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Aspects of the distribution of Cuvier's beaked whale (*Ziphius cavirostris*) in relation to topographic features in the *Pelagos Sanctuary* (north-western Mediterranean Sea)

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Cuvier's beaked whale is a poorly-known species. It has been considered common since 1980 in the *Pelagos Sanctuary* (north-western Mediterranean Sea), but it has hardly been studied, chiefly due to difficulties in sighting. Stranding data indicates that the beaked whale is present all along the Ligurian coast. As with any deep-diving odontocete, Cuvier's beaked whale feeds mostly on deep-sea squid, but also on some fish and a small number of crustaceans. As a consequence, it is thought to be found mainly in waters deeper than 1000 m, where the sea bed has a particular slope. The aim of this work is to analyse a large quantity of sightings in order to define the favoured habitat of the beaked whale. Topographic features such as depth, depth gradient and bathymetric anomaly were analysed due to their direct influence on the prey of Cuvier's beaked whales.

Data were registered between Genova and Imperia, from 2000 to 2006. Two hundred and forty-seven sightings were recorded, a total of 532 whales. The mean herd size observed was 2.3±1.5 (range=1–11). For 40 sightings, the group composition was divided into maturity categories, using results obtained by photo-identification. Seventeen groups consisted of purely immature animals, and 4 groups consisted of only mature animals. The 19 mixed herds were composed mainly of 4.0±2.2 individuals (range=2–8) and consisted of 58% mature individuals. The 17 immature groups consisted of 2.1±0.9 individuals. Mature animals were usually found alone. Forty-eight per cent of beaked whales were seen where the depth was between 756 and 1389 m but the encounter rate was higher between depths of 1389 and 2021 m. The sightings were more frequent (34%) where the sea floor slope was between 31 and 51 m/km but the encounter rate was higher where the sea floor slope was between 11 and 31 m/km. The encounter rate for Cuvier's beaked whales was higher where the depth anomaly was positive with values between 342 and 586 m.

INTRODUCTION

Cuvier's beaked whale (*Ziphius cavirostris*) belongs to the Ziphiidae family, and is among the least known of all the mammalian groups (Wilson, 1992; Rice, 1998). The species was described for the first time by Cuvier, thanks to a partial cranium found on the Mediterranean French coast, but despite this its presence in the Mediterranean was considered unusual. According to Tortonese (1957), the presence of Cuvier's beaked whale in the Mediterranean was regarded as a rare event, and all encountered individuals were supposed to have come accidentally from the Atlantic ocean. The species was not believed to feed in the Mediterranean Sea because none of the stranded animals found there had ingested recent prey. After a number of single or serial strandings that have occurred since the 60s (Paulus, 1962; Podestà et al., 2003; Littardi et al., 2004) and with a constant increase in sightings, Pilleri & Pilleri (1982) accepted that the species was common to the Ligurian Sea. Because of its cosmopolitan distribution around the world, it is viewed as a single global species (Rice, 1998). A further study on genetics has indicated, however, that the Mediterranean population could be endemic (Dalebout et al., 2005). The biological structure of the population is relatively unknown. Cuvier's beaked whales are usually found in small groups of between 2–7 individuals (MacLeod & D'Amico, 2006). Morphological aspects add some important information for the study of group composition. The probable sex and the maturity categorization of specimens can be determined thanks to the head colouration patterns, the presence or absence of two teeth on the lower mandible and the number of body scars (Heyning, 1989).

Generally, the lack of knowledge about the species is due to their elusive behaviour, especially in the presence of boats (Heyning, 1989). Moreover, its immersions can exceed 60 min (Baird et al., 2004; Walter Zimmer, personal communication), making field observations difficult. Its diving pattern alternates between deep-dives and shallow-dives. Beaked whales echolocate on prey at an average depth of 475 m (recorded with two tags, Johnson et al., 2004). Its diet is principally composed of mesopelagic and bathypelagic cephalopods. The mean number of beaks found in 2 stomachs was around 140 (Whitehead, 2003) and they belonged to the Cranchiidae, Histioteuthidae, Gonatidae and Pholidoteuthidae families (Blanco & Raga, 2000; Santos et al., 2001). The stomach contents of animals stranded in the

