Occurrence and spatio-temporal distribution of sperm whale (Physeter macrocephalus) in the submarine canyon of Cuma (Tyrrhenian Sea, Italy)

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ABSTRACT

1. Boat surveys aimed at studying sperm whales in the Tyrrhenian Sea were conducted between 2002 and 2011. During 768 daily surveys, a total effort of 32,602 km was achieved within an area of 8800 km² resulting in 92 encounters with 229 sperm whale individuals.

2. Average encounter rates of sperm whales was 0.5 groups per 100 km², with a higher concentration in the vicinity of the submarine canyon of Cuma, confirming the importance for the species of this small hotspot in the Mediterranean Sea.

3. Encounter rates increased with increasing distance from the coast. It is possible that the intense boat traffic and anthropogenic disturbance in the area may be moving animals away from the coast leading to habitat loss.

4. The species–habitat relationship documented in this study has implications for conservation.

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KEY WORDS: sperm whale; submarine canyons; distribution; Mediterranean; habitat; conservation

INTRODUCTION

Analysis of occurrence and distribution patterns is essential to understanding the role of an animal in its environment, and can provide information on spatial use, territoriality, reproduction and residency (White and Garrott, 1990). It is likely to reflect patterns of both resource and predatory distribution (Brown and Orians, 1970; Whitehead, 1996; Jaquet and Whitehead, 1999).

In the marine realm, cetaceans range widely over the course of a year or a lifetime, but may also focus their activities in smaller localized regions and within particular habitat parameters. Such different distributions are usually interpreted as resulting from a wide diversity of behavioural and life-history traits, such as feeding strategies (Baumgartner, 1997; Davis et al., 1998; Forcada, 2002; Hastie et al., 2004) and reproductive-related decisions (Forcada, 2002; Elwen and Best, 2004); however, habitat-related factors (temperature, salinity, depth, bottom topography), distribution and behaviour of predators and anthropogenic...
influences (pollutants, human induced sounds, incidental and direct kills) may also have a significant role (Hooker et al., 1999).

In the Mediterranean Sea, different authors have investigated relationships between sperm whale (*Physeter macrocephalus*) distributions, bottom topographies and environmental parameters (David, 2000; Drouot et al., 2004; Gannier and Praca, 2007; Azzellino et al., 2008; Moulins et al., 2008; Praca and Gannier, 2008; Aïssi et al., 2012; David and Di-Méglio, 2012). It has been shown that these animals seem to prefer deep continental slope waters (Azzellino et al., 2008) thought to be areas where mesopelagic cephalopods – the species’ preferred prey (Clarke, 1996; Whitehead, 2003) – are most abundant (Azzellino et al., 2008; Praca and Gannier, 2008). Sperm whales, however, can also be found in deep offshore waters (Praca and Gannier, 2008; Praca et al., 2009), in coastal areas where there is deep water and in proximity to features like sea mounts and submarine canyons (Drouot et al., 2004). In the North-western Mediterranean, for example, the occurrence of the species seems to be positively related with such topographical features (David, 2000; Gannier and Praca, 2007; Moulins et al., 2008; Aïssi et al., 2012; David and Di Meglio, 2012), highlighting the need to improve the understanding of the importance of deep sea features such as submarine canyons for endangered/vulnerable top predators such as sperm whales.

The sperm whale occurrence around Ischia and Ventotene Islands (Tyrrhenian Sea), a region characterized by the existence of a submarine canyon system, has been monitored since 1991 (Mussi et al., 1998), with sightings being made of both solitary males, and social units of females with immature animals and calves (Mussi et al., 2005). The area for this study, situated in the south-eastern Tyrrhenian Sea (Italy), covers 8800 km² and includes the islands of Ischia and Ventotene (Figure 1).

