation technology, and particularly remote sensing using satellite altimetry and deep diving vehicles, large deep ocean floors have started to reveal their secrets (Pitcher *et al.*, 2007). The desert turned out to be huge areas patched by mountains and hills with canyons and valleys, true reservoirs of biodiversity (Fig. 2), complementing ecosystem goods and services already known (Arrow *et al.*, 1996). While lately marine conservation has focused on bottom trawling issues, omitting other human activities that can degrade seas and oceans conditions, the role canyons play in biodiversity has been overlooked while studying seamounts (Morato and Clark, 2007). Canyons are increasingly targeted by passive fishing gears (nets and long lines), wrongly considered harmless for fish and its habitat (Whitmarsh, 1995). Although many questions remained unanswered, the scientific community has gained a better understanding of these specific geomorphologic formations thanks to advanced technology. In the light of these discoveries, the United States have already put forward two approaches to protect canyons, either through indirect protection when canyons are spawning grounds or, more comprehensively, as part of larger protected areas addressed under integrated management approaches.

Canyons have distinct characteristics, many of which are defined by the nature of their uneven and steep slopes. Canyons play different roles, natural and/or human induced, namely:

- shelters to marine living resources, particularly spawners;
- reservoirs to anthropogenic by-products, most of them used for dumping.

Canyons shelter long-lived species with low turnover (Danovaro *et al.*, 2010) fed by species with faster turnover (Bosley *et al.*, 2004); they epitomize the best living renewable capital resources that are at stake in the Mediterranean. Naturally protected for a while, these species are more vulnerable since technology is improving and harms the species themselves and their habitat.

Although many stringent national and international agreements and policies prohibit or at least monitor dumping (including incineration at sea) into canyons, States and industry are taking advantage of loopholes still remaining in the governance framework. Furthermore, Illegal, Unreported and Unregulated fishing (IUU) damages biodiversity in high seas or beyond national jurisdictions.

Another role canyons play, or the harm they undergo, is emerging as a result of climate change and Carbon dioxide (CO_2) surplus; canyons have drawn attention for CO_2 sequestration into geological formations and decommissioned gas and oil wells as they served as pollutant reservoirs. There is a risk of diffusion associated with sequestration especially when formations are porous, particularly in decommissioned wells; the key issue in this regard is timelines that can vary from years to thousands of years. CO_2 can migrate, naturally or artificially within a State or within geological formations shared by two or more States. Moreover, accidental leaks of CO_2 can occur anytime. Canyons are not spared when oil, gas or mineral ores have to be extracted from beneath the seafloor. Indeed, it is difficult to argue in favor of protecting rich fossil energy beds in these times of sparse and expensive energy resources. Overall canyons have been used to store various types of pollution such as sewage, radioactive waste, sludge; generally located below the continental shelf, canyons naturally concentrate human activities by-products that reach shorelines.

There is no doubt canyons require relevant protection measures. The identification of the relevant structures, whether institutional or not, will help highlight potential connections and synergetic actions for an efficient management plan.

Stakeholders involved in canyon issues

Protecting marine features depends on both current stakeholders and their relationships.

Institutional organizations

National institutions responsible for marine environmental protection can vary a lot between States. Whatever the Departments responsible for marine issues may be (Agriculture, Natural Resources, Environment, Fisheries, Transportation, Defence and so on), the main issue is the mandate each Department endorses and the mechanisms it uses for consultation. A Department devoted to marine issues would be a good solution but it does not prevent failures in management; other powerful Departments (Defence, Trade and others) can hamper protection initiatives if they have not been involved into the protection/management process from the onset.

National Environmental Protection Agencies are mandated to protect one or a combination of the following:

- fish;
- fish habitat;
- marine landscapes;
- other species granted a specific status.

When the aspects cited above are merged, management is flexible and issues are less prone to lead to conflicts between institutions. However fisheries are usually split from environmental considerations, leading to fragmented management regimes detrimental to the activities as well as the environment.

International institutions face challenges similar to those tackled by national bodies. Regional Fisheries Management Organizations (RFMOs) deal with fisheries issues, but they are toothless to manage pollution issues except when the latter impact negatively on marine living resources. Furthermore, the International Seabed Authority (ISA[10]) has a mandate for the seabed but is not involved in fisheries management issues, even though benthic species depend on the seabed.

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[10] ISA: http://www.isa.org.jm/en/home

Fig. 1:

Seafloor desert or Moon surface? (Courtesy of Dean Medeiros).

Canyons and other similar features can go beyond national jurisdictions and raise trans-boundary issues. The provisions of the United Nations Convention on the Law of the Sea (UNCLOS) are meant to address this type of concern at legal level; however, there is no operational authority to implement cross-cutting solutions as yet.

Implementation of the 27 principles of the 1992 Rio Declaration[11], and particularly the ecosystem approach and the precautionary principle, have provided scope for a broader and more inclusive management strategy. Both national and international institutions benefit from scientific supporting structures which include:

— fisheries management;

— promotion of sound ecosystems management and environmental protection;

— regulatory support.

These inherent discrepancies between Departments can be managed thanks to third parties involved in the management process; these structures are usually Non Governmental Organizations (NGOs), sometimes specifically devoted to the Environment (ENGOs).

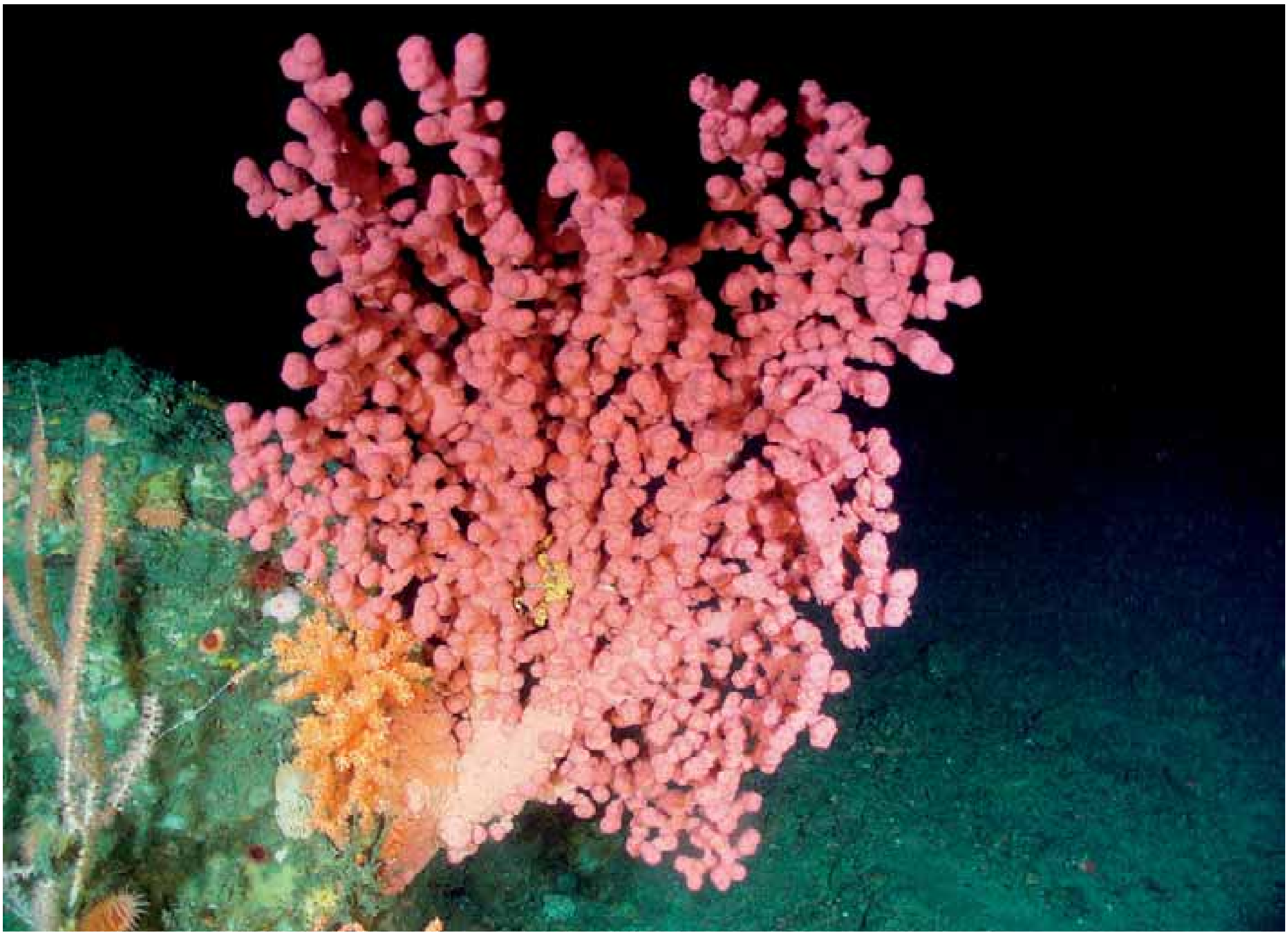
Non Governmental Organizations - NGOs

As for institutional structures, Non Governmental Organizations (NGOs) and particularly environmental ones (ENGOs) play an increasing role in protection and environmental management within the management framework as partners/watchdog; their contribution focuses essentially on valuation/protection of species, areas and practices.

Fig. 2:

Deep seafloor as reservoirs of biodiversity.

Courtesy of: DFO Canada.
www.dfo-mpo.gc.ca/international/media/bk_20090720-02-eng.htm



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[11] Rio Declaration:

http://www.unep.org/Documents.Multilingual/Default.asp?documentid=78&articleid=1163

As for institutions, NGOs and ENGOs are national (often local) and international citizens-driven. More recently, international industry-driven associations have been gaining momentum, such as the World Oceans Council[12] which brings together the Majors (four biggest oil companies), Gold and Diamond industry and so on. The role and influence of these latter players are still unknown as they are new and are still shaping their own involvement, though sustainability is heralded on their home page. Industry has moved to the management table because of a better awareness of its members; a new Private-Public-Partner (PPP) is still under construction and could lead to outstanding outcomes thanks to the contribution of industry.

CASES STUDY

There have not been any initiatives specifically devoted to canyons so far; however, several programmes and plans have included canyons and other conspicuous geological and ecological features. Examples outside the Mediterranean are presented, followed by two cases in the South-west Mediterranean similar to other locations in the entire Mediterranean.

Outside the Mediterranean

Phoenix Island Protected Area PIPA [13] – Kiribati

PIPA was established in 2006; its size doubled in 2008 and it has become largest marine protected area on Earth with 408,250 Km^2. It has been inscribed on the UNESCO World Heritage List. It is now the largest marine World Heritage site in the world (Pierce *et al.*, 2011).

PIPA includes all eight atolls and low reef islands of the Kiribati section of the Phoenix Island group; it also includes two submerged reefs. It is estimated that there could be more than 30 seamounts within PIPA, though to date only nine have been named. The greater part of PIPA by area is comprised of ocean floor with a water column averaging more than 4,000 meters deep with a maximum at 6,147 meters (Fig. 3).

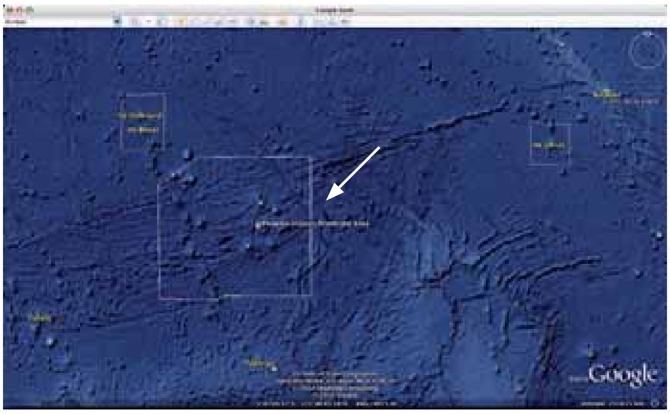

Fig. 3:
The Phoenix Island Protected Area (PIPA), source: Google Earth.

The North Western Hawaiian Islands Marine National Monument [14] – US

The Northwestern Hawaiian Islands Marine National Monument (Fig. 4) encompasses 362,600 Km^2:

- — it includes 11,655 Km^2 of relatively undisturbed coral reef habitat;
- — it is home to more than 7,000 species.

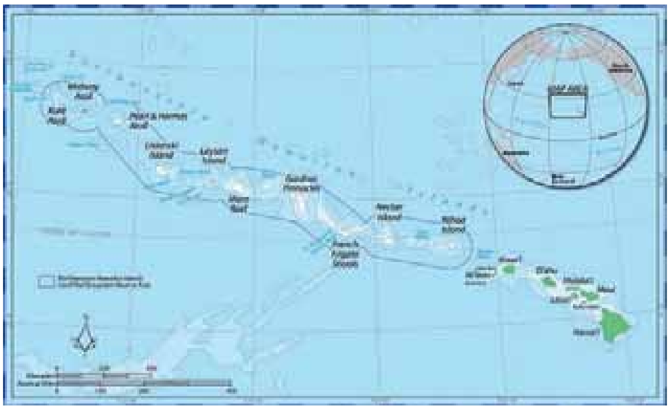

Fig. 4:
The North western Hawaiian Islands Marine National Monument, source: NOAA.

In addition, the **Marianas Trench Marine National Monument Programme** (Iverson, 2008) would expand the Monument to 505,758 Km^2, focusing on the deepest place on Earth, the trench encompassing approximately 92,515 Km^2. This new protected area would add:

- — shelter to more than 300 species of stony corals;
- — a series of active undersea volcanoes and thermal vents with 21 active hydrothermal submarine volcanoes and vents supporting life.

The Gully Marine Protected Area (MPA) - Canada

Among Marine Protected Areas, Canada has designated the Gully MPA, a quite original area located on the slope of the southern Newfoundland Continental Shelf in the Northwest Atlantic, at the limits of the current Canadian Exclusive Economic Zone. The Gully MPA encompasses 2,364 Km^2; it is an interesting area that includes a steep slope starting at 200 meters depth until 2000 m, reaching the glacis (Fig. 5).

Most of the Canadian MPAs are big enough to encompass diversified geological formations, including canyons and particular marine habitats (Sascha *et al.*, 2001). Life diversity is amazing either in the deep sea floor or on the surface, where marine mammals flock in specific periods of the year.