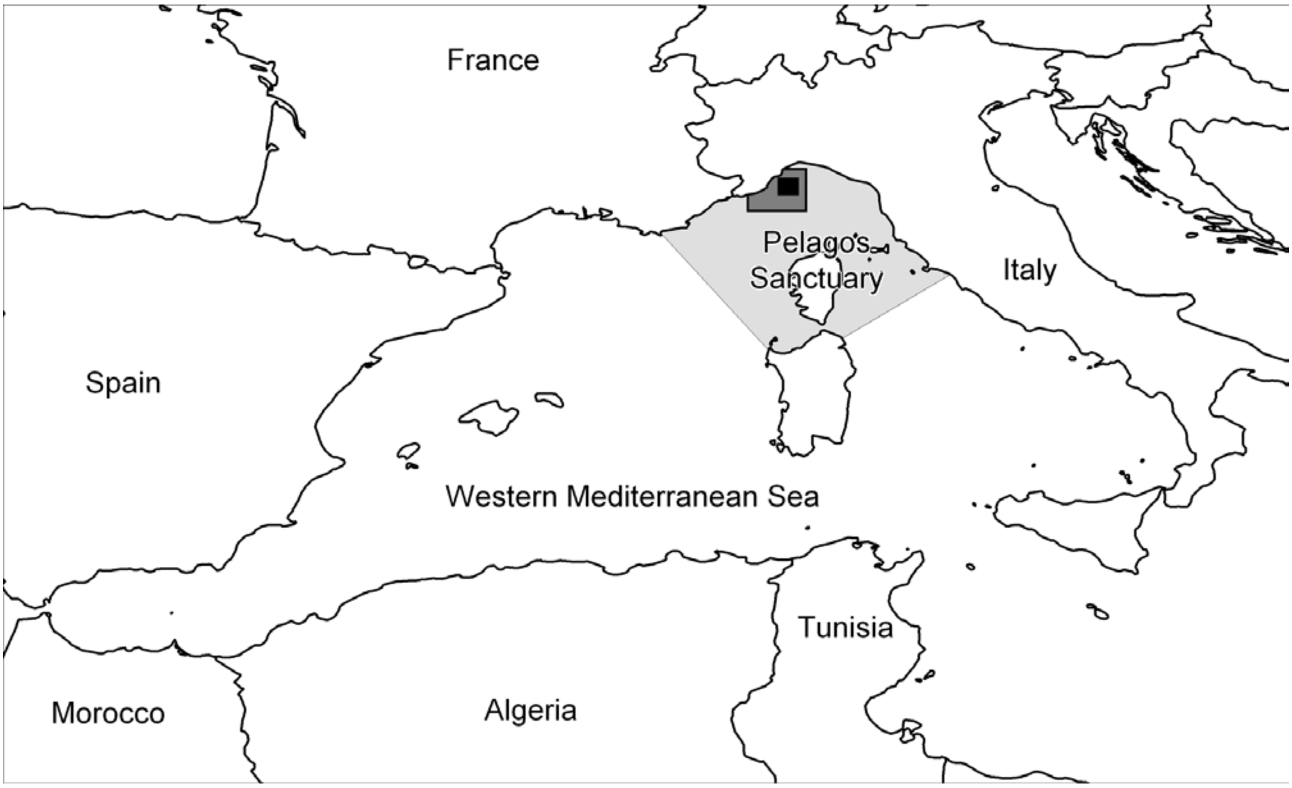

Figure 1. Location and extent of the study area (in dark grey). The black zone is the area where floating squid were collected.

Mediterranean Sea have been found to be mainly composed of Histiothidae with a majority of *Histioteuthis bonnellii* and *Histioteuthis reversa* (Podestà & Menotti, 1991; Carlini et al., 1992; Pulcini & Angradi, 1994; Frantzis & Cebrian, 1998). Sometimes, fish and a few crustaceans were also found in the stomach contents (Jefferson et al., 1993; Debrot & Barros, 1994; MacLeod et al., 2003). It is not surprising, therefore, that beaked whales prefer waters deeper than 1000 m (Nishiwaki & Oguro, 1972; Marini, et al., 1992; Jefferson & Lynn, 1994). The Ligurian Sea gathers all the characteristics for an important squid biomass: presence of submarine canyons and seamounts as well as the Ligurian front resulting from the Ligurian Current (Nesis, 1993). In 1999, the *Pelagos Sanctuary* was created in the Ligurian Sea to protect the biodiversity of the area and in order to counterbalance the high density of human activities in the area.

Evidence has shown that Cuvier's beaked whales are highly sensitive to sounds made by humans (Simmonds & Lopez-Jurado, 1991; Frantzis & Cebrian, 1998; Jepson et al. 2003). To moderate anthropologic pressures and protect the abundance of the species (Jones, 1994) it is necessary to understand which management measures should be applied. This demands a more complete knowledge of Cuvier's beaked whales' habitat. This work therefore analyses for the first time a large database of sightings of the species inside the *Pelagos Sanctuary*. As most biological processes are influenced by bathymetry and bathymetric gradient (Holligan, 1981; Nesis, 1993; Hooker et al., 1999) the study focused on the species distribution related to three different parameters: the bathymetry, the bathymetric gradient and the bathymetric anomaly. Some data on group size and group composition are also presented.

MATERIALS AND METHODS

Study zone

The study zone (Figure 1) extends from the coast to latitude 43°30'N and between 7°48' and 8°54'E longitude. This zone is in the northern part of the *Pelagos Sanctuary* (in the north-western Mediterranean Sea), representing 6409 km^2 and including both coastal and offshore waters. The Liguro-Provençal current is an important feature of this area, which leads to a relatively high nutritive productivity. This explains the dense concentration of cetacean species during spring and summer.

Cetacean sightings

All the information on Cuvier's beaked whale was collected in three different datasets, which provide a large and unique database of 247 sighting positions in the *Pelagos Sanctuary*.

The first dataset, S_{mk}, was gathered by the Biology Department of the University of Genoa. From May 2004 to May 2005, 68 one-day surveys were conducted aboard an 11 m semi-rigid vessel. Transect lines were defined according to a random stratified strategy, covering a total of 9532 km. Stratum 1 was delimited by depths between 800 and 1500 m. Stratum 2 was delimited by depths between 1500 and 2700 m. Both strata were surveyed equally in time and distance per day, and the starting positions in each strata were randomly selected. The observation platform was occupied by four trained observers with an eye height of 4 m above the sea level. Geographical positions of the ship were continuously recorded and their analysis indicated the sum of all transects in a given zone, further referred to as the effort distribution or density.