In this area, geological surveys using high resolution multibeam and side scan sonar (de Alteriis and Toscano, 2003; de Alteriis et al., 2004) have shown the presence of canyons (Cuma, Punta Cornacchia) and of erosional channels (Forio) along the island’s edge (Figure 2). Cuma is the deepest canyon in the area with the trench (850 m deep) forming a submarine valley between Ischia and Ventotene (Pennetta et al., 1998). This canyon provides a sedimentary basin for materials that are carried along the coast by outflow from the Volturno and Garigliano rivers (Gulf of Gaeta). The canyon increases the upwelling speed of water and also acts as a duct for conveying sediments to the waters of the deep basin (Pennetta et al., 1998).

The waters around Ischia Island have been also recently classified as a marine protected area (‘Regno di Nettuno’ MPA) in acknowledgment of their significant biological diversity. The area is
also an important economic and recreational resource, supporting commercial fishing and shipping as well as leisure boating and marine tourism, thus presenting the challenge of balancing the conservation of aquatic biota with the continuation of a variety of human activities. Increased understanding of the spatial distribution of the species in this area will be essential in refining marine spatial planning and designation of specially protected pelagic zones, and managing human activities in order to facilitate sperm whale conservation (Hooker et al., 1999). Data collected over a 10-year period (2002–2011) has been analysed to assess the relationship between sperm whale encounters and bottom topographies (depth, slope, distance from the nearest coast) and to estimate movements of the species in the area.

**MATERIALS AND METHODS**

**Study site**

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; Pace et al., 2012), as well as for populations of key species in the pelagic trophic web, such as the euphasiacean *Meganyctiphanes norvegica* (Mussi et al., 1999). Seven cetacean species have been regularly observed here. 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 IUCN Cetacean Action Plan (Reeves et al., 2003) as a critical habitat for the endangered short-beaked common dolphin (*Delphinus delphis* Mediterranean sub-population. Bottlenose dolphins (*Tursiops truncatus*) and pilot whales (*Globicephala melas*) are also present in the area (Mussi et al., 1998). Other pelagic species, such as *Mobula mobular*, *Mola mola*, *Thunnus* spp., *Xiphias gladius* and sea birds such as *Calonectris diomedea*, *Puffinus puffinus* and *Larus ridibundus* are also commonly sighted in the area (Mussi et al., 1999). The fishery resources are exploited by trawlers, as well as bottom gill nets set for *Merluccius merluccius*, encircling nets for *Scomberesox saurus* and small
mesh driftnets for Scombridae as well as bottom and surface long lines (Mussi et al., 1999).

Survey and data collection

Surveys were conducted from Jean Gab, a 17.7 m sailing vessel powered by 145-hp diesel engine, from 2002 to 2011. Surveys were conducted five days a week from June to October each year with a few additional surveys undertaken in winter and spring. Survey trips were only conducted in sea states of 3 or less during good light conditions, at a vessel speed of between 2 and 4 knots. Data were collected by at least three experienced observers during standardized visual and acoustic surveys within the study area. Survey tracks were laid out to provide a roughly even coverage of the study area, but were adapted to prevailing weather conditions.

Searches for sperm whales were made by continuously scanning with the naked eye and with 8–16 × binoculars at 3 m eye-height and by continuously listening for whales’ clicks using a towed stereo hydrophone array incorporating two hydrophones with preamps (100 Hz – 22 kHz bandwidth, ENEA UT-APRAD Radiation Sources Laboratory) spaced 3 m apart on a 100 m cable. Differences in the time of arrival of whale clicks on the two hydrophones were used to determine the bearings to the whales using Rainbow Click software (developed by IFAW; http://www.ifaw.org).

A detailed trip log of the route covered was kept and GPS positions were recorded every 3 min. During all surveys the data logging software ‘Logger 2000’ (developed by IFAW; http://www.ifaw.org) was used on a PC connected to the GPS. Visual and acoustic detections of cetaceans, numbers of whales regularly clicking and whales visually present, as well as notes on their behaviour were entered manually in Logger during all encounters.