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[12] WOC: http://www.oceancouncil.org/site

[13] PIPA: http://www.phoenixislands.org/index.php

[14] PMNM: http://www.fpir.noaa.gov/DIR/dir_nwhimnm.html

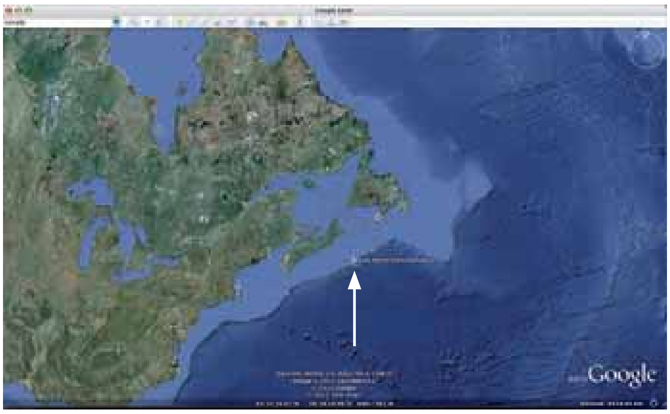

Fig. 6:
Location of the Alidade Shoal, source: Google Earth.

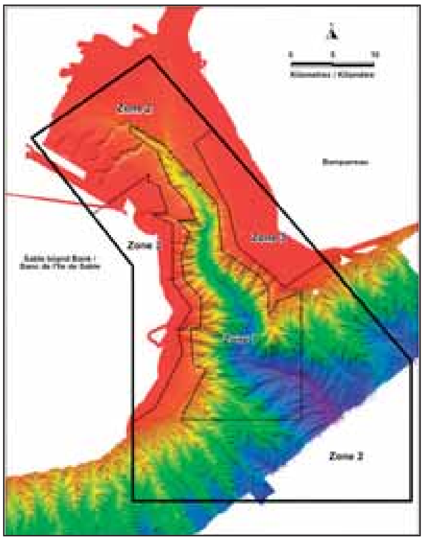

Fig. 5:
Canyons into the Gully MPA. Courtesy of: DFO Canada.

Fig. 7:
Catches on the Alidade Shoal in the early nineties
(courtesy of L. Rahmoun).

In the Mediterranean: example of Algeria

In Algeria, little is known and information is scarce on canyons and particularly their environmental and ecosystem role. Data presented within this document come from personal observations and notices gathered from professionals, fishermen and shipping sailors. Two examples of canyons are presented to highlight the ecological, environmental and economical importance of such features.

The Alidade Shoal is located in the Western part of Algeria, approximately midway between Oran and Ghazaouet (Fig. 6). Quite far from the shoreline (around 25 nautical miles from the harbour of Bou Zadjar), this area has been naturally protected for centuries thanks to its relative remoteness. As bottom trawling is impossible there because of the rocky geomorphologic nature of the substrate, only a few small boats had dared to venture so far for many years.

However, new technologies and speedier boats that appeared in the 'nineties have dramatically altered the area. Powerful and fast boats have started to fish the undisturbed site with amazing catches (Fig. 7), and in less than two years, fishing collapsed, as witnessed by the records of the fishermen themselves. This situation provides evidence of the vulnerability of such areas that are becoming rare in the Mediterranean and worldwide.

Protecting the Alidade shoal seems a difficult challenge; the area is known by fishermen and commercial ships only, and there is no public interest openly stated. Technical considerations could exceed the capacity of the Algerian government to provide the area with the right protection. From the geomorphologic standpoint, the Alidade shoal seems to be part of the many shoals between Habibas and Rachgoun islands, pointing out that canyons are narrowly connected to other geomorphologic features. Since Habibas islands have been recently designated as an MPA, and since the same process is underway for Rachgoun island, there is an opportunity to expand the protection status to the Alidade shoal and merge the whole area as one MPA that should encompass the Plane island west of Cap Falcon as well as the Round island and the Trois Frères island west of Rachgoun.

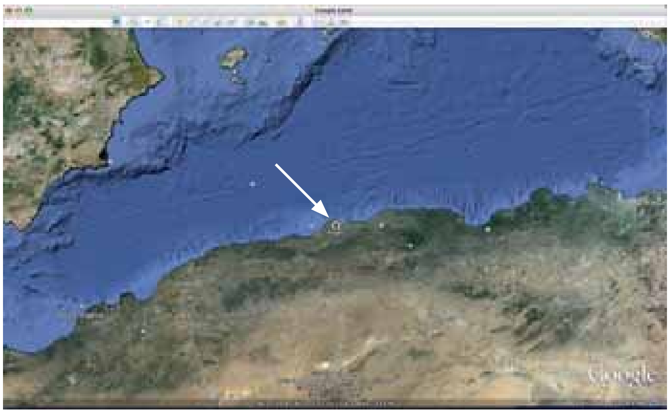

Fig. 8:
Locating Cap Caxine near Algiers, source: Google Earth.

The "Cap Caxine" canyon is located near the capital, Algiers (Fig. 8). It is a trench that goes deep from the shore. This particular geomorphologic formation has been used to dump dredging waste from the Algiers harbour. While the west side of the bay of Algiers is still alive with fishers, the East part of the capital seems dead with rare, if any, catches.

Main threats to canyons

Marine issues have essentially focused on marine coastal environment such as land-based pollution, and on bottom trawling which is now monitored (Fig. 9). However, other sea features that have been spared, thanks to their remoteness or because of lack of information to locate them, are being increasingly targeted by overfishing and as dumping spots.

Amongst the direct threats, destructive fishing practices and unsustainable fishing practices, even when operated by small boats (Fig. 10), can destroy habitat and cull spawners very quickly. Legally reporting and recording such catches would not solve the issue since it is a small-scale fishery encompassing a huge shoreline that would involve costly management. There is evidence that deep fishing for long-lived species with low turnover is becoming a serious issue in the Mediterranean.

Pollution, sewage and sludge all intensify the looming crisis. Though currents and winds disperse part of the pollutants continuously poured into the seas, molecules tend to sink into canyons where they concentrate. Besides, radioactive waste can last from years to thousands of years when it is trapped in such geological forms.

Although there is not yet any oil and gas or minerals beds exploitation in the Southern Mediterranean, it is likely that these areas will draw attention for further exploration as a result of increased energy demands and dwindling supplies of resources.

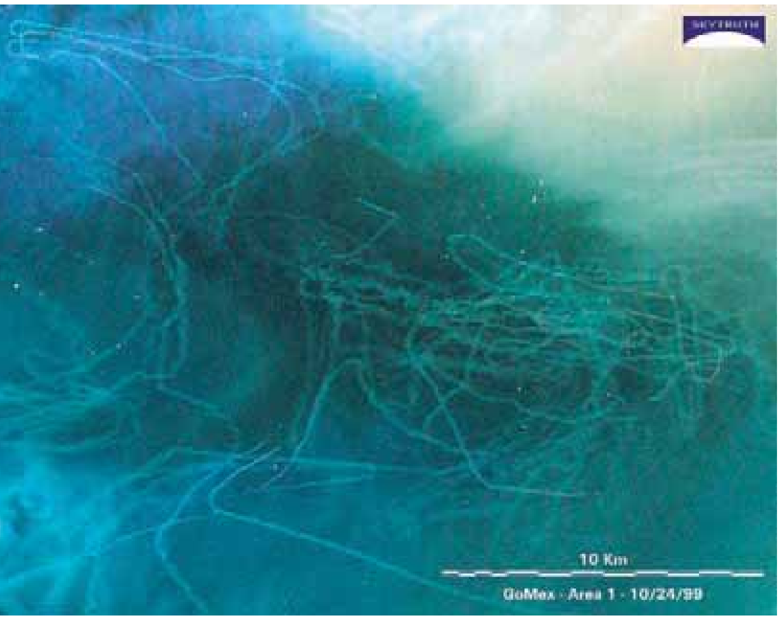

Fig. 9:
Image taken from space pointing out furrows left by bottom trawling in the Gulf of Mexico.
http://www.treehugger.com/files/2008/02/trails_of_destr.php

Fig. 10:
Groupers fished near the Algerian coasts (from ISTPM, 1983).

MANAGEMENT AND PROTECTION OPTIONS

International examples teach us that marine protection requires specific conditions, namely:

- huge diversified areas that encompass many seascapes and ecological features, referring generally to ecosystems;
- the best available science;
- the involvement of different stakeholders/users who must work together to achieve common and/or shared objectives and implement integrated management.

This process is supported by international commitments that guide national policies (DFO, 2004). A comprehensive review goes beyond this snapshot since national arrangements are as diversified as there are nations, even if they are aligned with a general pattern used as an international model (DFO, 2011). An overview of international considerations is provided as a reminder.

The toolkit: international legal/regulatory framework

Bilateral and especially multilateral agreements such as conventions help set up the right legal framework to support synergies while protecting canyons and related features from cross-cutting hazards:

- the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal[15] (this convention does not apply for CO_2);
- the London Convention/Protocol which specify conditions for dumping at sea (prevention of pollution by deliberate dumping of wastes or other material which represents 10% of the pollution) and options for CO_2;
- the United Nations Convention on the Law of the Sea (UNCLOS) which presents a comprehensive legal framework, though there is room for national/local interpretation (navigation, safety, environment, sovereignty, global commons);
- the International Maritime Organization (IMO) which has the onus of the London Convention/London Protocol since it is related to shipping and safety operations at sea;
- for the North East Atlantic States, the OSPAR Convention;
- for the Mediterranean States, the Barcelona Convention.

In addition to these bodies, the United Nations Environment Program (UNEP) has responsibility for managing pollution stemming from land-based activities, which represents 80 % of global pollution. Furthermore, the United Nations Framework Convention on Climate Change (UNFCCC) is involved in CO_2 and other greenhouse gas issues, as is the United Nations Convention on Biological Diversity (CBD) for marine biodiversity.

In addition, RFMOs of whatever kind (agreement between States and/or United Nations/FAO bodies such as in the Mediterranean) manage fisheries with potential overlapping with the CBD.

All these organizations have developed agreements, mostly under *Ad Hoc* commissions. However, conflicting jurisdictions and mandates have often led to neutralization or antagonistic actions. The issue now is how to overcome current coordination issues in order to move from fragmented and conflicting views to coherent and synergistic actions.

On the other hand, much marine protection has been achieved outside this international framework. The US example points out that protection can be done without international commitment. The US have set up several of the biggest world marine protected areas while they have neither signed nor ratified UNCLOS, nor have they ratified the CBD yet, opening a serious flaw for its implementation. Other States could follow the US example, but they do not have the same complementary process.

From content to substance

The aim is to achieve national/international integrated management strategies. Two main approaches seem relevant:

a) continue to fuel the current trend: add management bodies and as a result too many players, and few resources (RFMOs with different mandates/skills, redundancies and discrepancies in jurisdictions);

b) modify/enhance the mandates of each institution involved in the process:

- streamline the current regulatory and legal framework: identify redundancies and gaps,
- fill the gaps and improve policies,
- set up a mechanism based on active implementation/results, management by objectives, irrespective of jurisdictional constraints,
- implement performance measures and consensual accountability (common indicators, specific reference points).

Obviously, the second option seems more appropriate, since organizations already exist and the framework supports scientific bodies that are mandatory to enhancing management decisions. Moreover, stakeholders are familiar with existing structures and talk to each other more readily than if they had to belong to different structures. The main drawback in this option is the potential growth of the structure, which could lose its effectiveness and efficiency.

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[15] Basel Convention: http://www.basel.int

NEXT STEPS

Two aspects must be taken into account when addressing deep sea issues. The first is related to the right framework with an expanded mandate and a coordination mechanism. However this framework should be supported by a programme that includes:

a) a science-based impact assessment of:

— direct or indirect unsustainable human activities (i.e. *in situ* exploitation and land-based activities respectively);

— destructive fishing practices, unsustainable fishing, and Illegal, Unreported and Unregulated (IUU) fishing,

b) the identification of Ecologically and Biologically Significant Areas (EBSAs) as part of the Ecosystem-Based Approach to Integrated Management (EBM) that can lead to Marine Protected Areas designation (and other management rules common to all stakeholders),

c) the implementation of the Precautionary Approach to assess the impacts of:

— ocean fertilization

— ocean acidification

— new emerging fisheries (Frontier areas).

CONCLUSIONS

Canyons play a critical role in ecosystem functioning; they are twice more vulnerable than other marine features because they usually concentrate biodiversity and provide shelter to spawners, and because they are targeted directly or indirectly by dumping. Canyons are part of the ecosystem and must be protected accordingly, in terms of both structure and functions.

Protecting canyons requires resources, knowledge, data and finances, and political willingness. Because they are hidden from the public, it seems hard to meet these requirements concomitantly since decision-makers buy in when public pressure is high enough. A trade-off is, however, possible using species status provided by the IUCN red list. As soon as species benefit from a particular status or are considered as endangered, their protection includes their habitat, and can be expanded to canyons where the species live. In Canada, the Species At Risk Act[16] (SARA) provides protection for species and their habitat, with a direct positive impact for canyons and particular submarine features such as vents and deep sea corals, temperate or cold. This approach is a good example to showcase and use as guidance to set up Best Management Practices, pending legal measures.

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[16] SARA: http://laws.justice.gc.ca/PDF/S-15.3.pdf

5. MPAs FOR SUBMARINE CANYONS: PROPOSALS AND UP TO DATE SITUATION

5.1 Mediterranean Submarine Canyons 2012: Pending Protection

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INTRODUCTION

Until relatively recently, deep-sea environments had been regarded as lifeless voids. Ocean exploration in recent decades has changed this concept, and nowadays it is generally accepted that they are one of the greatest biodiversity reservoirs on the planet (Danovaro *et al.,* 2010). Different expeditions have discovered places with unique biological richness, although for the most part they remain hardly studied (Ramírez-Llodra *et al.,* 2011) and unprotected. The deep-sea environments documented host a diversity of ecosystems, which are regarded as unique as they include habitats and species that are not found anywhere else on the planet. It has been shown that the Mediterranean Sea shelters many of these submarine features, hydrothermal vents, cold seeps, seamounts and canyons, abyssal plains, trenches, and mud volcanoes (UNEP-MAP-RAC/SPA, 2010; UNEP, 2006; WWF/IUCN, 2004). Despite the relative lack of knowledge of these deep-sea habitats, human activity poses real threats, mainly from fishing (IUCN, 2004).

While the extension of the great deep-sea bottoms and the sedimented continental slope is relatively significant with respect to the planet's surface, rocky bottoms (rifts, canyons and seamounts) constitute hardly 4% of the sea bed surface (UNEP, 2006; Gjerde, 2006). Canyons are one of the main deep-sea geomorphological structures and may be located tens to hundreds of kilometres from the shore (Weaber *at al.,* 2009). Some are so long that they exceed 400 km length and 6.5 km deep. From a biological point of view, they are so significant that one of them has been described as one of the most productive habitats known to date (Kaikoura canyon, New Zealand). According to recent studies, it is foreseen that this type of highly productive system may be potentially replicated in canyons with similar characteristics, and it is estimated that some 100 submarine canyons may constitute this kind of biodiversity hotspots globally (De Leo *et al.,* 2010).