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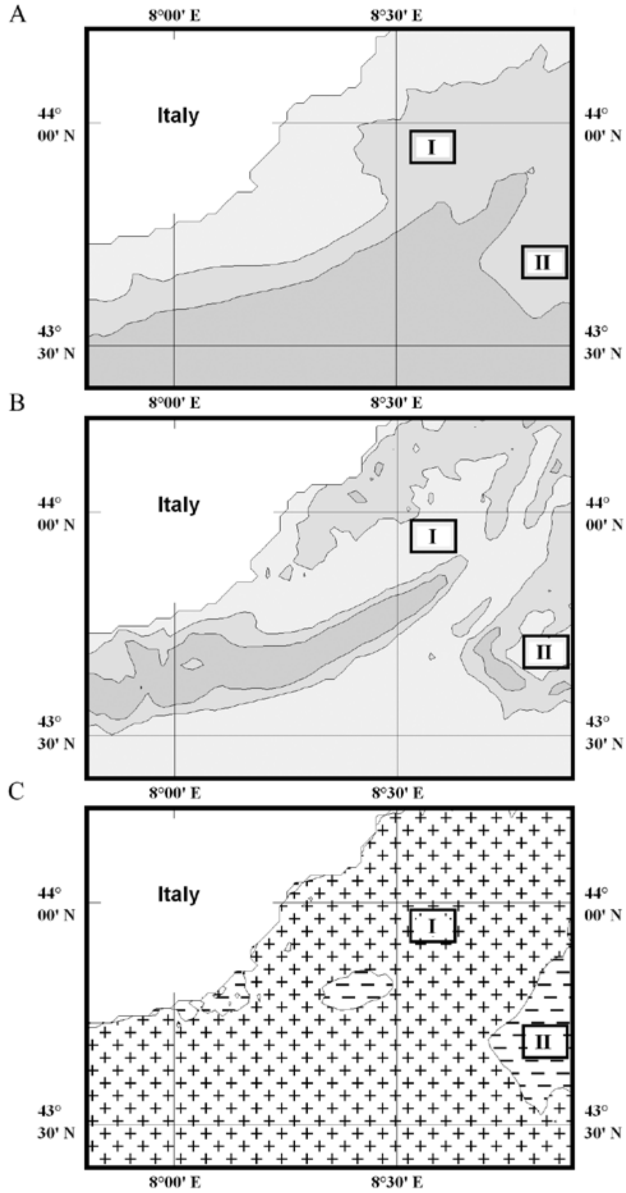

Figure 2. Study zone delimited by the three variables and with two sub-areas (Area I and Area II). (A) 3 depth categories are delimited: 0–1000 m, 1000–2000 m and +2000 m; (B) 3 sea-floor slope categories are delimited: 0–50 m/km, 50–100 m/km and +100 m/km); (C) 2 depth anomalies are delimited: negative ones and positive ones.

The second dataset, S_{ww} was gathered aboard whale watching boats (the 'Corsara' and the 'Stenella' from the bluWest company). From April 2004 to October 2005, 217 one-day surveys were conducted aboard the 'Corsara', a 25 m long ship, with an eye height of 7.5 m above sea level, covering 15,863 km. During the same period, 15 one-day surveys were conducted aboard the 'Stenella', a 15 m long ship, with an eye height of 6.5 m eye above sea level, covering 1,615 km. Sighting data were collected through opportunistic surveys, considering that whale-watching companies in this area mainly search for fin whales. Transect lines were not determined randomly but according to depths, searching mainly in 1800 m deep water or more (where fin whales are more likely to be found). In both cases, ships' GPS positions were continuously recorded. At least three trained observers participated in the surveys.

For both S_{mk} and S_{ww}, the same protocol was applied at sea. Fieldwork was carried out with a wind speed up to 28 km/h and a sea state inferior or equal to 4 on the Beaufort scale. At a searching speed of mostly around 13 km/h, observers scanned 360° with the naked eye and with binoculars (7×50, with compass). Field experience on Cuvier's beaked whale demonstrates the necessity of searching all around the boat. Due to the long time spent underwater, the specimen may surface in the rear 180° of the boats in spite of their relatively slow research speed. When cetaceans were sighted, GPS positions with distance sampling data were registered. Then the cetaceans were approached. To avoid boat disturbance, groups of whales were typically approached from behind at a speed of less than 5 knots, keeping a minimum distance of 200 m. Non-disturbance was assumed in the absence of change in the animal's behaviour (pattern of respiration, direction, break in the respiration cycle and immediate immersion). At this point registration of the relative GPS position, species identification, estimation of the minimum, the maximum and the 'best number' (being the most likely) of individuals were recorded. Afterwards, and as much as possible, the photo-identification protocol (as described below) was applied. The sighting positions used for the analysis for both datasets were therefore the position registered directly before the photo-identification protocol, to minimize boat disturbance of the animals.

Other data were pooled into a third dataset, S_h, covering the same study area, from 2000 to 2006. This dataset does not include the boats' effort distribution and only Cuvier's beaked whale positions were available. In this database, the GPS position used was that of the boats as they reached a distance of 200 m from the animals (the distance required for the identification of the species and estimation of relative number of individuals). The sources were whale-watching companies that did not have GPS real time recorders (*bluWest*, *Altamarea*, *Swiss Cetacean Society*, *Consorzio Liguria Viamare–WWF Liguria*) but were considered to be reliable sources given the constant presence of at least two trained observers on the ship. When different boats were in the same position to observe the same group, the position recorded was that of the first boat on the spot.

Throughout the surveys, additional information on squid presence in the area was obtained through collecting floating cephalopod remains.

Photo-identification protocol and group composition analysis

The protocol for photo-identification applied between 2004 and 2006 consisted of identifying as many animals as possible, from both the left and right sides. Whales were photographed from at least a height of 4 m above sea level. Photographs detailed each beaked whale's body, in particular its head, its back and its dorsal fin. All photographs were taken through 35 mm cameras equipped with 100–300 zoom lenses and were examined and ranked from 1 to 6 according to their quality (with 6 representing the highest quality), following the protocol used by Gowans & Whitehead (2001).