The following temporal and environmental variables were recorded during each survey: date, time, latitude and longitude, presence of and any association with other species (cetaceans, fish and/or sea birds), vessels within 100 m from the whales, cloud cover, Beaufort sea state and visibility; distance offshore, depth and water temperature were also available from the data collected routinely during the surveys.

When sperm whale clicks were detected the survey track was broken and whales were tracked acoustically and approached until sighted at the surface. Whales at the surface were approached carefully. Once within less than 300 m visual range, the boat would slow and travel parallel to the course of moving individual(s) and a ‘group follow session’ was initiated. This was continued for as long as possible or until the weather conditions deteriorated (e.g. poor visibility, sea state >3) or until all animals present had been identified photographically.

Encounters with sperm whales were considered as distinct sightings if they had been made on different days or were of distinct social units or groups encountered on the same day separated by more than 60 min (group identity was determined afterwards through examination of photo-identification images).

The number of whales comprising a group was estimated visually and group composition was confirmed afterwards using photo-identification images.

Photoidentification

A digital camera (Canon Eos 10D) SLR equipped with a high quality, image stabilized telephoto zoom lens (100–400 mm F4.5–5.6) was used to take photo-identification images. Images were stored in JPEG format (12 bit, 2.4 MB, 3072 × 2048 pixel).

Individual whales were photographed on the right and left side of the dorsal fin area, the trailing edge and both the dorsal/ventral side of the flukes. Patches, nicks, notches, scars or other irregularities were used to identify individuals (Whitehead and Gordon, 1986).

Analysis

Raw data collected in the field were stored in a database (Postgresql 9.1) and Postgis 2.0 geographical extension and the PL/R library with R 2.14 were used to undertake spatial and statistical analysis. Data were assigned to a grid of 8800 1 km² cells and covariates (depth, slope,
distance from the nearest coast) were calculated for each cell using inverse distance weighting interpolation (IDW) and a 50 m resolution bathymetric layer. Monitoring and sighting effort, size and composition of groups and all other distribution values were computed at grid level. Relevant descriptive statistics were calculated. To assure better performances, the database has been organized to generate shapes on the fly, choosing periods for grid, routes and sighting points.

A Cell Sighting Rate (CSR) was calculated as [Sighting effort (km)/Survey effort (km)], where the Sighting effort is the number of kilometres spent following the sperm whales and the Survey effort is the number of kilometres spent searching for the animals.

A group’s location was taken as being its position when initially encountered, however long it might be followed for. Depth, slope and distance from coast for an encounter were calculated as the values detected at the beginning of each sighting.

Relative abundance of sperm whales were scaled by a annual encounter rate (ER) (Table 1, Figure 7). ERs were calculated as the ratio \( n/L \), where \( n \) is the total number of sightings and \( L \) is the total number of km spent on effort per year.

This is equivalent to computing the weighted mean of the encounter rates \( (n_i/l_i) \) recorded within each cell, where \( n_i \) and \( l_i \) are the number of sightings and the number of km spent on effort in each cell, respectively, and the weights are given by the ratio \( l_i/L \) (Bearzi et al., 2005). The sampling variance of the encounter rate was then calculated using the formula (Buckland et al., 1993):

\[
\text{Var}(n/L) = \frac{k \sum_i l_i (n_i/L - n/L)^2}{k - 1}
\]

where \( k \) is the number of cells surveyed (1731). Cells with a total survey effort lower than a cell’s diagonal (1415 m) in any year were excluded from the analysis of encounter rates for all years, resulting in a single set of representative cells used for all analyses.

The correlations between ERs and km surveyed, and between ERs and number of sightings were tested to check if encounter rates for these cells were effort-biased. Neither correlation was significant (\( P = 0.94 \) and \( P = 0.72 \) respectively). Non-parametric multiple comparisons (Kruskal–Wallis tests) were applied by using the standard Bonferroni formula (\( P/k–1 \)). Temporal trends in the encounters were analysed in relation to depth, slope and distance from the nearest coast and evaluated by means of regression analyses using both an ordinary least square (OLS) method and a weighted least square method (WLS). The latter method was chosen to account for the variability in the yearly variance of the encounter rates (Mickey et al., 2004). The regression statistics presented in the Results section refer to the weighted least square trends estimators.