The Mediterranean Sea, despite its reduced size, contains a large number of known marine species and a high percentage of endemisms (Mouillot *et al.,* 2011). This exceptional biodiversity has been regarded as a global priority conservation area; it is faced by serious threats and the current MPA network only covers a low percentage of its total surface area (see Simard and Würtz, this volume). This MPA system is considered insufficient and weak, as most of the protected areas are located near the coast, and deep sea ecosystems are not well represented (Marín *et al.,* 2011). From a conservation point of view, submarine canyons in the Mediterranean Sea can be regarded as one of the most interesting structures. They are relatively more abundant and broadly distributed throughout the entire basin, as compared to other world marine regions (Harris and Whiteway, 2011).

In the Mediterranean basin, several areas stand out regarding submarine canyons:

- The canyons on the Ionian Sea slope, particularly the great Taranto valley, a NW-SE canyon more than 2,200 m length.
- The canyons off the coasts of Calabria and Sicily. At certain periods of the year, red shrimp from deep-sea waters can be caught together with coastal species on the continental shelf, overlapping with the upper area of the Roccella Ionica and Caulonia canyons.
- The Gulf of Lion is characterised by an intricate network of canyons which appear at a depth of 130 metres (e.g. Cap de Creus canyon, Lacaze-Duthiers). Most of the water is channelled from the shelf by these canyons, enriching the area to a large extent and supporting significant shrimp fisheries.
- The continental shelf to the north of the islands of Majorca and Minorca has a pronounced slop and several canyons can be found, such as those of Cabrera (Fig. 1) and Minorca.

Oceana is committed to protecting and restoring the world's oceans, and gathers evidence needed to protect areas of ecological interest and key species through at-sea expeditions using non-aggressive techniques (ROV, filming and photography). Regarding the current marine environmental status and in keeping with international commitments, it is necessary to improve the existing protection to reach a comprehensive, representative and effectively managed MPA network. For this reason, since 2006, Oceana has selected the Mediterranean Sea as a primary focus area with campaigns addressed to contribute to the biological description of important features, especially of submarine canyons and seamounts. The documentation gathered has provided highly valuable information that increases our scientific knowledge about the oceans.

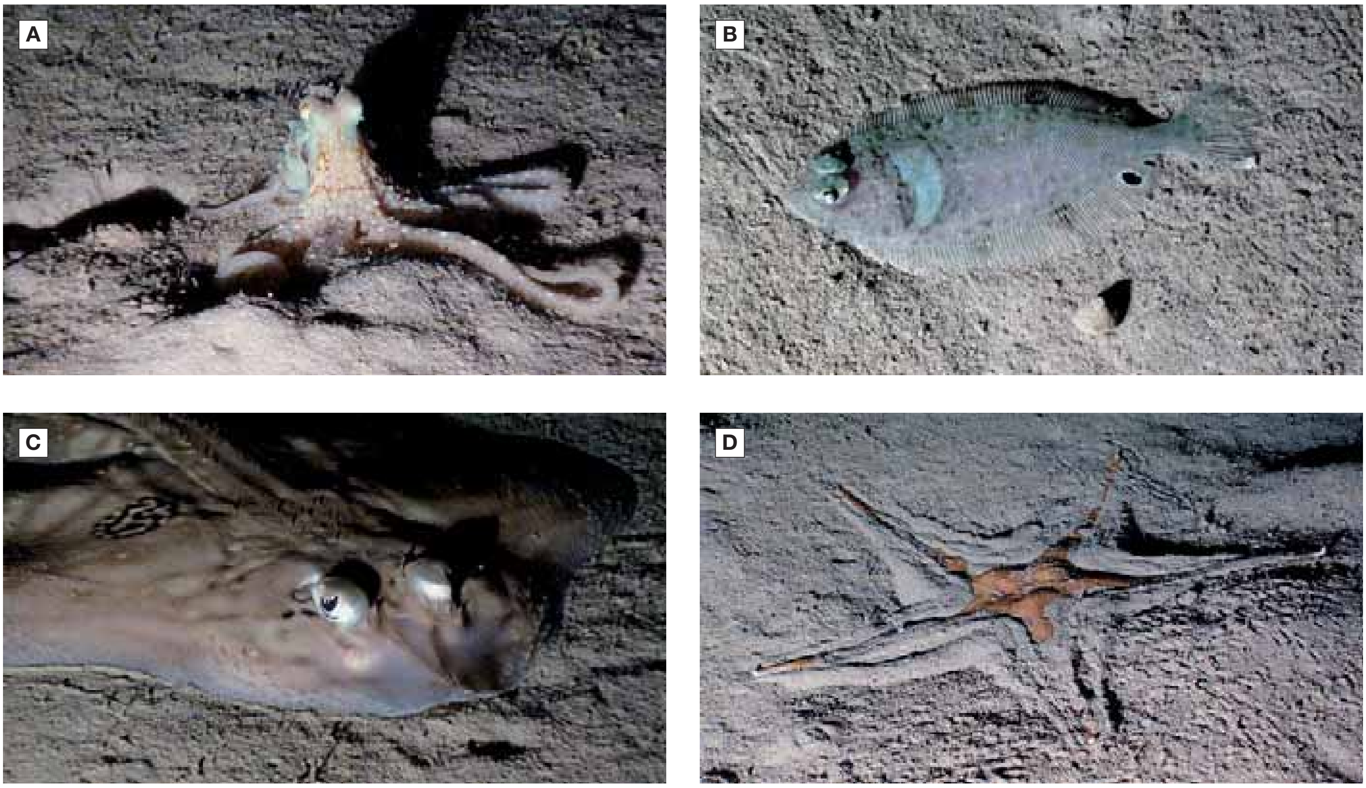

Fig. 1:
Records from Cabrera submarine canyon during Oceana Ranger expeditions.
(A) *Octopus salutii;* (B) *Lepidorhombus boscii;* (C) *Leucoraja naevus;* (D) *Luidia sarsi.*

A brief overview of submarine canyon protection around the world, together with the most important results and proposals on submarine canyons developed by Oceana, are described as follows.

PROTECTION OF SUBMARINE CANYONS ON A GLOBAL, REGIONAL AND NATIONAL SCALE

Globally, marine protection has been delayed as compared to land protection, and canyons are no exception. Unlike what happens on land, where canyons are regarded as being some of the most spectacular landscapes on Earth (e.g. the Grand Canyon), their marine equivalents have been completely ignored, particularly in the Mediterranean. Submarine canyons are "hidden" under the water column and present the added difficulty of their exploration due to an abrupt morphology with steep slopes and narrow channels (Weaber *et al.*, 2009a). Relatively recent knowledge has been acquired thanks to the latest advances in technology (e.g. ROVs - Remotely Operated Vehicles) which have led to great progress in their study (Weaber *et al.,* 2004) and demonstrated their ecological significance.

During the last decades, in different places around the world, several initiatives to promote biological knowledge of submarine canyons have been developed. In recent years, some of them have culminated in area protection: United States, Australia, United Kingdom, Canada and New Zealand (Tab. 1) (De Leo *et al.,* 2010; Hall-Spencer *et al.*, 2009; Mortensen and Buhl-Mortensen, 2005; Vetter and Dayton, 1998; Von der Borch, 1968). However, the first efforts to promote protection of submarine canyons in the Mediterranean were made by the IUCN/WWF in 2004 with the publication "The Mediterranean deep-sea: highly valuable ecosystems in need of protection". In this report, the value of canyons among other structures of biological and environmental interest were highlighted to be part of a representative network of MPAs for the Mediterranean.

To date, and despite its importance and later drives to perform scientific studies (HERMES, HERMIONE, ICES), there is no *de facto* protection of Mediterranean submarine canyons. Currently, none of the more than 500 submarine canyons that can be found in the basin have been protected under a national or international legal framework for nature protection (National Park, Natural Park, SPAMI, Marine Reserve, etc.). The only exception is the Gulf of Lion, where the following protected areas have been established:

- A Fisheries Restricted Area (FRA) under Recommendation GFCM/33/2009/1 to protect spawning aggregations and deep-sea sensitive habitats. This is a fishing management framework, which only involves the regulation of certain demersal fishing gears (Fig. 2).
- The *Parc natural marin du Golfe du Lion,* managed by the French Agency for marine protected areas, which partially covers some of the Gulf canyons (Lacaze-Duthiers canyon, Pruvot canyon, and Bourcart canyon). This park was designated in 2011 by the Ministry for the Environment, Sustainable Development, Transport and Housing of the French Republic through the "*Décret du 2011-1269 du 11 octobre 2011 portant création du parc naturel marin du golfe du Lion*".

Scientific literature shows that canyons are relevant for biodiversity and biological processes throughout the Mediterranean basin, although they are particularly significant in the north-west region (Catalan Sea, Gulf of Lion and Ligurian coast), as well as in the

CANADA	The **Gully** is the largest submarine canyon of the eastern Canadian continental margin. It is more than 70 km long and 20 km wide and supports the highest diversity of coral species found in Atlantic Canada. The area was designated as an MPA in **2004** by the Ministry of Fisheries and Oceans and the MPA regulations prohibit the disturbance, damage, destruction or removal of any living marine organism or habitat. The zoning provides varying levels of protection based on conservation objectives and ecological sensitivities. The regulations also control human activities around the Gully that could cause harmful effects within the MPA boundary.
UNITED STATES	In **2005**, the New England Fishery Management Council and Mid-Atlantic Fishery Management Council enacted two significant protections for submarine canyons in Amendment 2 to the Monkfish Fishery Management Plan. This action closed the **Oceanographer** and **Lydonia** Canyons to monkfish trawling, protecting their well-documented concentrations of cold-water corals.
AUSTRALIA	The **Murray** Submarine Canyon Group is a vast system of steep and complex deep-sea canyons including double valley formations (Sprigg Canyon). It contains unique geophysical, geological and biological features: extreme canyons at the edge of the continental shelf or deep-water upwelling events significant for whale feeding and for a range of cetaceans. Some national organizations were supportive in establishing a protection proposal to conserve and manage through high conservation areas. This initiative was based on findings of geologists and oceanographers and the evidence of significant whale stranding records. In **2007**, the Murray Commonwealth Marine Reserve was proclaimed, containing one of the most spectacular geological formations on the Australian continental block: the Murray Canyons which stretch for more than 150 kilometers.

Tab. 1:

Several examples of submarine canyon protection outside the Mediterranean Sea.

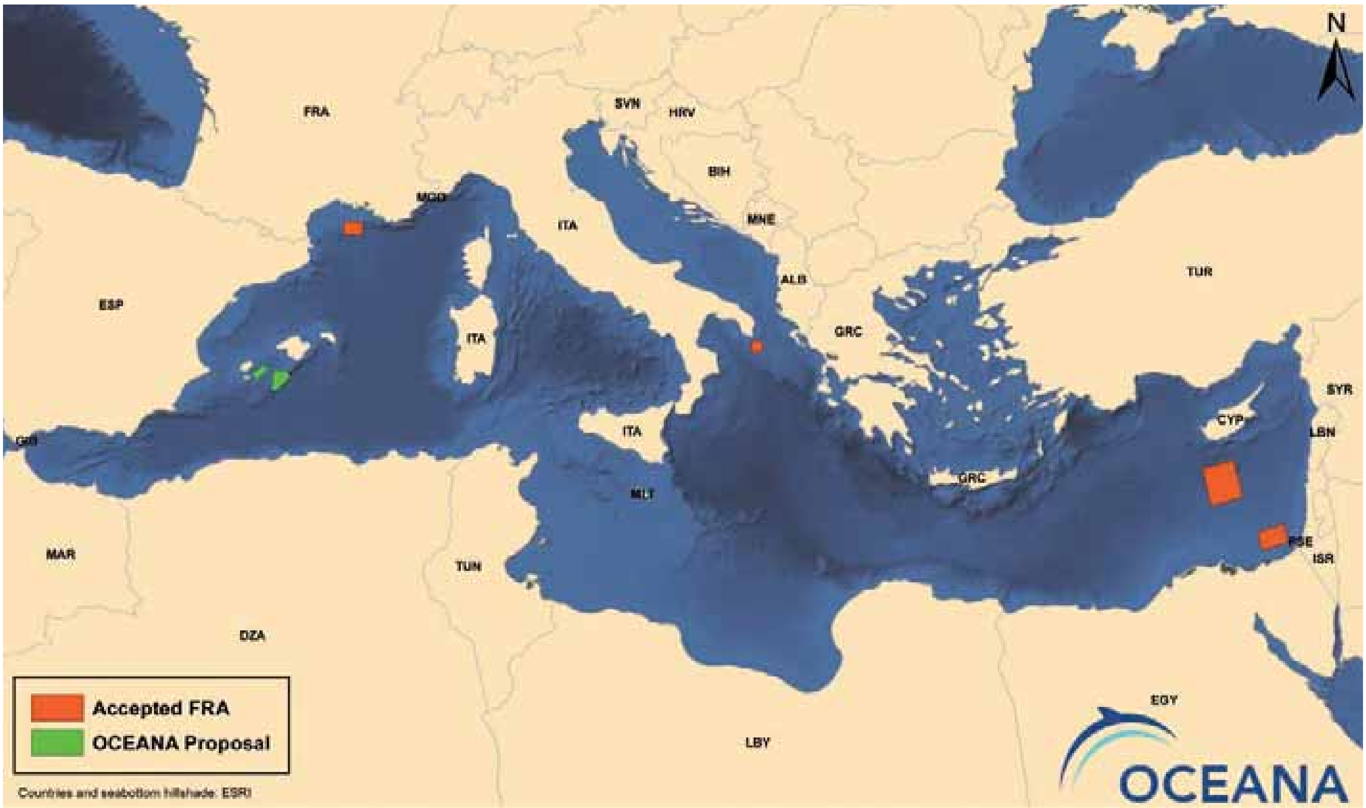

Fig. 2:

Fisheries Restricted Areas in the Mediterranean.
Note: the Oceana proposal corresponds to Balearic seamounts.

eastern basin (canyons associated with the Nile delta and the Levantine Sea). A comprehensive and representative MPA network should include this kind of feature (WWF/IUCN, 2004). In fact, according to the Convention on Biological Diversity (2008), submarine canyons have characteristics which would classify them as priority areas for conservation while acknowledging that they face various threats from human activity. In addition, UNEP-MAP-RAC/SPA (2010) suggests that canyons together with other deep-sea features should be protected through implementation of a Precautionary Principle as they are great reservoirs of biodiversity. Thus, and bearing in mind the target established by the CDB of protecting at least 10% of marine ecoregions in the world and the high number of canyons in the Mediterranean, its protection would greatly promote conservation of this sea.