Groups were analysed (size and composition) following the assumption of Gowans et al. (2001) that individuals belong to a unique group when whales are within 5 body lengths

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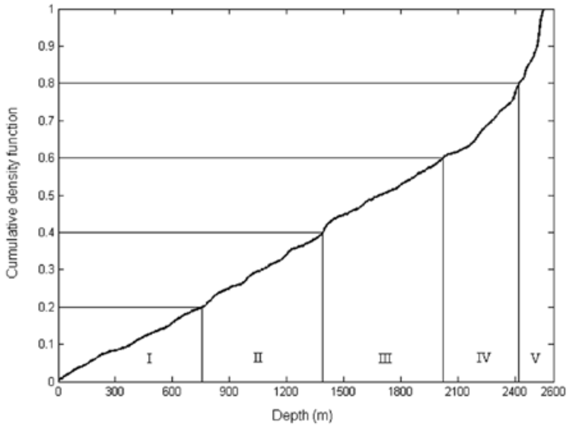

Figure 3. Cumulative density function of depth distribution in the study area. The 5 classes (from I to V) were delimited using the cumulative density function, in order to divide the total study zone into 5 areas of 20% each.

of each other (which represents an approximate range of 35 m) and show a coordinated immersion pattern. As the first step, each group was described *in situ* on the basis of the minimum, the maximum and the best estimation of the number of individuals. Only the best estimate was then used in the group composition analysis. Indeed, Cuvier's beaked whales are quite easy to count when the boat is not disturbing the animals. Marks on their bodies usually help in differentiating individuals and estimating the best number.

Pooling the sightings of all datasets, we calculated then the frequency of each category of group size. Photo-identification results were then taken into account in order to divide group composition into the maturity categories. In this specific phase, only groups in which all individuals were photographed were analysed. The animal's maturity was estimated using the pigmentation patterns, the presence or absence of erupted teeth and the body size (Heyning, 1989). The specimens were divided into two different categories: immature and mature. An immature animal is one that is in general less than 5 m long and which has a pigmentation pattern that is mostly dark brown with a distinctive brown or grey head. Light oval patches are more common than linear marks. Mature animals have a body pigmentation pattern that is mostly light grey to white with a distinctive white head. Marks are usually linear, an effect which sometimes gives them a mottled appearance (Heyning, 1989).

Topographic indicators

Three topographic variables were used as plausible physical oceanographic indicators of Cuvier's beaked whale habitat in the study area. The first two were depth and depth gradient (sea floor slope). These are usually notable features and are accepted indicators of cetacean presence (Hui, 1979; Selzer & Payne, 1988; Hooker et al., 1999; Baumgartner et al., 2001; Cañadas et al., 2002). In fact, the cetacean fidelity to certain canyons may be used to design Marine Protected Areas (see Hooker et al., 1999). The third variable used in this study is hereafter referred to as bathymetric anomaly (or depth anomaly). Given that the global underwater topographic pattern in the western Ligurian Sea is quite constant, with isobaths lying relatively parallel to the coast, it is possible to draw a theoretical map of bathymetry on which the same depth is found at a constant distance from the coast. The bathymetric anomaly for any given position consists of the difference between the real bathymetry and this theoretical one. The examples in Figure 2 show that neither depth nor sea-floor slope are sufficient to characterize certain special topographic features: a half-basin (Figure 2—Area I), quite deep yet quite close to the coast, presents a local depth anomaly. Indeed depth and slope characteristics of Area I are similar of to those of Area II (Figure 2), but the depth anomaly of I is quite different from that of II. Such particularities in the general topographic profile are made obvious through the depth anomaly analysis. Depth anomalies can be classified into two types: first, a positive anomaly of depth indicates areas where the waters are deeper than our theoretical bathymetry; second, a negative anomaly indicates areas where the waters are shallower than the theoretical bathymetry.

Our bathymetry grid is called $z_r(ij)$ where i is the longitude and j is the latitude. This has been adopted from the US Navy dataset (with a grid unit of 1×1 nautical mile). Depth gradient, $gz_r(ij)$ is derived from the depth grid $z_r(ij)$, using a 5×5 pixel gradient and is displayed in m/km. The bathymetric anomaly $az(ij)$ grid is the difference between the depth grid, $z_r(ij)$, and the theoretical bathymetry $z_t(ij)$. $z_t(ij)$ is obtained by taking all the pixels at the same distance from the coast d_k (the index k being all possible distance in the *Pelagos Sanctuary* on our grid) and calculating their average depth value. All studied parameters were projected according Mercator's coordinate system and have the same resolution (with a grid unit of 2.6 km^2).

Because each of the three parameters divided the study zone heterogeneously, the distribution of each one has been graphed through a cumulative density function (CDF) which permits the definition of 5 classes of even areas. For instance (as shown in Figure 3), the bathymetry CDF in our study zone did not grow regularly. Between 2400 and 2600 m the increase was steeper than at shallower depths. Deep waters (>2400 m) are relatively more spread out than shallower ones (Figure 3). To obtain 5 even areas, the depth-classes were defined as Class I=]0–756], Class II=]756–1389], Class III=]1389–2021], Class IV=]2021–2419] and Class V=]2419–2550] m (Figure 3). Likewise, 5 classes of sea-floor slope and 5 classes of depth anomaly were determined using their respective CDFs (Tables 1–3). For all parameters, each of the 5 classes represent 20% of the study zone.