Ultimately the value of ER was plotted as number of encountered groups per 100 km (Figure 6).

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Table 1. Search effort and tracking encounters (2002–2011)

<table>
<thead>
<tr>
<th>Year</th>
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<th>Tracking encounters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>km</td>
</tr>
<tr>
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<td>58</td>
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<tr>
<td>2003</td>
<td>70</td>
<td>1798.32</td>
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<td>2004</td>
<td>64</td>
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</tr>
<tr>
<td>2005</td>
<td>68</td>
<td>2794.13</td>
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<td>3608.96</td>
</tr>
<tr>
<td>2007</td>
<td>85</td>
<td>3758.72</td>
</tr>
<tr>
<td>2008</td>
<td>90</td>
<td>4243.38</td>
</tr>
<tr>
<td>2009</td>
<td>95</td>
<td>4567.75</td>
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<td>91</td>
<td>4248.73</td>
</tr>
<tr>
<td>2011</td>
<td>72</td>
<td>2992.47</td>
</tr>
</tbody>
</table>

Overall 768 32 602.58 5816.31 92 1079.13 254.82
RESULTS
In total, 768 daily surveys were conducted, during which 32,602.58 km of track line were completed in 5816.31 h of effort (Figure 3). There were 92 encounters with 229 sperm whales; animals were tracked for a total of 1079.12 km and followed for 254.82 h (Table 1).

Encounters and movements were principally located north-west of Ischia Island, with different patterns observed over the years (Figure 4). The region corresponds to the deepest parts of the Cuma and Punta Cornacchia canyons, between 300 and 900 m deep (Figure 2). Within this area, sperm whales seem to prefer the 600-800 m bathymetric range, as clearly outlined by CSR (Figure 5; see also Methods for details). The average depth for all encounters was 668.40 m with a non-significant trend through years (SD = 131.99; range = 278-1000; median = 661.99). The distribution of the ER values by cell over the study area is plotted in Figure 6. Encounter rates of sperm whale show an overall value of 0.56 groups per 100 km.

The yearly ER reveals increasing values between 2002 and 2011 (Kruskal-Wallis rank test H = 19.93, df = 9, $P < 0.01$; Figure 7) and multiple comparisons confirmed that ERs in 2009 were significantly higher than in all other years.

The mean value for bathymetric slope for all sperm whale encounters was 0.04 (SD = 0.02; range = 0-0.12; median = 0.02) (Table 2), with no significant variation between years.

The mean distance from the nearest coast for all encounters was 12.23 km (SD = 3.34, range = 3.16-19.32; median = 12.04). The distance from the coast for encounters showed an increase between 2002 and 2011 (Table 2, Figure 8), there was a significant positive regression over this period (ANOVA for regression F = 6.343, df1 = 1, df2 = 8, $P = 0.032$).

DISCUSSION
Environmental, oceanographic and anthropogenic factors can influence the occurrence and distribution of cetacean species in complex ways (Jaqet, 1996; Davis et al., 1998; Cañadas et al., 2002). The continental shelf in the study area is characterized by complex bathymetry, including a submarine canyons system, a deep basin between Ischia and Ventotene, submarine mountains and some shallow banks. Within the highly morphological variables, 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. Mixing rates inside canyons could be...
as much as 1000 times greater than rates measured in the open ocean and upwelling associated with canyons enhance local primary productivity and the effects extend up the food chain to include birds and marine mammals (Würtz, 2012; De Pippo, personal communication). This enrichment may attract prey like squids in deep water (Smith and Whitehead, 1993; Hamazaki, 2002; Whitehead, 2003; Gregr and Trites, 2001) and, as a consequence, teutophagic cetaceans such as sperm whales. During the sperm whale encounters ‘feeding sounds’ like creaks (highly directional pulsed train of clicks with high repetition rate, 20–200 pulse per second, emitted during foraging) (Miller et al., 2004) were recorded in over 90% of encounters, suggesting that individuals were actively feeding in the area.

