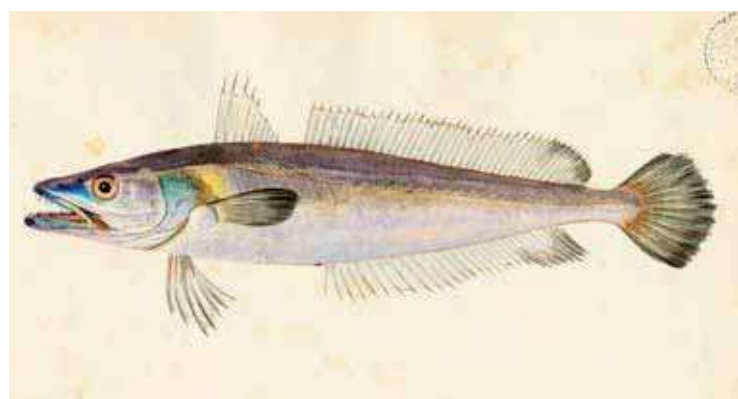
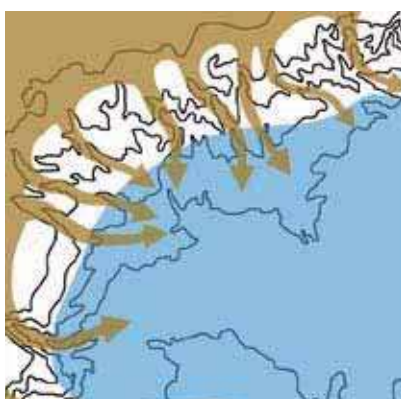
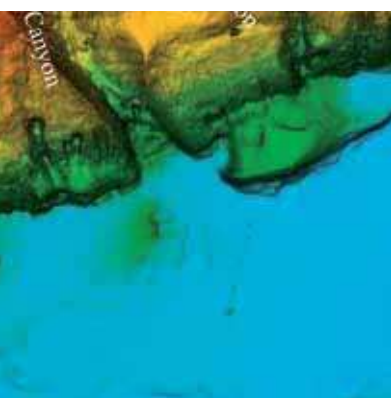
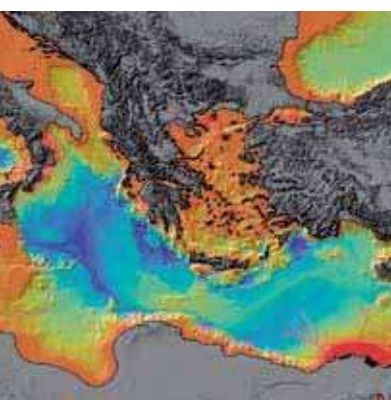




# Mediterranean Submarine Canyons

Ecology and Governance

Maurizio Würtz, Editor



## 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.



## Main canyons studied in the north-western Mediterranean Sea by EcoOcéan Institut, 1993-2011

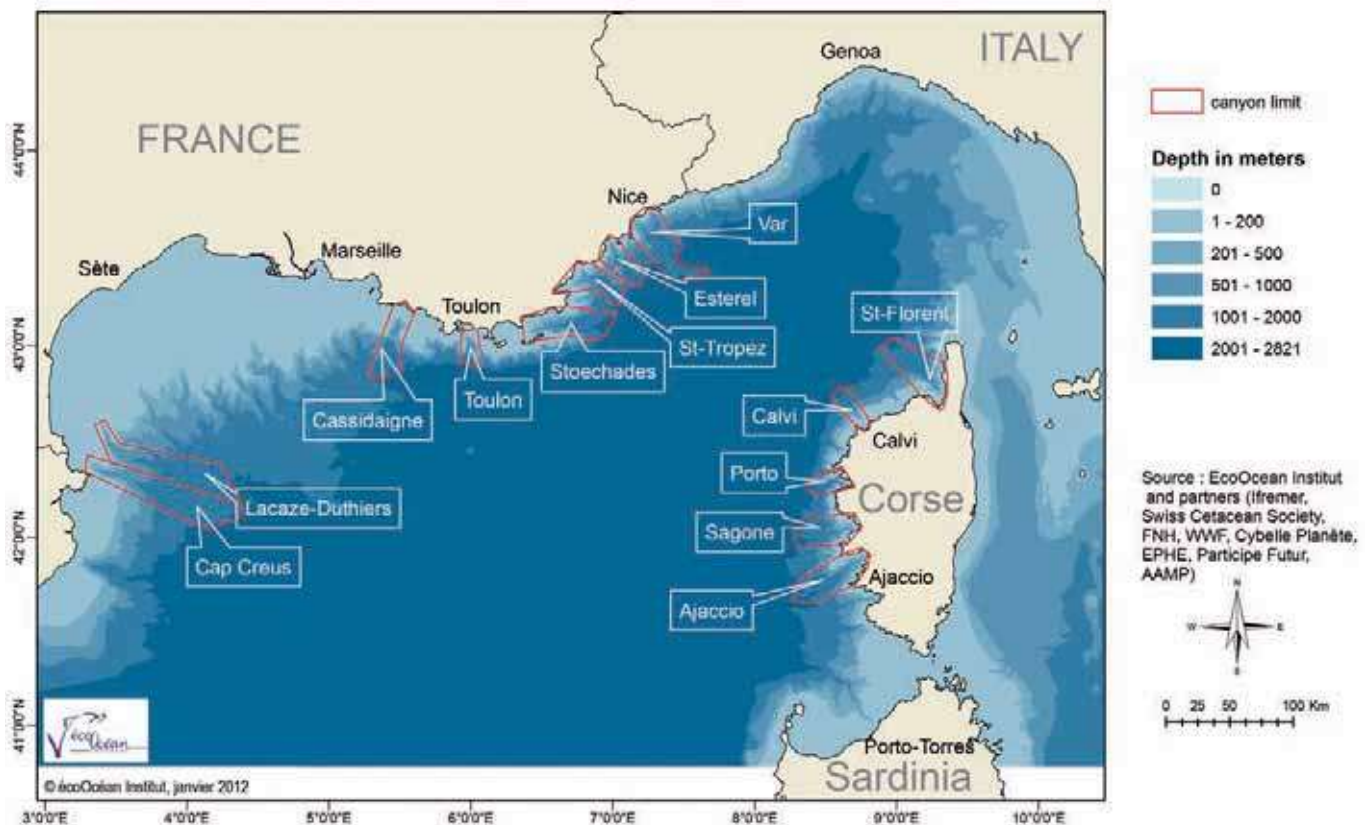


Fig. 1:

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 cavirostris*), 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	Mediterranean 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 <sup>-2</sup>	0.06 .10 <sup>-2</sup>	0.06.10 <sup>-2</sup>
> 2000 m	0.11	0.03	0.03	0.02 .10 <sup>-1</sup>	0.06.10 <sup>-2</sup>	0.02.10 <sup>-2</sup>	0.01.10 <sup>-2</sup>	0.03.10 <sup>-2</sup>

**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 teutophagous (squid eaters). Canyons are also important areas for the striped dolphin, which is an ichtyo-teutophagous species (fish and squid eater). Finally, the difference is less pronounced for the fin whale, the only Mysticeti (baleen whales) and planctonophagous 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 ichthyoteutophageous 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



Species	Canyons	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 black-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 nutriment 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 seamounts, 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 (Macquart-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 zooplankton, micronekton (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 0.12 ind./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).

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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.