Habitat data analysis

The whole study of the species' habitat was achieved using the presence data. The number of whales at sighting positions was only used for the group composition analysis. To determine if the Cuvier's beaked whale was influenced by depth, the study zone depth CDF was compared using the Kolmogorov–Smirnov test to a new CDF obtained by separating only the depth corresponding to the whales' positions (thus constituting a sub-sample of the study zone). The null hypothesis, H_0, considered that the sub-sample was representative of the study area. The alternative hypothesis,

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Table 1. *Relative frequencies (f_h and f_e) of Cuvier's beaked whale, relative number of sightings (n_h and n_e), relative km sampled (L_e), and relative encounter rate (er_e), obtained from the 5 equal area classes of depth (z). The standard deviation (SD) is calculated with the Monte Carlo (randomization) test on 20 subsets randomly extracted from the total dataset (S_h or S_e). Each subset is made up of 25 different positions randomly extracted.*

Datasets		S_h			S_e		
Variable	z (m)	f_h (n_h)	$\pm SD_h$	f_e (n_e)	$\pm SD_e$	L_e (km)	er_e (n_e/km)
Class I	]0;756]	0.01 (2)	±0.004	0.05 (5)	±0.007	6259	0.00080
Class II	]756;1389]	0.56 (80)	±0.016	0.38 (39)	±0.019	7505	0.00520
Class III	]1389;2021]	0.31 (44)	±0.015	0.34 (35)	±0.021	4508	0.00776
Class IV	]2021;2419]	0.08 (12)	±0.008	0.15 (15)	±0.013	3985	0.00376
Class V	]2419;2550]	0.04 (6)	±0.006	0.09 (9)	±0.012	2870	0.00314

Table 2. *Relative frequencies (f_h and f_e) of Cuvier's beaked whale, relative number of sightings (n_h and n_e), relative km sampled (L_e), and relative encounter rate (er_e), obtained from the 5 equal area classes of depth gradient (gz). The standard deviation (SD) is calculated with the Monte Carlo (randomization) test on 20 subsets randomly extracted from the total dataset (S_h or S_e). Each subset is made of 25 different positions randomly extracted.*

Datasets		S_h			S_e		
Variables	gz (m/km)	f_h (n_h)	$\pm SD_h$	f_e (n_e)	$\pm$ SD_e	L_e (km)	er_e (n_e/km)
Class I	]0;11]	0.02 (3)	±0.005	0.08 (8)	±0.014	2505	0.00319
Class II	]11;31]	0.22 (32)	±0.013	0.25 (26)	±0.020	4579	0.00568
Class III	]31;51]	0.35 (51)	±0.016	0.33 (34)	±0.018	6620	0.00514
Class IV	]51;79]	0.26 (37)	±0.016	0.25 (26)	±0.017	5511	0.00472
Class V	]79;191]	0.15 (21)	±0.010	0.09 (9)	±0.013	5912	0.00152

Table 3. *Relative frequencies (f_h and f_e) of Cuvier's beaked whale, relative number of sightings (n_h and n_e), relative km sampled (L_e), and relative encounter rate (er_e), obtained from the 5 equal area classes of depth anomaly (az). The standard deviation (SD) is calculated with the Monte Carlo (randomization) test on 20 subsets randomly extracted from the total dataset (S_h or S_e). Each subset is made of 25 different positions randomly extracted.*

Datasets		S_h			S_e		
Variables	az (m)	f_h (n_h)	$\pm SD_h$	f_e (n_e)	$\pm$ SD_e	L_e (km)	er_e (n_e/km)
Class I	]−712;88]	0.07 (10)	±0.007	0.12 (12)	±0.017	4402	0.00273
Class II	]88;342]	0.22 (32)	±0.014	0.14 (14)	±0.017	5956	0.00235
Class III	]342;586]	0.36 (52)	±0.015	0.40 (41)	±0.021	5394	0.00760
Class IV	]586;942]	0.26 (38)	±0.013	0.28 (29)	±0.024	4262	0.00681
Class V	]942;1569]	0.08 (12)	±0.012	0.07 (7)	±0.009	5114	0.00137

H_1, indicated that the sub-sample obtained was not representative of the study area. Slope and depth anomalies were then tested in the same way.

The analysis continued by determining where specimen sightings were more numerous. Dividing the study zone into 5 equal areas for each variable, a sighting frequency was calculated for each sub-area, defining where the species was to be more frequently found. Nevertheless, in cases of a heterogeneous survey effort, the effort density had also to be taken into consideration.

The two datasets, S_{mk} and S_{ww} were pooled inside the dataset S_e. The study zone was mapped on a grid of a 2.6 km^2 resolution, and for each cell the effort density, the number of sightings and the encounter rate were determined. The effort density *L(ij)* (where *i* is the cell longitude and *j* is the cell latitude) was the total transect length (in km) realized by the three boats ('Corsara', 'Menkab' and 'Stenella') 'on-effort' (Figure 4B). The encounter rate *er(ij)* was calculated by dividing the number of sightings, *n(ij)* with the number of surveyed kilometres *L(ij)* (Figure 4C, Tables 1–3). For each of the 5 classes defined by the CDF of 3 parameters, the total of surveyed kilometres and numbers of sightings are added (Tables 1–3) and the encounter rate recalculated.