After this brief analysis, it can be stated that, despite the effort and investment made in the studies performed, the only binding protection for Mediterranean submarine canyons is currently that established within the GFCM framework.

ONGOING PROTECTION INITIATIVES FOR SUBMARINE CANYONS IN THE MEDITERRANEAN

Gulf of Lion canyons

These submarine canyons host high biodiversity and have been described as one of the most productive areas in the western Mediterranean. In addition, other significant habitats, species and features such as cold water corals, cetaceans or cold seeps can be found (Greenpeace, 2006). This is an area of relevance for high-value commercial species such as hake, monkfish and red shrimp. In fact, in 2007 European Scientific, Technical and Economic Committee for Fisheries (STECF) claimed that hake is one of the main demersal species for commercial fishing in the Gulf of Lion. It has also been classified as a significant area for seabirds (UNEP-MAP-RAC/SPA, 2010).

Given the information available, the canyons and the adjacent slope have been recognised to date as priority areas within the RAC/SPA project to identify EBSAs, being clear candidates to be designated as SPAMI. Due to the confluence of the Spanish and French fishing fleets, they require improved management as their exploitation might endanger the fisheries because of recruit overexploitation (UNEP-MAP-RAC/SPA, 2010).

In addition to the fishing regulations in force since the area's designation as a FRA, in recent years the Gulf of Lion canyons have acquired particular relevance through the number of scientific studies performed, which promote their protection from a biological point of view. In September 2009, a collaboration agreement was signed between the French Agency for Marine Protected Areas and the IUCN to identify the significance of submarine canyons and seamounts in the Mediterranean, with particular emphasis on the Gulf of Lion canyons (IUCN, 2010). This agreement finally led to the designation of the aforementioned "Parc naturel marin du Golfe du Lion" in 2011.

Cap de Creus canyon

The protection of the Cap de Creus canyon is a firm proposal of the Spanish government for protection. In fact, it is included in the Life+ INDEMARES project as one of the areas which will become part of the marine Natura 2000 Network in Spain. Even though the adjacent coastal area and a narrow marine strip are already protected (Natural Park of Cap de Creus), the canyon as such is not legally protected. However, environmental and scientific organisations agree that it should be fully-protected as a single entity. The biological value of the canyon is widely acknowledged (Gili *et al.,* 2011) (see also chapter "3. Case Studies"), and even the GFCM Scientific Committee has acknowledged the environmental value of its beds. However, proposals for its protection have been repeatedly blocked, even though it would benefit marine biodiversity and the fishing communities (WWF, 2009).

Given the presence of benthic organisms of high ecological importance, mainly cold-water corals *Dendrophyllia cornigera*, *Madrepora oculata* and *Lophelia pertusa* (Orejas *et al.,* 2009) and the impact of certain fishing activities on these communities, prohibition of bottom fishing has been repeatedly recommended. This measure would be a considerable advance towards their recovery, given the presence of a high number of recruits around gorgonian and pennatulacean populations on the shelf (Gili *et al.,* 2011).

Minorca canyon

The Minorca canyon as well as the Cap the Creus canyon is included in the Life+ INDEMARES project as a candidate to become part of the marine Natura 2000 Network in Spain. The Minorca Channel comprises 98,700 Ha of continental shelf and has been proposed due to the wide range of species and habitats of high conservation value found here, such as *Posidonia oceanica* meadows and maërl and coralligenous beds (Barberá *et al.,* 2012). The canyon has been included in several oceanographic campaigns, but relevant data has not been published, being much scarcer than in the Cap de Creus case. Despite this, Oceana, after analysing the information gathered in the area (Fig. 3, Fig. 4, Fig. 5), considers that its protection should be speeded up, and for this reason sent the Spanish government the results of its campaigns in the canyon. The finds are particularly relevant because of the presence of protected species under various conventions, agreements or international laws (CITES, Barcelona Convention, Bern Convention, Habitat Directive), national legislation (Spanish List of species under a special protection regime), even in the IUCN Red List (Tab. 2, Fig. 6).

PHYLUM	SPECIES	CITES Convention	IUCN Red List	Bern Convention	Barcelona Convention	Habitats Directive	Spanish List
Brown algae	*Laminaria rodriguezii*			Appendix I (Med)	Annex II		(Med)
Poriferans	*Tethya aurantium*				Annex II		
Cnidarians	*Corallium rubrum*			Appendix III (Med)	Annex III	Annex V	
	Dendrophyllia cornigera	Annex II					
	Eunicella verrucosa		Vulnerable				
	Antipathes dichotoma			Appendix III (Med)	Annex III		
	Caryophyllia cyathus	Annex II					
	Caryophyllia sp.	Annex II					
Arthropods	*Palinurus elephas*			Appendix III Med)	Annex III		

Tab. 2:
Protected species recorded in the Minorca submarine canyon during Oceana campaigns, (Med): only in the Mediterranean Sea.

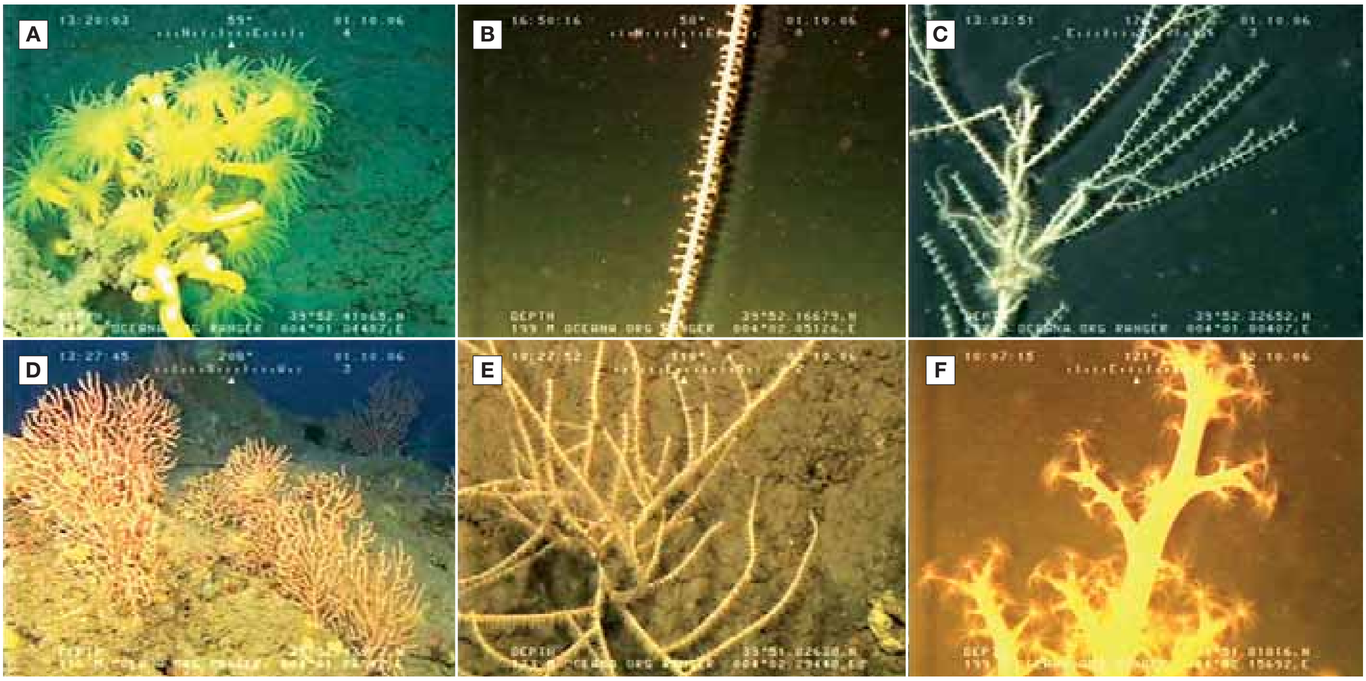

Fig. 3:

Corals and gorgonians documented in the Minorca canyon.
(A) *Dendrophyllia cornigera*; (B) *Funiculina quadrangularis*; (C) *Callogorgia verticillata*; (D) *Eunicella verrucosa* garden; (E) *Antipathes dichotoma*; (F) *Paralcyonium spinulosum.*

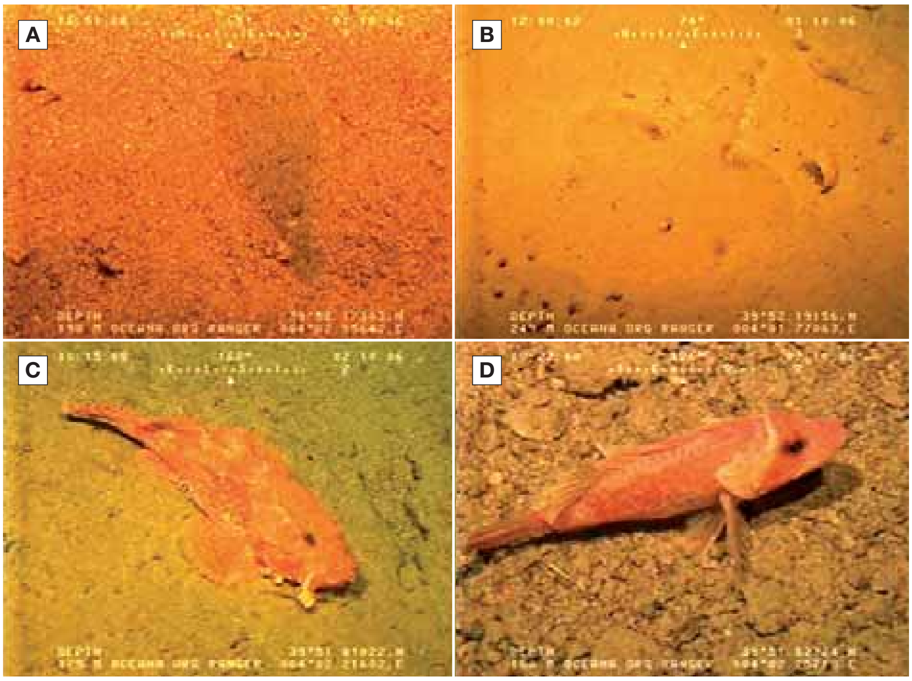

Fig. 4:

Vertebrates (fish) documented in the Minorca canyon.
(A) *Arnoglossus* sp; (B) *Lophius piscatorius*; (C) *Scorpaena scrofa*; (D) *Pontinus kuhli.*

Alboran Sea canyons

Submarine canyons in the Alboran basin are small and distributed along the Iberian and African continental margin. Particularly outstanding are the Algeciras, La Línea and Ceuta canyons and farther east, the Guadiaro, Calahonda, Fuengirola and Guadalmina canyons, and Ceuta canyon to the South.

According to De Juan and Lleonart (UNEP-MAP-RAC/SPA, 2010), the Alboran Sea seamounts are regarded as demersal priority areas due to the existence of Sensitive Habitats containing cold-water coral reefs and submarine canyons. As regards fisheries, hake is also one of the most important target species for trawling

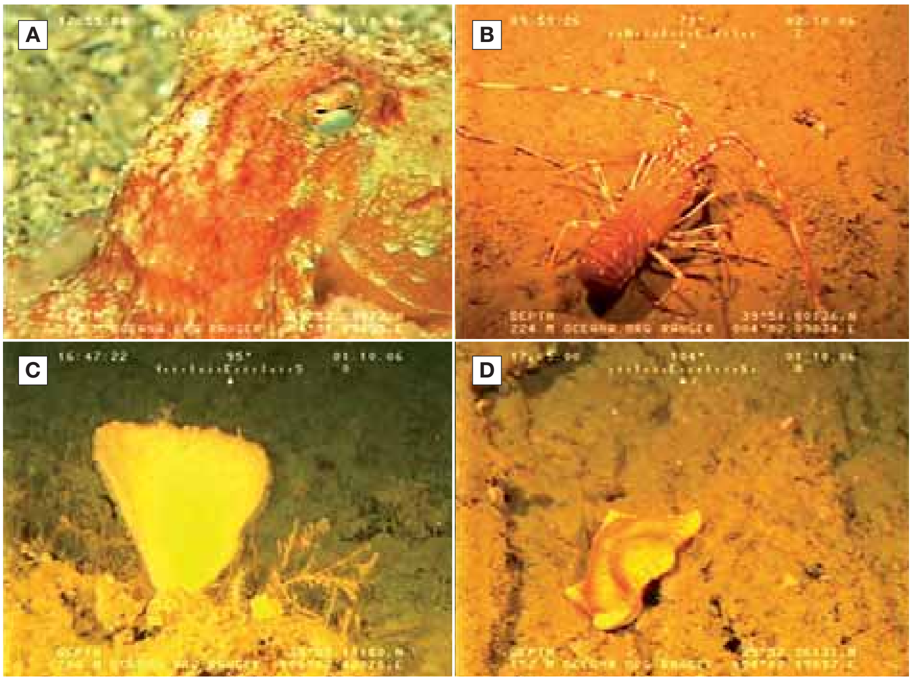

Fig. 5:

Invertebrates (molluscs, crustaceans, sponges and echinoderms) documented in the Menorca canyon. (A) *Eledone cirrhosa*; (B) *Palinurus elephas*; (C) Sponge *Phakellia ventilabrum*, (D) Starfish *Peltaster placenta.*