The topography of the Cuma submarine canyon system seems to induce phenomena that support high concentrations of sperm whales in such a small area, similar to the Gully, a prominent submarine canyon on the edge of the Scotian Shelf.
(eastern Canada; Hooker et al., 1999), in Bleikdjupet, a submarine canyon that cuts into the continental shelf north-west of Andenes (Norway; Lettevall et al., 2002), and in Kaikoura, a submarine canyon located just south of the Kaikoura Peninsula (New Zealand; Childerhouse et al., 1995).

The high re-sighting rate deduced from photo-identification results (see Pace et al., 2014) suggests a high degree of site-fidelity both by social units and assemblages of immature males to the deep waters of the canyon of Cuma and shows the importance of the area through the years. Immature males in bachelor groups showed the largest re-sighting range (2004–2010), with repeated identification of the same individuals over the course of years, indicating their tendency to return to or remain in the same area over time (rather than just passing through) (see Pace et al., 2014).

Comparison of the photo-identification catalogue with Tethys (courtesy S. Airoldi) and University of Genoa (courtesy M. Würtz) records, from the Ligurian Sea, revealed several individuals common to both, indicating that there is movement between the Tyrrenian Sea and Ligurian Sea. In particular, three individuals (all immature males), showed transfers from north to south and vice versa, being recorded in both seas.
1–2 months apart during a summer. This is analogous to other findings (Frantzis et al., 2011; Carpinelli et al., 2014), involving only males, thus suggesting that Mediterranean sperm whales behave in a similar way to those in other places, where males move between feeding and breeding grounds whereas females with their calves are more sedentary. Comparison between photo-identification databases is still quite rare in the Mediterranean Sea, but the few recent attempts (Carpinelli et al., 2014; Rendell et al., 2014) have demonstrated that it could help to reveal new important information about sperm whale movements.

The high sperm whale occurrence in the study area during the summer months is a matter of concern. Commercial and passenger traffic (ferries, fast ferries and hydrofoils) in the Gulf of Naples and in the nearby Phlegrean Islands (Ischia, Procida and Vivara) exceeds 200 000 trips per year, and up to 2000 recreational boats may be moored during the summer in the harbours around Ischia (Strada, 2000). Marks from propeller strikes were noted on the backs of whales, and there are documented ship collisions in the area involving four cetacean species, including sperm whale (Centro Studi Cetacei, 1996, 1998, 2003, 2004; Mussi and Miragliuolo, 2003; Pace et al., 2006). The risk of collision is particularly great in the study area owing to its overlap with the Naples harbour traffic and the threat of boat based harassment similar to that reported by Miragliuolo et al. (2004) for Grampus griseus in the coastal waters around Ischia Island. Harassment behaviour by pleasure boaters included heading towards the animals at high speed every time they surfaced, sudden changes of route, and continuous attempts to approach the animals at close quarters to take photographs or ‘interact’ with them.

The significant increasing trend related to distance from the coast of encounters with sperm

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<td>668.21 ± 68.85</td>
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Overall | 278.27 | 1000 | 668.40 ± 131.99 | 661.99

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Overall | 0 | 0.12 | 0.04 ± 0.02 | 0.02

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<td>6.82</td>
<td>19.21</td>
<td>13.47 ± 5.28</td>
<td>13.93</td>
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</table>

Overall | 3.16 | 19.32 | 12.23 ± 3.34 | 12.04
whales during the 2002–2011 period may suggest that animals are slowly moving away from habitats where anthropogenic disturbance occurs.

This study highlights that sperm whales regularly visit the Cuma’s canyon area, possibly exploiting local feeding resources and provides evidences of a habitat-species association with implications for conservation.

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