In this analysis only the results from S_e are presented since this constitutes the only dataset where effort density is available. That unfortunately reduces the sighting

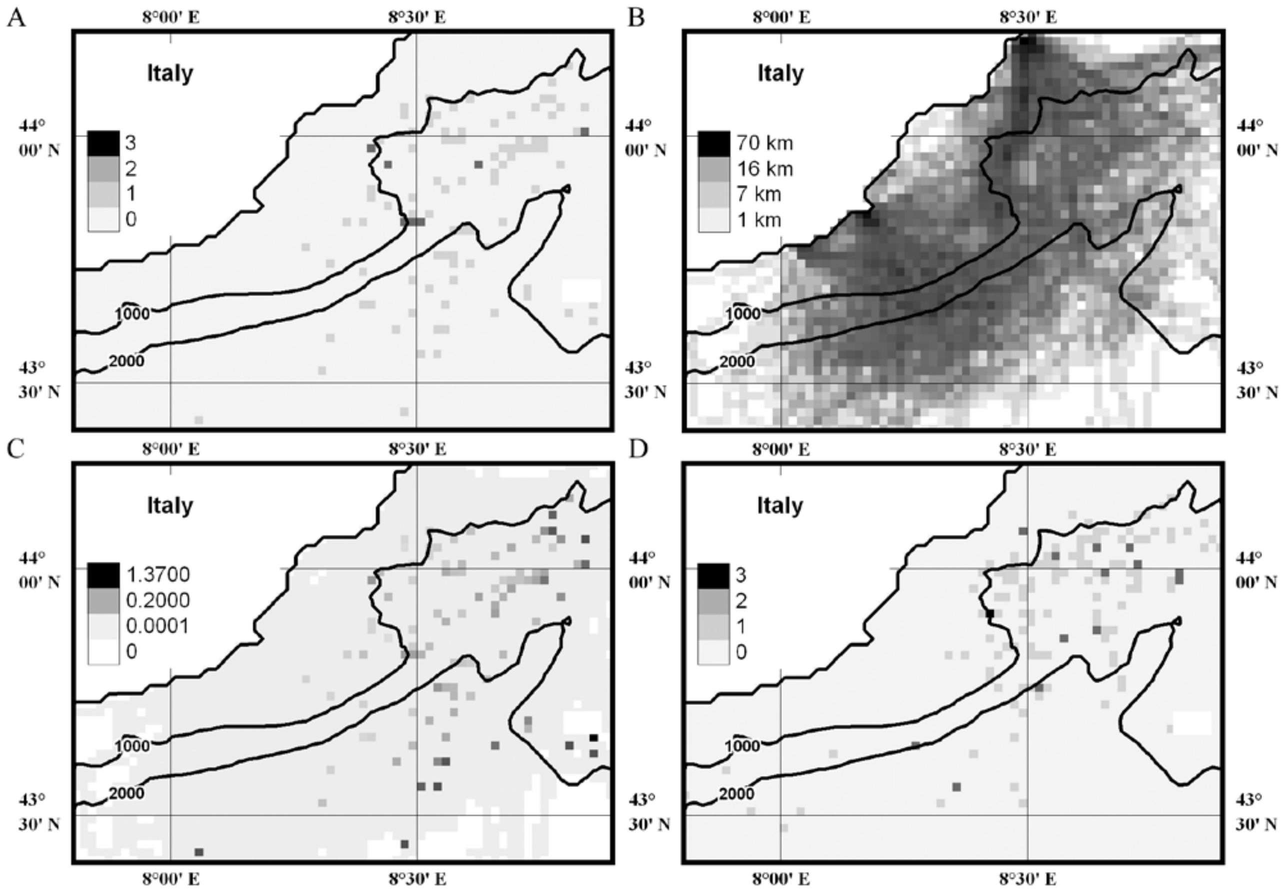

Figure 4. Maps showing results' distribution in the study area divided in cell units of 2.6 km^2. (A) Number of Cuvier's beaked whale sighted in each cell, from the S_e dataset; (B) effort distribution represented as number of kilometers surveyed by cell from the S_e dataset; (C) encounter rate (as estimated as number of sightings divided by number of surveyed distance in each cell) from the S_e dataset; (D) number of Cuvier's beaked whale sightings by cell from the from the S_h dataset.

positions to a mere 103. The rest of the data (S_h) is analysed independently since the effort distribution is unknown; it is not possible to calculate its encounter rate. In this case, only sighting frequency is calculated over the 5 classes of each parameters.

RESULTS

Of the total of the 957 cetacean sightings collected inside the S_e database, 103 positions were Cuvier's beaked whales (totaling 242 whales). This species represented 11% of the total cetacean sightings. Striped dolphins (*Stenella coeruleoalba*) represented 62% (sightings), fin whales (*Balaenoptera physalus*) 19%, Risso's dolphins (*Grampus griseus*) 4%, and sperm whales (*Physeter catodon*) 3%. The S_h database contained 144 positions of Cuvier's beaked whales (representing 290 whales). The entire dataset indicated 247 positions of Cuvier's beaked whales, with 532 whales counted.

Structure and size of groups

Based on the 247 available sightings of Cuvier's beaked whales, group composition is described on Figure 5. The average group size was 2.3±1.5 (range=1–11). On all sightings, isolated animals were located 87 times, representing the most frequent case.

All the specimens of the groups were photo-identified for only 40 groups. Maturity results indicate that 19 groups were mixed herds (with both immature and mature individuals), 17 groups were herds of only immature animals and 4 groups were herds of only mature animals. The 19 mixed herds were composed mainly of 4.0±2.2 individuals (range=2–8) and were made up of 58% mature individuals. The 17 immature groups were composed of 2.1±0.9 individuals. Mature animals were usually found alone.

Beaked whale distribution

The total of 247 Cuvier's beaked whale positions, collected between 2000 and 2006, suggests an aggregation of the species in particular areas of the study zone (Figure 4A, D).

The depth average corresponding to species positions was 1544±489 m (range=581–2541 m). This value is similar to the depth average in the studied area (1580±802 m), but the comparison between the depth distribution in the study zone and the depth sub-sample (where Cuvier's beaked whales have been sighted) indicates a highly significant difference (where the D-value of the observed data, *Do*, is 0.227 with sample size N=247 and the *P*-value <0.01).