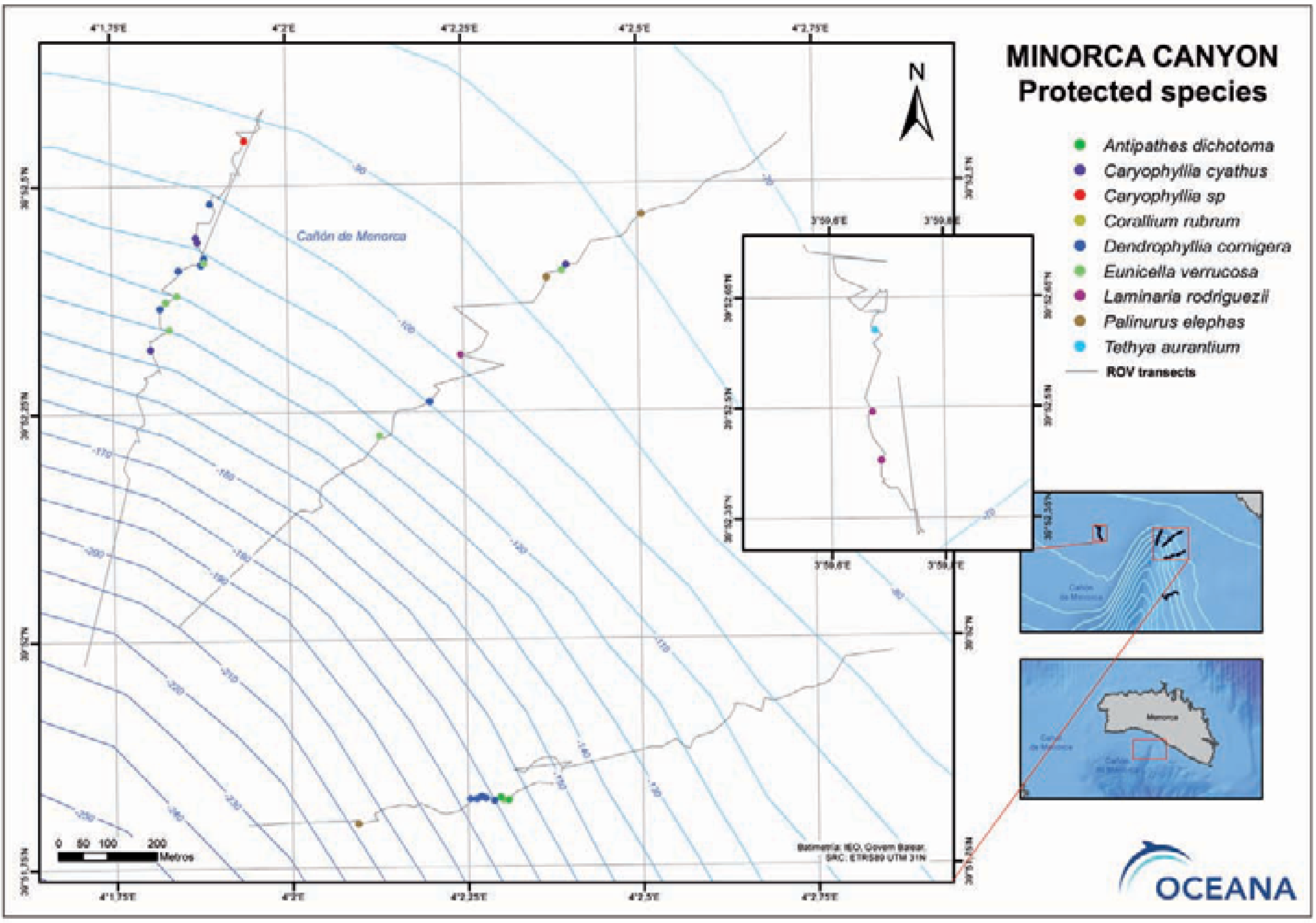

Fig. 6:

Location of the protected species found in the Minorca canyon.

vessels as it is associated with the *Nephrops norvegicus* fishery (Cardinale *et al.,* 2008). Due to the presence of ecosystems highly vulnerable to bottom fishing, the area could be protected.

A FRA proposal was presented to the GFCM Subcommittee on Marine Environment and Ecosystems (SCMEE) in 2005 (de Juan and Lleonart, 2010). However as it was reported, "the information provided was not considered sufficient to justify the conservation issues put forward by the proposal. Nevertheless, the SCMEE considered it important to initiate steps towards more effective conservation procedures. The first step to undertake this task is to collect data and references that testify to the uniqueness and high diversity of this particular ecosystem". As the main part of the proposal, the restriction and limitation of any demersal fishing activities should be considered. To date, data collection from the area seems to be scarce within the GFCM framework, because no actions or protection measures have been taken.

OCEANA'S SURVEYS AND PROPOSALS ON SUBMARINE CANYONS

It has been verified that the special geomorphology and functioning of submarine canyons enables the presence of specific communities, as they all have unique dynamics and have not undergone the same evolution processes. The complex structure of canyons, the different environmental and climatology conditions, the diversity found, and the fact of endemic species described (Toropova *et al.,* 2010; WWF, 2005; Gili *et al.,* 1999) makes them exclusive: each canyon can be considered as a unique formation (HERMES Project, 2009; UNEP, 2006; Weaber *et al.,* 2004). The occurrence of various biological communities gives rise to rich ecosystem diversity which is probably an expected common characteristic to most of submarine canyons in the Mediterranean Sea.

Given the aforesaid features (in addition to those mentioned in previous chapters), one might expect that the most productive canyons are those located near the coastline, as they capture littoral sediments (Harris and Whiteway, 2011). However, submarine canyons off the coast are structures which have reached a certain geological balance and whose stability facilitates colonisation by varied benthic fauna and are also characterized by a high biodiversity concentration. In these kinds of canyons, which are not directly connected to the continent, dense water cascades also take place (e.g. Bourcart canyon) (Gaudin *et al.,* 2006) which can favour the establishment of diverse forms of life. For example, the Nazaré canyon on Portugal's continental margin is not directly related to any river system (Weaber *et al.,* 2009b), but the wide variety of substrates present along its length of over 200 km (from sands to fine muds) provide wide habitat heterogeneity (Tyler *et al.,* 200) and high biodiversity.

Thus, according to Oceana's expeditions, several characteristics describe Mediterranean submarine canyons:

1. Sometimes, those areas with more pronounced slopes, or even formed from compacted muds, allow the establishment of communities that are more typical of rocky beds. In fact, we find scale-rayed wrasse (*Acantholabrus palloni*), gadella (*Gadella maraldi*), lobster (*Palinurus elephas*) and shrimp (*Plesionika edwardsii*) which excavate galleries in vertical walls or occupy those created by other fauna.

2. Given the high degree of sedimentation that takes place on canyon flanks and bottoms, various antozoa species, such as fan gorgonians (*Callogorgia verticillata*) or alcyonaria (*Paralcyonium spinulosum*) display a more slender and stylised appearance, as opposed to those which can be found in other kind of seabeds. In addition, life in such a hostile environment limits the species' distribution and may result in massive mortalities due to colmatation episodes. Such events provoke an abundant proliferation of parasites and other species over damaged corals and gorgonians.

3. The presence of large amounts of detritivore organisms that take advantage of the food channelled by the canyon is likewise frequent. Thus, significant concentrations of echinoderms can be found, such as sea cucumbers (*Parastichopus regalis),* various sea urchin species *(Echinus melo*, *Cidaris cidaris),* brittlestars *(Amphiura* sp.), crinoids (*Leptometra phalangium)* etc. This abundance of echinoderms has also been documented in **La Fonera** canyon (Catalan Sea) for small *Penilpidia ludwigi* elapsipodes (Pagés *et al.,* 2007).

4. The canyons also modify the presence of certain species according to bathymetric ranges, allowing the most common species of bathyal zones to ascend up to the circalittoral. Thus, in the heads of canyons, environments of black corals such as *Antipathes dichotoma* can be found mingled with coralligenous areas.

To reflect the submarine canyons' exclusiveness, some of them with different dynamics and morphologies can be compared in the Western Mediterranean:

— **Guadalmina canyon**. Linked to a river system whose high activity gives rise to great turbidity and sediments. This makes it impossible to generate algae communities even at its head, despite its slight depth. The high rate of sedimentation also makes it difficult to establish habitat-creating sessile species, but gives rise to a wide, varied vagile fauna of fish and other detritivore organisms. Also with high-moderate activity and located in the Catalan Sea southward of Blanes, we found the **Clot de Sant Salvador canyon** with soft morphology at the head and steep slopes in deeper areas where it becomes part of a complex deep-sea canyon system together with **d'Almera canyon** and **Foix canyon** around 1,500 meters depth. The communities observed in the Clot varied from invertebrates to large cetaceans. Its highly sedimented muddy bottoms host benthic species such as essential habitats of crinoids (*Leptometra phalangium*), anthozoans such as *Cerianthus membranaceus* and *Funiculina quadrangularis* (probably associated with the *Aristeus antennatus* fishery), fish like *Coelorhynchus coelorhynchus*, *Helicolenus dactylopterus*, *Gadiculus argenteus*, *Trichiurus lepturus*, *Lepidopus caudatus* or small elasmobranches such as Small-spotted catshark (*Scyliorhinus canicula*). The fin whale (*Balaenoptera physalus*) has also been documented.

— **Minorca canyon**. Located in the Balearic archipelago and with medium activity, it has a large extension and bathymetric distribution. It gives rise to a wide range of environments and communities: from coralligenous beds at its head to black coral communities, rocky beds with porifera and cnidarians, shell-generating beds, sedimentary and muddy beds etc. Retaining the insularity specificities of the Minorca canyon, the **Gata canyon** can be cited off the south-eastern coast of Spain. This canyon begins on the continental shelf and crosses the slope showing a medium-low dynamic due to the scarce river affluence. In spite of this, some algae and phanerogams rests can be found on the

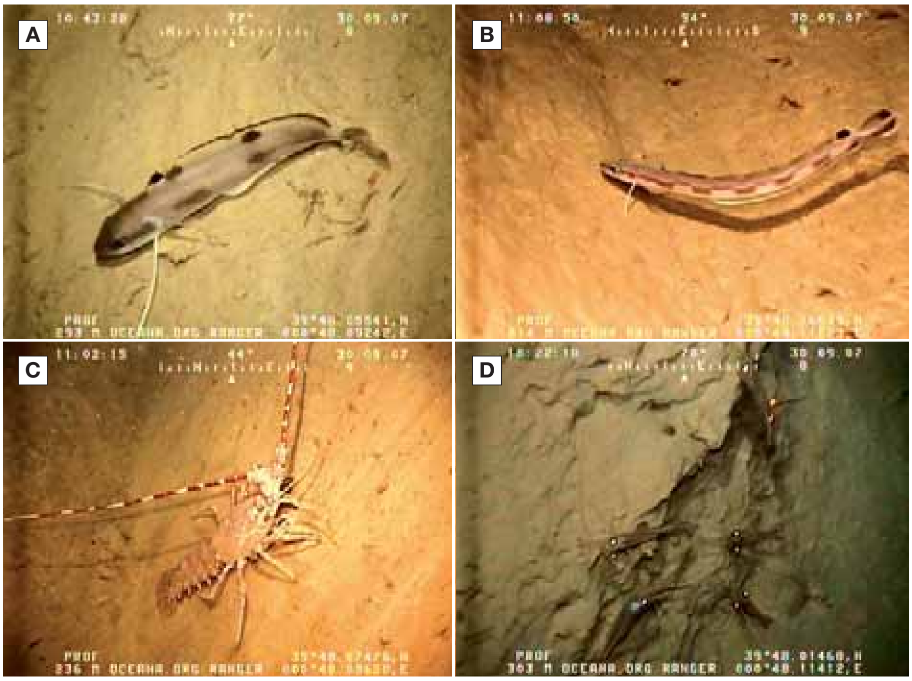

Fig. 7:

Some pictures from Columbretes submarine canyon during Oceana Ranger expedition in 2007.
(A) *Phycis blennoides*; (B) *Molva dypterygia*; (C) *Palinurus mauritanicus*; (D) *Plesionika edwardsii* school.

bottom. This allows the presence of muddy bottoms with emerging rocks or important detritic beds. The most abundant species over the soft bottom are molluscs, cephalopods (*Sepia orbignyana*, *Sepiola atlantica*, etc.), woody canoe-bubble (*Scaphander lignarius*), as well as crustaceans (*Plesionika* spp.) and fish (*Peristedion cataphractum*, *Helicolenus dactylopterus*, *Capros aper*, *Phycis blennoides*, *Gadiculus argenteus*, *Macroramphosus scolopax*, *Pagellus* spp.). Over rocky substrate one finds bryozoans (*Reteporella grimaldi*, *Pentapora fascialis*), anthozoans (*Caryophyllia cyathus*, *Eunicella verrucosa*, *Paramuricea clavata*), polychaetes (*Filograna implexa*, *Serpula vermicularis*, *Protula* spp.) or fish such as *Scorpaena scrofa*, *Gadella maraldi* and *Anthias anthias.*

— **Columbretes canyon.** Distant from the coast but close to a small volcanic archipelago. Grounds and walls of compact muds predominate, and despite the scarcity of habitat-forming sessile species, it shelters a varied range of species adapted to a relatively stable geomorphology which for centuries has been markedly influenced by fine sediment inputs (Fig. 7).

Fig. 8:

Madrepora oculata and *Lophelia pertusa* reef
discovered during the Oceana Ranger expedition in July 2011
(Cabliers bank, Alboran Sea).

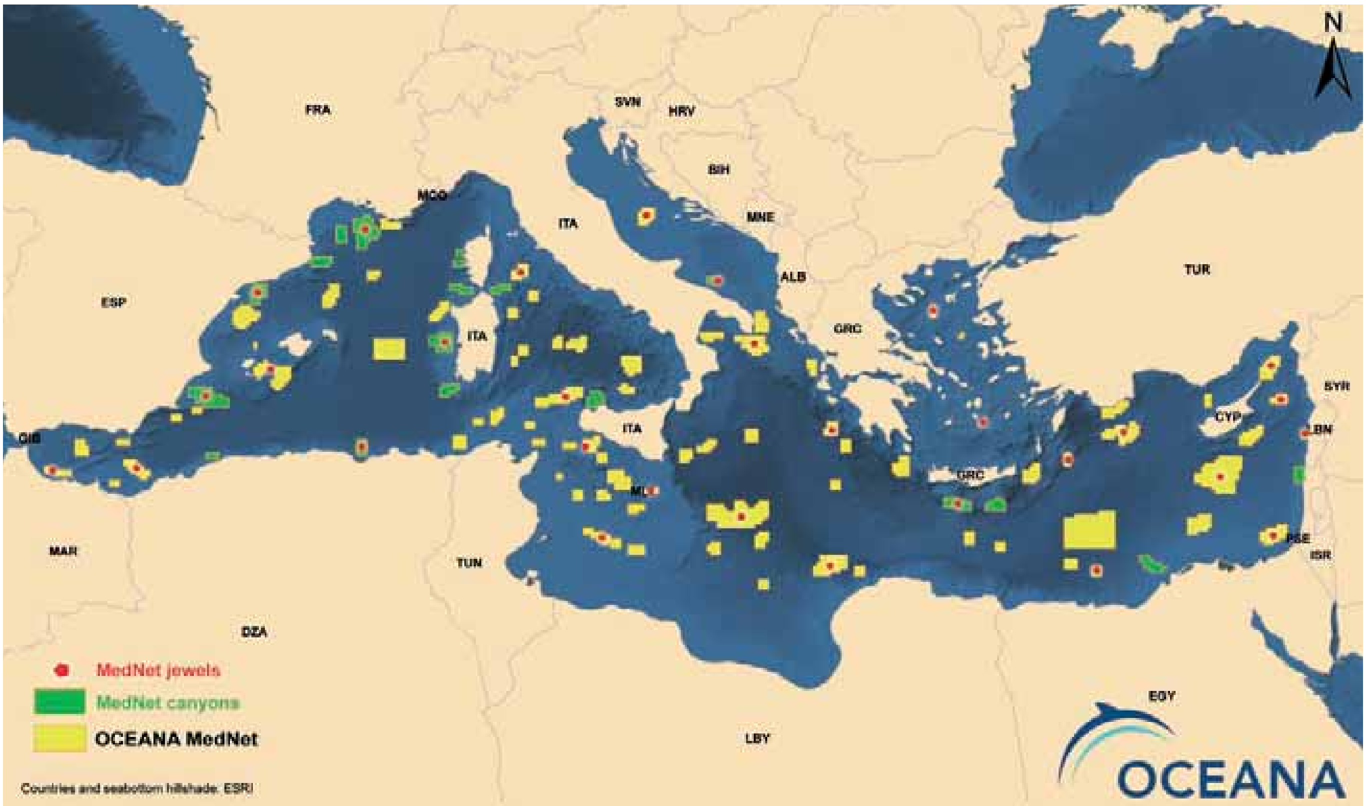

Fig. 9:
Oceana MedNet and canyons.