As already noted, in order to determine where the species was more represented, frequencies of sighting were calculated

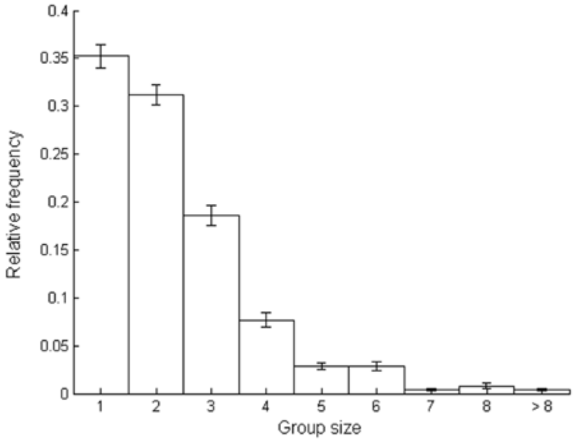

Figure 5. Frequency distribution of Cuvier's beaked whale group size. The standard deviation (shown as error bars) was calculated using the Monte Carlo (randomization) test on 25 sub-sets randomly extracted from the total dataset (N=247 groups). Each sub-set was made up of 50 different groups randomly extracted.

for each of the 5 equal areas, according to depth distribution. In both dataset cases (S_h and S_e), the number of sightings was higher between 756 and 1389 meters (Table 1) and in S_h the frequency reached 0.56. Nevertheless, the effort density was not homogeneously distributed in the study area (see Table 1). A high frequency may also have been the result of a more thorough survey in some areas. In fact, the two zones that were most surveyed were the closest classes to the coast, a logical fact considering the boats' dependency on the coast. In the closest, Class I, the survey effort was 6259 km and in Class II, it was 7505 km. The sighting quantity was weighted as a function of the effort density in order to determine where animals were more frequent. The major encounter rate relative to depth was found in Class III (between 1389 and 2021 m, see Table 1). The smaller one was in Class I (between the coast and depth of 756 m). Indeed in spite of an important effort density, no Cuvier's beaked whales were found at a lower depth than 581 m.

The average seabed slope corresponding to the species presence was 47±31 m/km (range=1–174 m/km). This value is similar to the average of the study area (48±40 m/km). A comparison between the slope distribution in this area and the sub-sample (represented by the values at specimens' positions) gives a highly significant difference (*Do*=0.159; N=247; *P*-value <0.01).

For the two datasets S_h and S_e, the highest frequency was found where the slope was between 31 and 51 m/km (see Class III in Table 2). The value was quite similar for both. Results also indicate, however a stronger effort in this class (6620 km) which may explain a lower encounter rate obtained in Class III than the one in Class II. Nevertheless, in both cases the encounter rate was quite high with a value around 0.005 sightings/km. On the contrary, in Class V, where the effort was important, the encounter rate was the lowest, suggesting that the species does not prefer slopes which are too steep. On the other hand, in Class I where the seabed was quite flat, Cuvier's beaked whales seem to be quite absent; but it is also true that the effort density there was quite low.

The average depth anomaly of Cuvier's beaked whale positions was positive (497±316 m). This means that the species is more represented where depth is deeper than expected according to the general topographic profile of the *Pelargos Sanctuary*. Generalized to our study area, the average depth anomaly was also positive (501±455 m). A comparison between the depth anomaly distribution in the study zone and the sub-sample area, which isolates the depth anomaly values at species positions, indicated a high significant difference (*Do*=0.190; N=247; *P*-value <0.01).

As shown in Table 3, there was a higher frequency of sightings for depth anomalies between 342 and 586 m for both datasets, indicating once again that the species prefers deeper water than was expected. According to the effort results, Class II was sampled more frequently, rendering the encounter rate relatively low for that Class. In Class III (between 342 and 586 m), where there were more sightings, the encounter rate reached 0.0076 sightings/km, indicating that this area is preferred by whales. Overall, the study zone was characterized by deep water very close to the coast. The major anomaly is to be found in the south-western part where it ranged from 942 and 1569 m. Yet looking at the species distribution, whales were more represented in the areas where the anomaly was moderate.

Fifteen samples (27 specimens) of floating squid were collected during the surveys. The specimens belonged to only two species: *Histioteuthis reversa* (81%) and *Histioteuthis bonnellii*. Because all squid were freshly dead, we concluded that their positions were poorly biased by the current. All squid were collected into one reduced area of less than 1100 km^2 and this may indicate their regular presence here (see Figure 1).

DISCUSSION

In this study, the average group size obtained for 247 sightings was 2.3±1.5 individuals. It is similar to the average published by MacLeod & D'Amico (2006) with 2.3±1.5 individuals (obtained with 189 sightings in an undetermined area) and to results of May-Collado et al. (2005) with 2.6±1.4 individuals on 14 sightings, in the Costa Rican Pacific. The largest group sighted during the survey was composed of 11 individuals, whereas at least one group of 15 was reviewed by MacLeod & D'Amico (2006). Given our available data, on the 247 sightings, 34% were single individuals. Considering the number of animals involved in mass strandings, larger groups seem to be under-estimated in the field (see the review of MacLeod & D'Amico, 2006).

We can compare the Cuvier's beaked whale group size with other Ziphiidae species. The northern bottlenose whales (*Hyperoodon ampullatus*), a species that has been studied for about 15 y, has a mean group size of 3.1±1.9 (Gowans et al., 2001, with a range between 1 and 14) or is 3.6±2.4 (on 895 sighted groups in MacLeod & D'Amico, 2006). As for the southern bottlenose whales (*Hyperoodon planifrons*), the groups are usually composed with 2.4±2.2 animals with a range between 1 and 20 (MacLeod & D'Amico, 2006).

To gather preliminary results on the description of group composition, systematic photographs of all individuals inside the same group were sorted according to two categories, mature and immature. Considering only 40 groups, all

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the whales in the same group were classified on the basis of maturity. In those groups, immature animals constituted small groups (2–3) of the same maturity-class, and adults formed mixed groups or were found alone. When adults were associated with other specimens, they were with newborns and calves (as observed according to their smaller size). The lack of information on sexual identity made it difficult to interpret the group composition. Single individuals, mature adults, could be solitary animals that only meet for reproduction. Small groups could be composed of immature individuals only, gathered to solidify social bounds with other animals of the same class-category. Large groups could be formed by whales with reproduction bounds. Nevertheless, these are still merely hypotheses, and the results are still preliminary. More information is necessary on the age and sex composition of groups, on photo-identification results and on genetic results to better understand the behaviour of Cuvier's beaked whales. Let us add that the very definition of a group is difficult. Instead of choosing as criterion for determining a group, the number of body-size distances between animals or the synchronal pattern of immersion, we could favour the capacity of communication between the animals of a same group, in a higher distance range. A new criterion may interfere with group composition results. But its effect on a study is hard to foresee, especially in our state of knowledge of this species.

Turning to habitat characteristics, Cuvier's beaked whale seems to have been concentrated into a specific area of the study zone. Since it is usually accepted that topographical conditions interact with a cetacean's distribution (Nishiwaki & Oguro, 1972; Baumgartner et al., 2001; Cañadas et al., 2002), this concentration may be related to three topographic parameters.

In this study, the majority of sightings (119 out of a total of 247, Table 1) were located between 756 and 1389 m. However, the encounter rate (calculated on one part of the available data only), was higher between 1389 and 2021 m. Some previous workers have also suggested that the species stays mainly close to the 1000 m isobath (Houston, 1991; Robineau & di Natale, 1995).

According to seabed slope, sightings are more frequent in areas with a slope between 31 and 51 m/km (with 85 sightings on a total of 247, see Table 2). But the encounter rate was highest between 11 and 31 m/km. The species seems not to prefer areas with too much variation of sea floor. Yet the species seems also quite rare where the seabed is flat. In this case, however, the encounter rate may be under-estimated because of a low relative effort. This is also described by Williams et al. (1999) explaining that the species occurs more on Cap Breton Canyon in the Bay of Biscay. Indeed, according to data on bathymetric anomalies, it is possible to further predict the area where animals might be met more frequently. The bathymetric anomaly is another indicator defined according to two parameters: the depth and the distance from the coast. Considering the general topographic pattern in the *Pelagos Sanctuary*, it is possible to define areas with higher depth than other areas at the same distance from the coast, and define areas with lower depth than other areas at equal distance from the coast. For example, the north-eastern Ligurian Sea is far shallower than the north-western part, so its depth anomaly is negative. In the north-western part, generally the depth anomaly is null or positive indicating that the depth is greater than that usually obtained at a defined distance from the coast. The Cuvier's beaked whale encounter rate is higher where the depth anomaly is positive with values between 342 and 586 m. These results indicate that compared to the entire study zone, whales are more frequent where the sea bottom is deeper and close to the coast than other parts of the *Pelagos Sanctuary* with shallower depth. This result confirms Carwardine's review (1995) indicating that Cuvier's beaked whales may be found close to the coast especially in the presence of submarine canyons. Considering the bottom pattern, most of the sightings were collected in a mid-closed basin. Its edge is limited by the 1000 m isobath and its bottom intersects with the Genoa Canyon bottom. This mid-basin constitutes a topographic southward barrier to the Liguro-Provençal Current running parallel to the coast. Nesis (1993) described how topographic features with barriers that are obstacles to currents may participate in enriching the nutritive production in front of the feature. In such a case, cephalopod presence may be higher. Indeed, all collected floating squids have been found where the mid-basin makes a barrier to the Liguro-Provençal Current. This topography could account for a local high concentration of squid, especially of the two collected species, *Histioteuthis bonnellii* and *Histioteuthis reversa*, well known to be the main prey of Cuvier's beaked whales in the Mediterranean Sea (Podestà & Menotti, 1991; Carlini et al., 1992; Frantzis & Cebrian, 1998).

According to Ferguson et al. (2006) Cuvier's beaked whales are found in the eastern tropical Pacific Ocean at a mean depth of 3446 m and a mean slope of 13 m/km, where waters are well-mixed or stratified and where the mean sea surface temperature is 27°C. The characterization of the Cuvier's beaked whale habitat is one of the first steps in proposing monitoring and management measures that may help to protect the species. MacLeod & Mitchell (2006) class the Genoa Canyon as a key area for Cuvier's beaked whales. The study zone selected is an area where animals are present as well as an area characterized by a large range of oceanographic descriptors. Nonetheless, it is necessary to investigate other factors to further our study of the species. Given the status of the *Pelagos Sanctuary* as a wide Marine Protected Area, it is necessary to define other sub-areas where the species could be also present and to conduct new surveys there (for example, our study area was similar in range of depth, slope and depth anomaly to an area off the northern part of Corsica). Moreover, in order to delimit accurately Cuvier's beaked whale habitat, further work must include information on dynamic oceanographic features (such as current forces) as explained by Hooker et al. (1999). Marine Protected Areas have to be described according to both fixed and dynamic parameters. Considering that Cuvier's beaked whale prey distribution is difficult to sample and study, indicators such as sea surface temperature, chlorophyll concentration and current forces may offer indirect clues about the whales' distribution. This study will help to define possible habitat areas and will help to organize future surveys in order to establish a more general picture of the presence of the Cuvier's beaked whale in the entire *Pelagos Sanctuary*.

This may reduce the anthropological pressure, especially off the Ligurian coast where the human population density is the highest in the Mediterranean.

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