This benthonic diversity described generally extends to the pelagic area, as the high productivity influences the water column, constituting significant feeding areas for small pelagic species (e.g. anchovy) as well as apex predators such as sea birds, sharks, large pelagic fish and cetaceans, mainly sperm whales (Smith *et al.,* 2010; Toropova *et al.,* 2010). The highest abundance is mainly located in the canyon heads (Harris and Whiteway, 2011). In fact, some are well known for the high variety of cetaceans that can be found (Secretariat of the Convention on Biological Diversity, 2008; Weaber *et al.,* 2004).

Deep-sea corals should also be mentioned when assessing the significance of submarine canyons (Fig. 8). Generally speaking, these reefs serve as the basis for a complex food chain, and according to the FAO (2008) they are one of the best-known examples of Vulnerable Marine Ecosystems (VMEs) for this reason. These reefs are formations of high environmental significance as they are extremely fragile structures when faced by certain physical impacts: habitat destruction by bottom trawling and other fishing gears (Orejas *et al.,* 2000), climate change etc. As has been pointed out in previous chapters, cold-water corals and other VMEs composed by filtering organisms appear more abundantly at the head of shelf canyons, but particularly in those located at depths above 1500 metres (Harris and Whiteway, 2010).

Despite their ecological significance, the interest for canyon distribution has so far been a consequence of different human needs: laying of cables and underwater pipes, support for submarine naval operations, study of the geological evolution of the continental margin, or oceanographic and ecological processes associated with canyons (Harris and Whiteway, 2011). However, the interest in biological communities hosted by submarine canyons and their importance as key features in the protection of ecosystems has grown thanks to improved knowledge of their geology and oceanography. More recently, research has focused on benthic habitats associated with shelf canyons characterised by rocky walls with pronounced gradients, on which highly diverse biological communities have been established (Harris and Whiteway, 2011). On the other hand, it is also a well-known fact that canyons are regarded as a significant economic source of wealth for nearby fishing local communities. Even though this is a good reason for their protection, it is not yet a fact (see "The fisheries importance of four submarine canyons in the Spanish Mediterranean Sea", this volume).

In early 2011, based on scientific available information and its own expertise and background, Oceana launched a new proposal for protection of the Mediterranean called MedNet (Fig. 9). The proposal is formed by a set of 100 sites which are considered to be in need of protection, to complete a coherent, representative and well-connected MPA network for the Mediterranean Sea. Each site has been analysed from various points of view in order to evaluate its ecological importance, but also to stress other features such as jurisdictional problems and threats, or even if it has been proposed by any other organization. MedNet envisages various geomorphological features such as seamounts, escarpments, mud volcanos etc., also including submarine canyons as a significant part, as it has been designed to take the relief of the sea bottom into account. The proposal contains a total of 28 submarine canyons and two trenches located in 20 MedNet areas (Annex I). Within the network, 30 of those sites have been selected by Oceana as "jewels of the Mediterranean" for which urgent measures should be taken.

SUBMARINE CANYONS: A VISION FOR THE FUTURE

The Mediterranean Sea is in a critical situation, as it has a large number of over-exploited stocks, habitat destruction, pollution, and it faces the risk of climate change among others threats and impacts (Mordecai *et al.,* 2011; Ramírez-Llodra *et al.,* 2011; Stora *et al.,* 2011; Dauvin, 2010; Toropova *et al.,* 2010; Würtz, 2010; Martín *et al.,* 2008; Galgani *et al.,* 1996). For all these reasons, actions towards its recovery should be taken.

An adequate and planned MPA network on a regional scale might contribute to sustainable use of biodiversity, mitigating the adverse effect of anthropogenic impacts or climate change (Hooker *et al.,* 2011). However, the current MPA network is neither coherent nor representative and, furthermore, there are hardly any connections between protected areas to ensure genetic exchange. This involves the loss of long-term profit provided by MPAs, particularly if they include integral protection areas (no-take) to safeguard habitats, species and/or natural processes. The most important aspect is that national and international MPA networks might mitigate irreversible biodiversity loss (Mora and Sale, 2011), protecting unique, fragile, and representative pelagic and benthic ecosystems on a regional scale, such as those found on shelf edges, canyons, seamounts, hydrothermal vents, cold seeps and abyssal plains, and open ocean features such as eddies, fronts and upwelling areas (IUCN, 2004). Taking into account the limited biologic knowledge of canyons and given that some experiences have proven that the implementation of protection measures has a positive effect by comparison to non-protected areas (Clemente *et al.,* 2001), a number of short-term actions ensuring maintenance of the diversity and wealth of submarine canyons should be established.

The previous chapters reflect the wealth of submarine canyons, their complexity in hydrographical and geological terms, their biological fragility, the existence of unique genetic resources and special relevance in the carbon cycle. All of them prove their relative importance at global level and make them potentially susceptible to climate change and human disturbances (ICES, 2008; Weaber *et al.,* 2004). Despite their high significance and key role in deep-sea environments, canyons are not well-represented in the MPA Mediterranean network, even though the suitable framework and legally binding instruments exist for their incorporation. Canyon protection should become a priority action in national political agendas with the support of the relevant regional bodies, as they are highly productive formations which at the same time can be part of a system to achieve sustainable fishing. Their protection should therefore be marked by international and regional obligations for the conservation of nature and fishing resources.

Achieving the 10% target established by the CDB and contributing to the protection of vulnerable ecosystems involves speeding up the MPA declaration process in the next few years. As for European countries, they should contribute to compliance with Directives to minimise the insufficient nature of the Natura 2000 network in the marine environment and achieve a "good environmental status" as soon as possible.

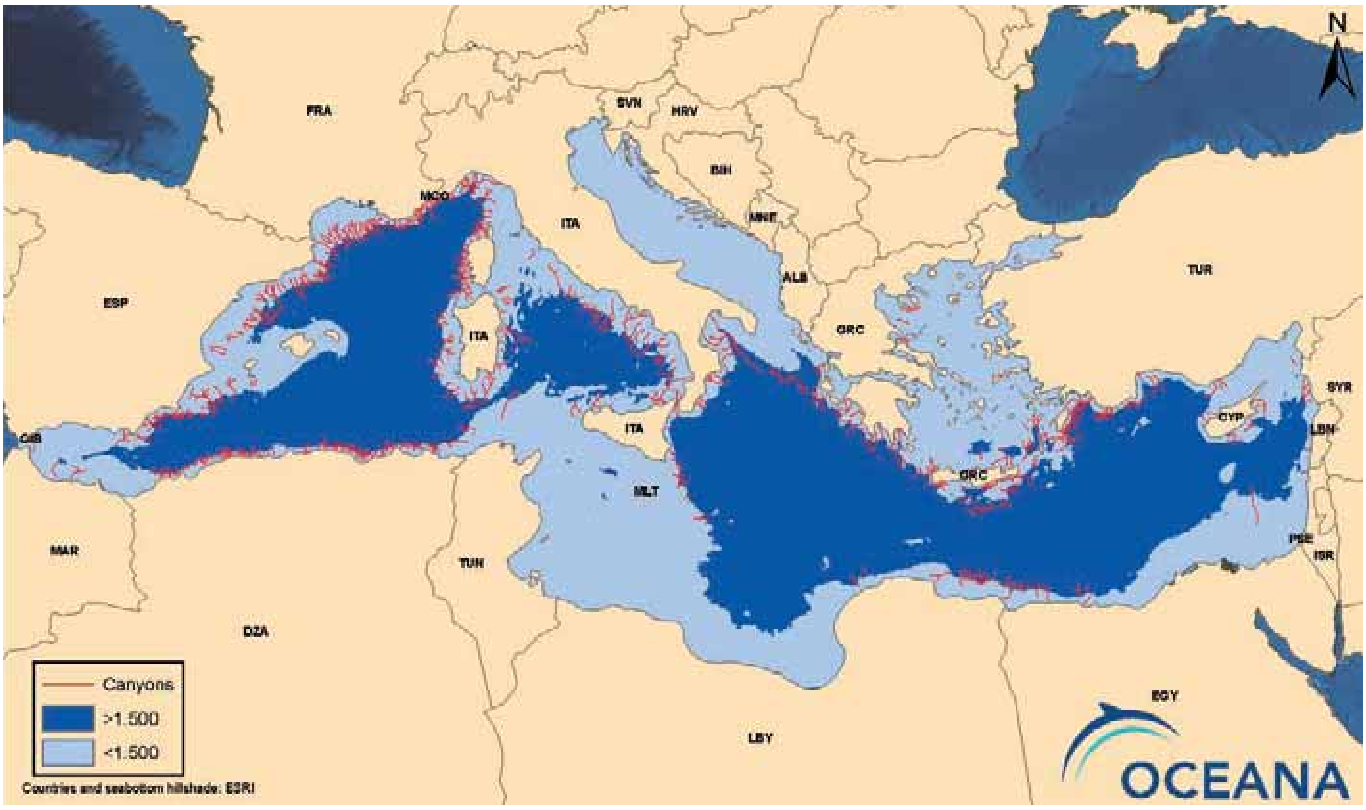

Fig. 10:

Mediterranean submarine canyons and Carbonate Compensation Depth.

According to the analysed sources, proposals to protect submarine canyons should be comprehensive, that is to say, in addition to the central channel, the head, flanks and sedimentary fan should be included, as they constitute significant elements for the preservation of canyon biodiversity and functioning. For instance, canyon heads usually constitute cetacean feeding areas and margins corresponding to *Aristeus antennatus* and *Aristeomorpha foliacea* over-exploitation areas.

The high number and peculiarities of each of the Mediterranean submarine canyons make selction difficult for their protection. In this sense, Harris and Whiteway (2011) made an interesting proposal to evaluate the relative significance of canyons in different geographic regions and thus apply conservation measures. This criterion is mainly based on the average carbonate compensation depth or CCD (-1,500 metres). On it depend the presence of such organisms as cold-water corals and other filtering species that constitute vulnerable marine ecosystems. Moreover, it should be taken into account that ecosystems located above this depth are more vulnerable to ocean acidification as a consequence of climate change, as well as destructive fishing practices (e.g. bottom trawling above 1,000 metres in the Mediterranean).

Taking average CCD depth into account, and analysing canyons which are located above or below this depth limit, the criterion might serve to make a systematic spatial selection establishing the priorities of the canyons to be protected on a regional scale in the next feature (Fig. 10).

FINAL THOUGHTS

All the references in previous sections strongly justify the need to include submarine canyons in national and international MPA networks. This should lead national and regional administrations to make use of the Precautionary Principle and implement at least a preventive protection regime to manage them adequately.

In addition to the previous general consideration, Oceana recommends that the following aspects should be taken into account:

— It is necessary to follow scientific recommendations and establish urgent actions concerning already identified priority areas, such as the Gulf of Lion canyons, the Cap de Creus canyons, the Minorca canyon and the Alboran Sea canyons.

— Given the presence of Essential Fish Habitats and Sensitive Habitats in submarine canyons, at least precautionary measures to prevent direct effects on vulnerable ecosystems should be taken. According to UNEP-MAP-RAC/SPA (2010), any measure pertaining to the closing of fishing grounds would serve to protect juveniles of the main fisheries.

— Convergence areas for surface and deep ocean currents might constitute an aspect to take into account when it comes to systematically selecting the submarine canyons to be protected, in order to reach a well-connected MPA network.

— Bearing in mind the economic benefits for local fishing communities and also that most catches of certain commercial species (e.g. hake or red shrimp) are obtained in submarine canyons, this activity requires additional management measures.

— Given their productivity, there are submarine canyons where different fisheries overlap, as is the case of the Gulf of Lion, where trawling, bottom longlines and gillnets from Spanish and French fisheries can be found. This requires immediate action measures to control fishing activities.

— Protection of canyons must be performed in an integrated way, be it from an administrative point of view (by the competent administrations) or from the physical point of view, as the head, flanks or water column constitute a complete, continuous system which affects both pelagic and benthic biodiversity.

— The recommendations made within the framework of international conventions and agreements as regards protection of VMEs and EBSAs must be followed. In this sense, it is also necessary to comply with national and international obligations, establishing the necessary protection measures for the species listed in international conventions or under some kind of threat (i.e. IUCN Red List).

Achieving effective management in marine protected areas involves considerable institutional effort and requires time to demonstrate that the measures taken are effective. Given that the 10% CBD target must be reached by 2020, the protection of submarine canyons as well as other conservation priorities should be considered in national and regional political agendas in the short term.

ANNEX I

BRIEF DESCRIPTION OF SUBMARINE CANYONS INCLUDED IN THE OCEANA MEDNET PROPOSAL

NOTES:

★ Jewels of the Mediterranean Sea;

IUCN Red List Categories: EX - Extinct, EW - Extinct in the Wild, CR - Critically Endangered, EN - Endangered, VU - Vulnerable, NT - Near Threatened, LC - Least Concern, DD - Data Deficient.

EBSA criteria: (1) Uniqueness or rarity; (2) Special importance for life history stages of species; (3) Importance for threatened, endangered or declining species and/or habitats; (4) Vulnerability, fragility, sensitivity or slow recovery; (5) Biological productivity; (6) Biological diversity; (7) Naturalness.

Threats: BT – Bottom trawling; IUU - Illegal, Unregulated and Unreported Fishing; OG - Oil/gas drilling.

Proposal by: SH – Sensitive Habitat; EFH – Essential Fish Habitat

ALGERIA

BEJAIA CANYON ★

Key species - Red List status: *Monachus monachus* (Mediterranean Monk Seal) - CR

EBSA criteria: (3)

Threats: BT

Proposal by: OCEANA

Remarks: This canyon coincides with the area where eddies are formed by the Algerian current. In a national jurisdictional area

KHADRA CANYON (GUELTA and KHADRA)

Key species - Red List status: *Monachus monachus* (Mediterranean Monk Seal) - CR

EBSA criteria: (3)

Threats: BT; OG

Proposal by: GREENPEACE; OCEANA

Remarks: Located in the path of the Algerian current. Khadra is the deepest canyon in the area. The Khadra canyon is a site of interest for gas/oil drilling

CORSICA ISLAND

PORTO CANYON

Proposal by: ACCOBAMS; GREENPEACE; OCEANA

SAGONE CANYON

Proposal by: ACCOBAMS; GREENPEACE; OCEANA

CRETE ISLAND

PLINY CANYON (Trench)

Key species - Red List status: *Prionace glauca* (Blue Shark) - NT

EBSA criteria: (3); (5)

Proposal by: CIESM, OCEANA

Remarks: The Aegean Sea is one of the areas with the highest relative abundance of sharks (mainly *Prionace glauca*). In an area where eddies form (IE-Ierapetra Eddy)

PTOLEMY CANYON (Trench)

Key species - Red List status: *Prionace glauca* (Blue Shark) - NT

EBSA criteria: (3); (5)

Proposal by: OCEANA

Remarks: Affected by the Cretan Cyclone and the Levantine surface water current (LSW). The Aegean Sea is one of the areas with the highest relative abundance of sharks (mainly *Prionace glauca*)

GULF OF LION

GULF OF LION CANYONS (GRAND RHÔNE and MARSEILLE) ★

Key species - Red List status: *Cetorhinus maximus* (Basking Shark) – VU; High primary productivity of pelagic waters; High productivity area, important for globally threatened and other seabird populations; *Madrepora* reefs in Lacaze-Duthiers and Cassidaigne Canyons, and possibly beyond; *Balaenoptera physalus* (Fin Whale) – EN; *Stenella coeruleoalba* (Striped Dolphin) – LC; *Grampus griseus* (Risso's Dolphin) – LC; *Physeter macrocephalus* (Sperm Whale) - VU

EBSA criteria: (3); (4); (5)

Threats: BT

Proposal by: EFH; GFCM; GREENPEACE; RAC/SPA; OCEANA

SÈTE CANYON

Key species - Red List status: *Cetorhinus maximus* (Basking Shark) – VU; High primary productivity of pelagic waters; High productivity area, important for globally-threatened and other seabird populations; Madrepora reefs in Lacaze-Duthiers and Cassidaigne Canyons, and possibly beyond; Balaenoptera physalus (Fin Whale) – EN; *Stenella coeruleoalba* (Striped Dolphin) – LC; *Grampus griseus* (Risso's Dolphin) – LC; *Physeter macrocephalus* (Sperm Whale) - VU

EBSA criteria: (3); (4); (5)

Threats: BT

Proposal by: EFH; GREENPEACE; OCEANA; RAC/SPA

LEVANT

ALEXANDRIA CANYON

Key species - Red List status: *Caretta caretta* (Loggerhead Turtle) habitat – EN; *Chelonia mydas* (Green Turtle) habitat - EN

EBSA criteria: (3)

Proposal by: OCEANA

Remarks: The Nile delta is one of the most important areas in the Mediterranean for sea turtle feeding and hibernation (*Caretta caretta* and *Chelonia mydas*). Egyptian shelf loggerhead and green turtle habitat

ISRAEL CANYONS (AKHZIV, SAAR, NAHARIYA, SHOMRAT, HILAZON and QISHON)

Key species - Red List status: Fisheries targeting large pelagic species

Proposal by: GREENPEACE; OCEANA

LEBANON CANYONS (SAINT GEORGES and JUNIEH)

Key species - Red List status: Fisheries targeting large pelagic species; *Rhinobatos rhinobatos* (Common Guitarfish) nursery area - EN

EBSA criteria: (3)

Proposal by: GREENPEACE; OCEANA

SPAIN

ALICANTE CANYON ★

Key species - Red List status: *Thunnus thynnus* (Bluefin Tuna) – DD; *Caretta caretta* (Loggerhead Turtle) – EN; Various odontocete; *Merluccius merluccius* (hake) nursery

EBSA criteria: (2); (3)

Threats: BT

Proposal by: EFH; OCEANA

Remarks: Spawning area for bluefin tuna

TORTOSA CANYON ★

Key species - Red List status: *Aristeus antennatus; Lophius* sp. (Anglerfish); Dolphins and various odontocete; Large pelagic fishes; Merluccius merluccius (hake - adults); *Caretta caretta* (Loggerhead Turtle) – EN; *Isidella elongata*

EBSA criteria: (2); (4)

Threats: BT; IUU

Proposal by: SH; OCEANA

Remarks: Spawning area for bluefin tuna. High productivity area. The functional groups were organized into four trophic levels with the highest levels corresponding to anglerfish, dolphins, large pelagic fishes and adult hake

PALAMÓS CANYON

Key species - Red List status: *Aristeus antennatus;* Important suitable habitat for small pelagics; High primary productivity of pelagic waters; *Balaenoptera physalus* (Fin Whale) – EN; *Stenella coeruleoalba* (Striped Dolphin) – LC; *Grampus griseus* (Risso's Dolphin) – LC; *Physeter macrocephalus* (Sperm Whale) – VU; *Merluccius merluccius* (hake) nursery

EBSA criteria: (3); (5)

Proposal by: EFH; GREENPEACE; OCEANA

Remarks: Production area for red shrimp, whose distribution is directly related to submarine canyons

SARDINIA

CASTELSARDO CANYON

Key species - Red List status: *Cetorhinus maximus* (Basking Shark) - VU

EBSA criteria: (3)

Proposal by: ACCOBAMS; GREENPEACE; OCEANA

WESTERN SARDINIA CANYONS (IL CATALANO and ORISTANO) ★

Key species - Red List status: Fisheries targeting large pelagic species; *Cetorhinus maximus* (Basking Shark) – VU; *Balaenoptera physalus* (Fin Whale) – EN; *Stenella coeruleoalba* (Striped Dolphin) – LC; *Grampus griseus* (Risso's Dolphin) – LC; *Physeter macrocephalus* (Sperm Whale) - VU

EBSA criteria: (3); (4)

Proposal by: OCEANA

Remarks: The southern area of the Sardinian Sea is affected by the formation of eddies from the Algerian current

CAPRERA CANYON

Key species - Red List status: *Cetorhinus maximus* (Basking Shark) – VU; *Scyliorhinus canicula* (Small Spotted Catshark) nursery area – LC; *Raja clavata* (Thornback Skate) nursery area – NT; *Raja asterias* (Starry Ray) nursery area – LC; *Carcharhinus brachyurus* (Bronze Whaler) nursery area – NT; *Galeus melastomus* (Blackmouth Catshark) nursery area – LC; *Etmopterus spinax* (Velvet Belly Lanternshark) nursery areas – LC; Important area for feeding of endemic and other seabird species of conservation concern that concentrate for breeding in Corsica-Sardinia-Tuscan archipelago

EBSA criteria: (3); (5)

Proposal by: OCEANA - RAC/SPA

Remarks: Bordering the Ligurian Sea Sanctuary (SPAMI) and in area of upwelling. High primary productivity of pelagic waters

SAN ANTIOCO CANYON

Key species - Red List status: Fisheries targeting large pelagic species

Proposal by: OCEANA

SAN VITO CANYON

Key species - Red List status: Fisheries targeting large pelagic species

Proposal by: OCEANA

SOUTHERN ADRIATIC

BARI CANYON ★

Key species - Red List status: *Lophelia*; *Madrepora*; *Dendrophyllia*

EBSA criteria: (4); (6)

Threats: BT

Proposal by: CIESM; OCEANA

Remarks: The discovery is located at less than 200 meters depth off the coast of Pescara. HERMES project *Lophelia pertusa* reefs (OSPAR list of Threatened and/or Declining species and habitats)

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5.2. Approaching the conservation issues of the Mediterranean submarine canyons

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APPLYING EBSA CRITERIA TO MEDITERRANEAN SUBMARINE CANYON HABITATS

The Mediterranean basin supports one-third of global maritime traffic, its coasts are home to 150 million people and attract almost 200 million visitors each year. Nearly half of its coastline has become "artificial"; lost habitats, climate change as well as overfishing are increasingly affecting the functioning of the entire ecosystem. For these reasons, the Mediterranean serves as a catalyst for questions related to integrated management of human activities and governance, issues that need to be addressed through valuable tools such as an effective marine protected areas (MPA) network.

MPAs currently represent about 5% of the entire surface of the Mediterranean Sea (which is far from the goal of attaining 20% and the CBD's 10% Aichi Target) and they do not represent the natural marine heritage diversity of the Mediterranean. According to the UNEP/MAP Regional Activity Centre for Specially Protected Areas (RAC/SPA, Tunis), 41% of the Mediterranean MPAs are too small (less than 1,000 ha), only 15% are mainly marine and mostly located along the north-western coast; moreover, a large gap exists between deep sea and pelagic habitat protection (data from the side event proposal under the Mediterranean Action Plan - UNEP/MAP document. Conference of the Parties of the Convention on Biological Diversity, Nagoya, Japan, 18-29 October 2010).

Clearly, management, conservation and preservation of the pelagic realm has been hindered by its deep, distant and dynamic nature, and by the governance difficulties presented by an environment that crosses national borders and is largely in areas beyond national jurisdiction.

The Convention on Biological Diversity (CBD) took up the call to identify such areas in 2006 at the eighth meeting of the Conference of Parties. Decision VIII/24, paragraph 46, called for the convening of an expert workshop to "*Refine and develop a consolidated set of scientific criteria for identifying ecologically or biologically significant marine areas in need of protection, in open ocean waters and deep sea habitats, building upon existing sets of criteria used nationally, regionally and globally*". The Expert Workshop, held in the Azores in 2007, collated available criteria suites and selected those which fell within the purview of the CBD to supply scientific information on the management and conservation of biodiversity to authorities entrusted with managing marine resources. The workshop produced a set of seven criteria, which were later adopted by the Parties to the CBD in Decision IX/20 at COP9 in 2008.

The seven scientific criteria for identifying ecologically or biologically significant marine areas (EBSAs) in need of protection are:

1. Uniqueness or rarity
2. Special importance for life history of species
3. Importance for threatened, endangered or declining species and/or habitats
4. Vulnerability, fragility, sensitivity, slow recovery
5. Biological productivity
6. Biological diversity
7. Naturalness

COP 9 also called for a follow-on CBD expert workshop to be convened to provide "*scientific and technical guidance on the use of biogeographic classification systems and identification of marine areas beyond national jurisdiction in need of protection*".

The scientific guidance refers to five required network properties and components to establish a representative network of MPAs:

— Ecologically and biologically significant areas
— Representativity
— Connectivity
— Replicated ecological features
— Adequate and viable sites.

Taking into account traditional MPA criteria, the CBD EBSA criteria are specially designed to apply to open ocean and deep seabed areas including marine areas beyond national jurisdiction (Dunn *et al.,* 2011)

Taking up the challenge of the CBD's strategic plan and the 2012 Millennium Development Goals with regard to the protection of biodiversity and the creation of marine protected areas, the Contracting Parties to the Barcelona Convention adopted, during their Sixteenth Ordinary Meeting (Marrakesh, November 2009), a «Regional Working Programme for the Coastal and Marine Protected Areas in the Mediterranean including the High Sea».

The UNEP/MAP-RAC/SPA and all relevant partner organisations (ACCOBAMS, IUCN-Med, MedPAN and WWF MedPO) are endeavouring to implement this ambitious programme of work. RAC/SPA, WWF MedPO and IUCN-Med are currently acting to assist Mediterranean countries in developing a Mediterranean marine and coastal protected areas network by boosting the creation and management of marine protected areas in zones within national jurisdiction and in open seas. As part of this overall objective, RAC/SPA is also promoting the establishment of a representative ecological network of marine protected areas, using the SPAMI (Specially Protected Areas of Mediterranean Importance) system. Indeed, the MAP Focal Points meeting held in Athens from 28 November to 1 December 2011 was unable to agree on the decision including the list of 12 candidate SPAMIs proposed by the RAC/SPA in conformity with EBSA criteria, because of State reservations. Consequently the CoP 17 of the Barcelona Convention, held in Paris from 8 to 10 February 2012, had to cope with the opposition of Egypt (on the Nile delta site) and decided not to adopt this SPAMI list.

As discussed above (Würtz, in this volume), processes allowing high biodiversity levels in the Mediterranean (less than 0.8% of the world ocean surface encompasses over 7% of known marine species) seem to be based on very fast energy turnover through water columns over time. The funnelling effect of submarine canyons concentrates key prey species within their rims and along their walls, and most of these species are characterized by short life cycles, fast growth and wide vertical migrations.

Over 500 submarine canyons have been identified in both the eastern and western Mediterranean basins and, even if their ecology is poorly investigated, the scientific community generally recognizes their importance in the functioning of the ecosystem. EBSA criteria can thus be applied to such static oceanographic structures:

Uniqueness or rarity

Considering the complex geological history of the Mediterranean, which was marked by wide sea level variations during the last 5,000,000 years, the unique nature of submarine canyon habitats favoured the settlement of rare, relict deep-sea and cold water communities, in both hard and muddy substrates (Harris and Whiteway, 2011; Hecker, 1990; Rogers *et al*., 2002).

Special importance for the life history of species

Being feeding grounds as well as breeding areas, submarine canyons are stepping stones for many migratory species such as many pelagic top predators (i.e. swordfish, tunas, tuna-like species, sharks, sea turtles, birds and cetaceans).

Importance for threatened, endangered or declining species and/or habitats

Submarine canyons are refuges for spawners of commercially exploited species and for benthic communities (i.e. Gulf of Lion submarine canyons for Mediterranean hake, cold water corals community etc., see also Farrugio, this volume).

Vulnerability, fragility, sensitivity, slow recovery

Deep sea red shrimp fishing grounds are mainly located within the canyons and are heavily exploited; some benthic and pelagic communities are highly sensitive to pollution from land in canyon environments closer to coastal waters. The pelagic environment is believed to have high resilience, nevertheless because of high variability and the special functioning of the Mediterranean ecosystem, all degradation processes are speeded up through the water column and over time.

Biological productivity

Static oceanographic structures such as submarine canyons enhance the Mediterranean's biological productivity, which is mainly located and concentrated in offshore areas rather than on the continental shelf (i.e. dense shelf water cascades, upwellings, downwellings, etc.).

Biological diversity

Submarine canyons host many Mediterranean endemic species. Water mixing over such structures favours the "ocean triads" formation (fertilization, concentration and retention), and hence the processes creating high biological diversity through seasonal food web dynamics.

Naturalness

Mediterranean naturalness is linked with the very long history of human civilisation along its coasts and it could be asserted that very few natural habitats exist there, possibly none that are complete. Nevertheless, submarine canyon habitat heterogeneity has generated conditions for maintaining sufficient levels of naturalness to allow for the settlement of a very high diversity of faunal assemblages.

CURRENT CONSERVATION PROPOSALS AND INITIATIVES AT MEDITERRANEAN LEVEL

Recently an MPA network proposal and a detailed review of the current status of conservation initiatives thoughout the Mediterranean has been published by Oceana (2011); this useful tool allows us to identify those areas (already protected or proposed for conservation) corresponding to, or encompassing, submarine canyons, and to discuss aspects related to the priority of their conservation both as benthic and pelagic habitats. This document also emphasizes the limited MPA coverage (0.24% of the total surface) in Mediterranean off shelf habitats, probably resulting from its highly complicated jurisdictional pattern.

A list of EBSAs encompassing candidate Specially Protected Areas of Mediterranean Importance (SPAMIs) was compiled by the Regional Activity Centre for Specially Protected Areas (RAC/SPA - Barcelona Convention) following the CBD criteria, and approved by the Extraordinary Meeting of the Focal Points for Specially Protected Areas in June 2010 (UNEP(DEPI)/MED WG.348/5). In many cases, the listed areas have been designated in order to include specific habitats (i.e. nursery, feeding grounds, etc.) and biocenoses (i.e. *Madrepora* reefs), which can be located within submarine canyons. Identified EBSA are mainly in the Northern Mediterranean, while a large gap exists around areas to the South. Being already a SPAMI as from 2001, the Pelagos Sanctuary is on the list; this large pelagic area encompasses a large number of submarine canyons playing a fundamental role in the entire Mediterranean ecosystem functioning, and thus necessarily to be considered as priorities for conservation.

Submarine canyons have been demonstrated to provide refuge for fishery exploited species (see Farrugio, this volume), thus such habitats are crucial to maintain stocks at a sustainable exploitation level. The Mediterranean Group of the Scientific, Technical and Economic Committee for Fisheries (STEFCF) of the European Commission identified Sensitive and Essential Habitats for fish in the Mediterranean Sea, where establishment of recovery and management plans, limits to fishing efforts, areas and periods of season closure, and other protection measures should be applied.

Essential Fish Habitats (EFH) must be identified as physical areas where individuals in a critical phase of an exploited species are concentrated (i.e. spawning or feeding areas, nursery grounds), while Sensitive Habitats (SH) include fragile habitats which support key assemblages of commercial and non-commercial species and which may require conservation management measures. EFH and SH allocation has been proposed by de Juan and Lleonart (2010); these areas also encompass fishery restrictive areas (FRA) corresponding to canyons, which have been proposed through several recommendations by the General Fisheries Commission for the Mediterranean (GFCM) other than the Southern Balearic seamounts FRA proposed by Oceana.

Moreover, according to the REC.CM-GFCM/29/2005/1 (Management of certain fisheries exploiting demersal and deepwater species)*, Members of the GFCM shall prohibit the use of towed dredges and trawlnets fisheries at depths beyond 1000 m*, the sea bottom on the rim and inside the canyons beyond this depth being protected from direct impact on benthic communities.

Likewise, the GFCM adopted a protection measure for a set of canyons in the Gulf of Lion in 2009 (REC.CM-GFCM/33/2009/1): *The fishing effort for demersal stocks of vessels using towed nets, bottom and midwater longlines, bottom-set nets shall not exceed the level of the fishing effort applied in 2008 in the fisheries restricted area of the eastern Gulf of Lion as bounded by lines joining the following geographic coordinates: 42°40'N, 4°20' E; 42°40'N, 5°00' E; 43°00'N,* 4°20' E; 43°00'N, 5°00' E. (see Farrugio: A refugium for the spawners of exploited Mediterranean marine species:the canyons of the continental slope of the Gulf of Lion, in this volume)

In 2007, the Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) adopted Resolution 3.22 in order to maintain better conditions for the life of Mediterranean cetaceans. In addition to the Pelagos Santuary and the “Regno di Nettuno” MPA, which also encompasses the Cuma submarine canyon on the northern side of Ischia Island (see also Pace *et al.* this volume), eleven areas have been identified, many of which include submarine canyons as favourable habitats for deep diving teutophagous species such as the sperm whale and Cuvier's beaked whale as, for example, the area of the Hellenic trench and southern Crete.

The Commission Internationale pour l'Exploration Scientifique de la mer Mediterranée (CIESM) launched the Peace Parks initiative in 2010 with the aim of preserving the Mediterranean's marine biodiversity by means of cross-border parks, and of achieving the protection of more than 10% of the Mediterranean before 2020. Eight broad priority areas have been identified on the basis of their unique ecological features, but also because they are located in zones where improved relationships between neighbouring states and cooperation between the countries involved are needed to obtain effective and harmonized conservation measures. Some of these broad areas include submarine canyons, which have not been covered by the previously described proposals, in particular canyons off the southern coast of Italy (Ionian sea), east Rhodes and southern Cyprus.

The proposal made in 2006 by Greenpeace includes 32 areas. Even if submarine canyons have not been mentioned as specific criteria for the selection of each area, their number and extension cover many key canyon structures throughout the entire Mediterranean.

Oceana (2011) chose another approach by selecting 100 priority sites on the basis of a detailed study of their unique ecological features and their importance in ecosystem functioning. By limiting the areas' extension but increasing their number, it should allow for the establishment and connectivity of an effective MPA network in respects other than those of reducing governance problems and minimizing patrolling costs.

Each site in the Oceana MedNet has been analysed from various points of view in order to evaluate its ecological importance, but also to stress other features such as jurisdictional problems and threats. Among the 100 sites, 25 submarine canyons have been listed as priority for conservation. For further details, see Marin and Aguilar, this volume.

APPROACHING SUBMARINE CANYON CONSERVATION ISSUES

Awareness of the key role of submarine canyons in the Mediterranean's ecosystem functioning is a recent achievement, also at scientific level. To date, we dispose of detailed sea floor maps of both the Mediterranean basins, and geological investigations of canyons have been carried out there since the early 'seventies, mainly driven by interest in non-renewable resources exploitation. However, biological studies, habitat characterizations, human impact assessments and even detailed oceanographic studies on highlighted circulation processes over a single canyon or canyon systems still remain scarce and, in too many cases, absent. This review of Mediterranean submarine canyons, which was commissioned by the French MPA Agency and the IUCN, clearly demonstrates unbalanced levels of knowledge about canyon ecology in the two Mediterranean basins. Simply from the number of case studies in the third chapter of this review, it is quite easy to verify that we dispose of much less information about the eastern than the western Mediterranean and, in this last sector, there are many more studies on submarine canyon ecology and faunal assemblage diversity on the northern side than on the southern side. Moreover, unbalanced research efforts are also evident among north-western Mediterranean countries, i.e. Spain has invested considerable resources in order to obtain exhaustive knowledge about whole canyon systems off its Mediterranean coast, and this work is still in progress on the same scale as that pursued by France, while very low effort is being shown by Italy, even though very important canyons dissect its Ligurian, Tyrrhenian and Sardinian margins.

Taking these considerations into account, the urgent need to fill these gaps is evident, mainly concerning faunal assemblages and biodiversity, as well as the canyon's role as a stepping stone for a variety of top pelagic predator species. In this last aspect, recent research leads to the conclusion that it would not be enough to protect one single canyon; a wide basin-scale view should be considered in order to carry out effective conservation measures (see Aissi *et al*. about sperm whale, and David and Di Meglio for other pelagic predators, in this volume).

A wide basin view is needed not only for highly migratory species, but also for fishery resources, which very frequently show wider ontogenetic mobility than previously thought. Farrugio (this volume) has demonstrated the importance of submarine canyons as spawner refuges, on the other hand it has been also documented that pelagic eggs and larvae of coastal benthic vertebrate and invertebrate species can be found very far from the coast, due to the advective circulation effect. Canyons can enhance this effect by funnelling the current from the coast to open sea, where the main current can transport this biological crop very far from its original location; other canyons can then successively capture it, thanks to the retention effect of their internal eddies. It is known that these processes are exploited by many species, which regulate their reproduction, spawning locations and periods as well as eggs and larvae development duration according to the presence of favourable conditions within a canyon system (Würtz, 2010). Here, the term "system" biologically acquires a quite different meaning than in the case of its geological characterization, which frequently considers a canyon system as constituted by adjacent canyons. Consequently, this should have an impact on governance and conservation processes (see connectivity within the CBD criteria to establish an effective MPA network); in fact, the biological canyon system can be constituted by canyons not necessarily adjacent, but sometimes very far from each other.

Even in the case of headless canyons, it can be stated that they are the highway through which the coast is directly connected to the deep sea and, of course, this is truer when a canyon is the seaward extension of a river mouth. The importance of submarine canyons in sediment transport and dense shelf water cascades along their walls in the nutrient enrichment of deep bottoms, as well as for deepwater formation and spread throughout the entire Mediterranean, has been well documented, whereas less effort has been devoted to the assessment of pollutants (in terms of both amounts and impacts), which reach the deep sea floor through these processes. Then, from the sea bottoms, pollutants return to the surface layers via upwelling and are re-circulated throughout the entire ecosystem by the food web energy turnover, which is particularly accelerated within the Mediterranean. Chemical pollutants (e.g. POPs) are invisible and when their effects occur, it means that the exceeding concentration thresholds within the organisms as well as in the environment have triggered an irreversible process. Submarine canyons are involved in this mechanism not only due to their morphology (generally their major axes are more or less straight to the coastal lines), but also because, being so deep and so close to the coast, they have been used (and are still used) as dumping sites for highly polluted industrial and harbour dredging sediments.

It is evident that effective conservation measures must consider the scale of these aspects as a priority, particularly when the canyon or canyon system is a key sub-basin structure.

Man-made debris can concentrate within canyons and represents another important issue. Plastic is the most abundant, and to remove this material from the remote canyon wall and floor habitats is not practical; therefore, being in a cold, dark environment, it will persist there for thousands of years. The impact of this kind of debris on animals seems to be low and sometimes fishes and invertebrates have been observed to use it as a habitat and settlement substrate; nevertheless, one of the most abundant types of man-made debris comes from fishing activities and, in the case of ghost nets, its impact cannot be ignored (see also Sacchi, this volume). In any event, as of now, man-made debris will continue to accumulate unless actions are taken to prevent it from being introduced into the marine environment; a cumulative effect on seafloor morphology and sediment dynamics must thus be considered.

It has been stated that each submarine canyon habitat offers, in its entirety, unique features which are different from those of all the other canyons, thus each canyon deserves protection. However, this has seemed to be an impossible task up to now; this review shows that some canyon systems play a much more important role than others, particularly in areas where canyons act as main conduits for sinking water masses which thus affect the whole Mediterranean ecosystem through deep water formation (i.e. Gulf of Lion canyons). It is clear that these are priority areas for conservation actions. Habitat and faunal richness have been described here in a series of case studies, together with threats and impacts on single canyons (i.e. Iberian margin canyon case studies). As our knowledge about canyons is extremely unbalanced, we can expect that in the near future, through studies filling knowledge gaps in the eastern and southern Mediterranean, more and more canyon systems will be identified as fundamental to the functioning of the entire Mediterranean basin.

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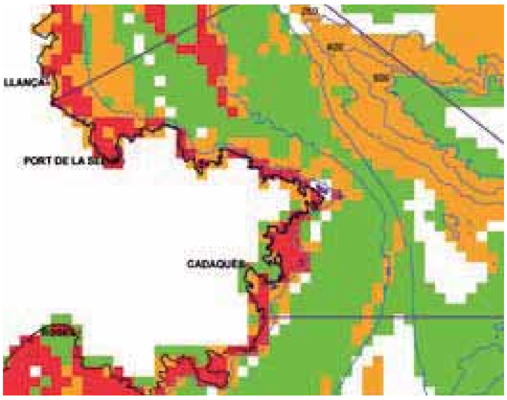

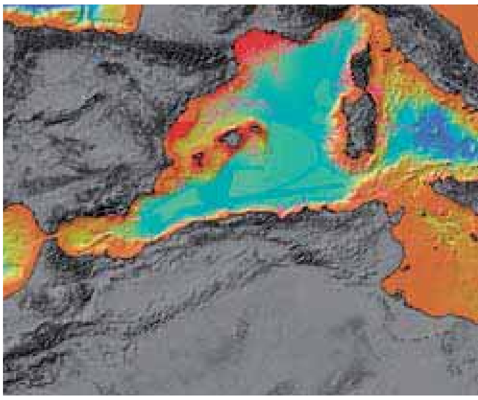

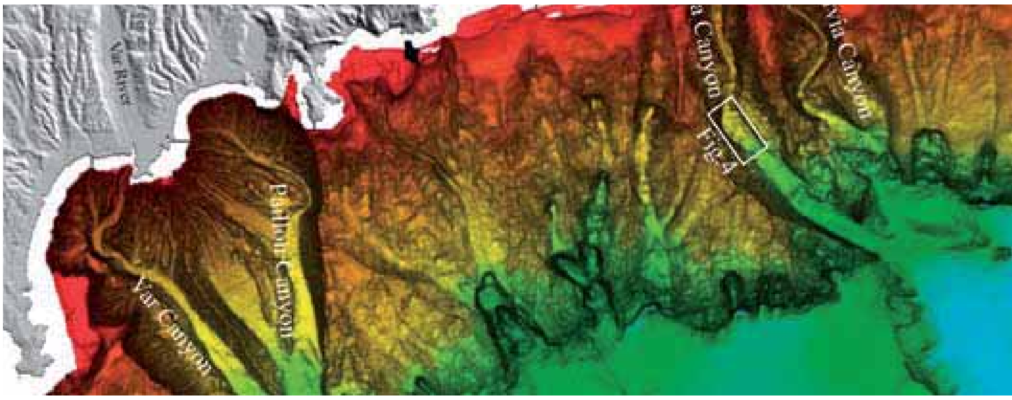

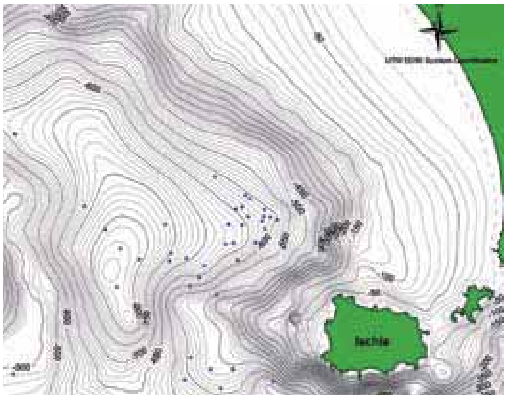

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